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Enric Cortés[1] and Xinsheng Zhang[1]

ABSTRACT

Updated indices of abundance were developed for sandbar shark (*Carcharhinus plumbeus*) based on the US pelagic longline observer program covering the period 1992-2015. The indices were estimated using a two-step delta binomial-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately and uses year interactions as a random variable in the final Generalized Linear Mixed Model. Observations that were affected by fishing regulations (time-area closures or bait restrictions) were excluded in a restricted analysis. The updated time series decreased from 1992 to 2003 and showed an increasing trend thereafter.

KEYWORDS

Catch/effort, Commercial fishing, Long lining, Pelagic fisheries, Shark fisheries, By catch, Observer programs, Sandbar shark

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1. INTRODUCTION

Relative abundance indices from the U.S. pelagic longline fishery targeting tuna and tuna-like species were previously generated for sandbar sharks by Ortiz (2005) and in SEDAR21-DW-08. In this document we update the pelagic longline observer program series (1992-2009) reported in SEDAR21-DW-08 to include six additional years of data (2010-2015) for use in SEDAR 54 (sandbar shark standard stock assessment).

2. MATERIALS AND METHODS

2.1 Data

The pelagic longline fishing grounds for the US fleet extend from the Grand Banks in the North Atlantic to 5-10° south, off the South American coast, including the Caribbean and the Gulf of Mexico. Eleven geographical areas of longline fishing are defined for classification (Fig 1): the Caribbean (CAR, area 1), Gulf of Mexico (GOM, area 2), Florida East coast (FEC, area 3), South Atlantic Bight (SAB, area 4), Mid-Atlantic Bight (MAB, area 5), New England coastal (NEC, area 6), Northeast distant waters (NED, or Grand Banks, area 7), Sargasso (SAR, area 8), North Central Atlantic (NCA, area 9), Tuna North (TUN, area 10), and Tuna South (TUN, area 11).

Data from the US pelagic longline observer program are available since 1992 and the analyses covered the period 1992-2015. Geographically, areas 2 to 6 account for virtually all the observations for sandbar shark and thus the analysis was restricted to those areas (Fig. 1).

Several data restrictions were implemented in the present analysis to account for time-area closures or bait restrictions following Walter and Lauretta (2015). Due to the different effects of spatio-temporal closures in different areas, a single “closure” effect could not be considered because it would likely differ among areas and thus the most parsimonious approach was to exclude data from the entire time series before and after the closure for each area. More specifically, the following data restrictions were applied: (1) the DeSoto Canyon Closed Area in the Gulf of Mexico, closed year-round; (2) the East Florida Coast Closed Area, closed year-round; (3) the Charleston Bump Closed Area, closed February-April; (4) the Northeastern United States Closed Area, closed in June; (5) the Northeast Distant Gear Restricted Area, closed year-round except for specific bait-gear configurations; and (6) the Spring Gulf of Mexico Gear Restricted Areas, closed April-May (Fig.1). The analysis incorporating the data restrictions to account for management regulations is referred to as “restricted analysis”; the analysis with the whole dataset is referred to as “full analysis”.

Based on methodology used in multiple other SEDAR and ICCAT (International Commission for the Conservation of Atlantic Tunas) publications (e.g., see Cortés [2015] for a recent publication), the following factors were considered in the analyses: year (1992-2015), area (2,3,4,5,6), quarter (January-March, April-June, July-September, October-December), presence or absence of light sticks, and whether or not the data were part of experimental fishing (conducted in years 2000-2003 in the Northeast Distant area only). Additionally, nominal catch rates (catch per thousand hooks) of swordfish, *Xiphias gladius*, and tuna (the sum of albacore, *Thunnus alalunga*, skipjack, *Euthynnus pelamis*, bigeye, *Thunnus obesus*, and yellowfin tuna, *Thunnus albacares*) were calculated for each set, and a categorical factor based on the quartile of those catch rates was assigned to each set (the factors are denoted as Sqr and Tqr, respectively). The reason for creating these factors, which correspond to the <25%, 25-49%, 50-75%, and >75% of the proportion, was to attempt to control for effects of shark catch rates associated with changes of fishing operations when the fleets switch between targeted species. I also considered the following interactions: year*area, year*quarter, and the interactions between area and the nominal catch rate quartiles for tuna and swordfish (area*Tqr and area*Sqr). Nominal catch rates were defined in all cases as catch (the sum of animals kept, released alive or discarded dead) per 1000 hooks.

Trends in length were also examined by using records of animals that were brought onboard and measured (fork length, measured in a straight line) by scientific observers form the pelagic longline observer program (observation code=1). No estimated lengths, sometimes recorded by observers, were used.

2.2 Analysis

Relative abundance indices were estimated using a Generalized Linear Modeling (GLM) approach assuming a delta lognormal model distribution. A binomial error distribution is used for modeling the proportion of positive sets with a logit function as link between the linear factor component and the binomial error. A lognormal error distribution is used for modeling the catch rates of successful sets, wherein estimated CPUE rates assume a lognormal distribution (lnCPUE) of a linear function of fixed factors. The models were fitted with the SAS GENMOD procedure using a forward stepwise approach in which each potential factor was tested one at a time. Initially, a null model was run with no explanatory variables (factors). Factors were then entered one at a time and the results ranked from smallest to greatest reduction in deviance per degree of freedom when compared to the null model. The factor which resulted in the greatest reduction in deviance per degree of freedom was then incorporated into the model if two conditions were met: 1) the effect of the factor was significant at least at the 5% level based on the results of a Chi-Square statistic of a Type III likelihood ratio test, and 2) the deviance per degree of freedom was reduced by at least 1% with respect to the less complex model. Single factors were incorporated first, followed by fixed first-level interactions. The year factor was always included because it is required for developing a time series. Results were summarized in the form of deviance analysis tables including the deviance for proportion of positive observations and the deviance for the positive catch rates.

Once the final model was selected, it was run using the SAS GLIMMIX macro (which itself uses iteratively reweighted likelihoods to fit generalized linear mixed models with the SAS MIXED procedure; Wolfinger and O'Connell 1993, Littell et al. 1996)). In this model, any interactions that included the *year* factor were treated as a random effect. Goodness-of-fit criteria for the final model included Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion, and –2* the residual log likelihood (-2Res L). The significance of each individual factor was tested with a Type III test of fixed effects, which examines the significance of an effect with all the other effects in the model (SAS Institute Inc. 1999). The final mixed model calculated relative indices as the product of the year effect least squares means (LSMeans) from the binomial and lognormal components. LSMeans estimates were weighted proportionally to observed margins in the input data, and for the lognormal estimates, a back-transformed log bias correction was applied (Lo et al. 1992).

3. RESULTS AND DISCUSSION

Restricting the analysis to account for management regulations resulted in a reduction from 19,759 observed sets for the full analysis to 16,051 sets for the restricted analysis, or 19% of the observed sets. For the restricted analysis, factors retained for the proportion of positive sets were year, quarter, area, and the Sqr*area interaction; and for the positive catches, the factors year, quarter, Tqr, Sqr, area, Sqr*area, and year*quarter were retained (Table 1). The only difference for the full analysis (without data restrictions) was that the factors retained for the positive catches were quarter, Tqr, Sqr, and area. The estimated annual mean CPUE and CV values for the full and restricted analyses are given in Table 2. The indices showed a declining trend since 1992 that can be decomposed into a decline from 1992 to 2003, followed by an increasing trend from 2003 to 2015 (Fig. 3). There was only one positive set with one sandbar shark observed in 2002 and 2003.

Overall, the indices from the full and restricted analyses showed very similar trends, with the restricted analysis index showing larger interannual variation during the 1990s compared to the full analysis index, likely due to smaller sample sizes in those years (Fig. 3). Both nominal series also showed a similar trend, except for the absence of the steep decline from 1992 to 1994 visible in the standardized series. Diagnostic plots for the restricted analysis showed some pattern towards positive residuals in the proportion positive and the distribution of positive CPUEs was slightly skewed to the right of the normal distribution assumed by the model (Fig. 4).

There was no trend in fork length over time; only 288 sandbar sharks were measured. Animals measured were both immature and mature (ca.> 152-155 cm FL; Fig. 5).

Acknowledgments

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Table 1. Factors retained in the model of proportion of positive sets and positive catch of sandbar sharks for U.S. pelagic longline observer data.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	14754	3473	-1736
Final model			
YEAR QUARTER AREA SQR*AREA	14709	3090	-1547

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	371	274	-471
Final model			
YEAR QUARTER TQR SQR AREA SQR*AREA YEAR*QUARTER	283	153	-362

Table 2. Deviance analysis table of explanatory variables in the delta lognormal model for sandbar shark catch rates (number of fish per 1000 hooks) from the US pelagic longline fishery observer program. Percent of total deviance refers to the deviance explained by the model

Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% reduction**	**% of total deviance**
Null		3473			
Year	23	3337	136	3.92%	35.8%
Year Quarter	3	3234	103	3.09%	27.1%
Year Quarter Area	4	3136	98	3.03%	25.8%
Year Quarter Area Sqr*Area	15	3093	43	1.37%	11.3%

Model factors positive catch rates	**d.f.**	**Residual deviance**	**Change in deviance**		**% of total deviance**
Null		274			
Year	23	244	30	10.95%	24.8%
Year Quarter	3	230	14	5.74%	11.6%
Year Quarter Tqr	3	222	8	3.48%	6.6%
Year Quarter Tqr Sqr	3	215	7	3.15%	5.8%
Year Quarter Tqr Sqr Area	4	211	4	1.86%	3.3%
Year Quarter Tqr Sqr Area Sqr*Area	16	189	22	10.43%	18.2%
Year Quarter Tqr Sqr Area Sqr*Area Year*Quarter	69	153	36	19.05%	29.8%

GLM Mixed Model	**deviance**	**AIC**	**BIC**
Proportion Positives			
Year Quarter Area Sqr*Area	7637	7639	7644
Positive catch rates			
Year Quarter Tqr Sqr Area Sqr*Area Year*Quarter	857	861	865

Table 3. Estimates of mean annual CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for sandbar sharks from the U.S. pelagic longline observer data.

	Full analysis			Restricted analysis		
	Standardized		Nominal	Standardized		Nominal
Year	CPUE	CV	CPUE	CPUE	CV	CPUE
1992	0.568	0.351	1.779	0.593	0.403	1.779
1993	0.527	0.233	1.395	0.483	0.287	1.338
1994	0.329	0.263	1.345	0.192	0.379	1.448
1995	0.291	0.310	1.369	0.304	0.362	1.225
1996	0.253	0.428	1.364	0.071	0.978	1.230
1997	0.211	0.384	0.998	0.281	0.435	0.998
1998	0.172	0.590	1.246	0.113	0.783	1.334
1999	0.252	0.429	1.035	0.300	0.498	0.965
2000	0.11	0.462	0.904	0.112	0.535	0.899
2001	0.087	0.555	0.906	0.085	0.595	0.906
2002	0.007	2.303	0.206	0.007	2.480	0.206
2003	0.006	2.306	0.322	0.006	2.488	0.322
2004	0.117	0.375	0.883	0.11	0.442	0.924
2005	0.041	0.542	0.679	0.032	0.642	0.505
2006	0.15	0.497	1.452	0.161	0.552	1.452
2007	0.079	0.417	1.324	0.094	0.489	1.427
2008	0.094	0.312	0.860	0.109	0.360	0.823
2009	0.108	0.317	0.882	0.138	0.385	0.845
2010	0.064	0.461	0.937	0.075	0.493	0.937
2011	0.084	0.405	1.238	0.097	0.439	1.238
2012	0.086	0.330	0.809	0.081	0.394	0.713
2013	0.136	0.277	0.878	0.128	0.350	0.913
2014	0.079	0.389	0.734	0.079	0.488	0.760
2015	0.134	0.333	1.102	0.126	0.401	1.133

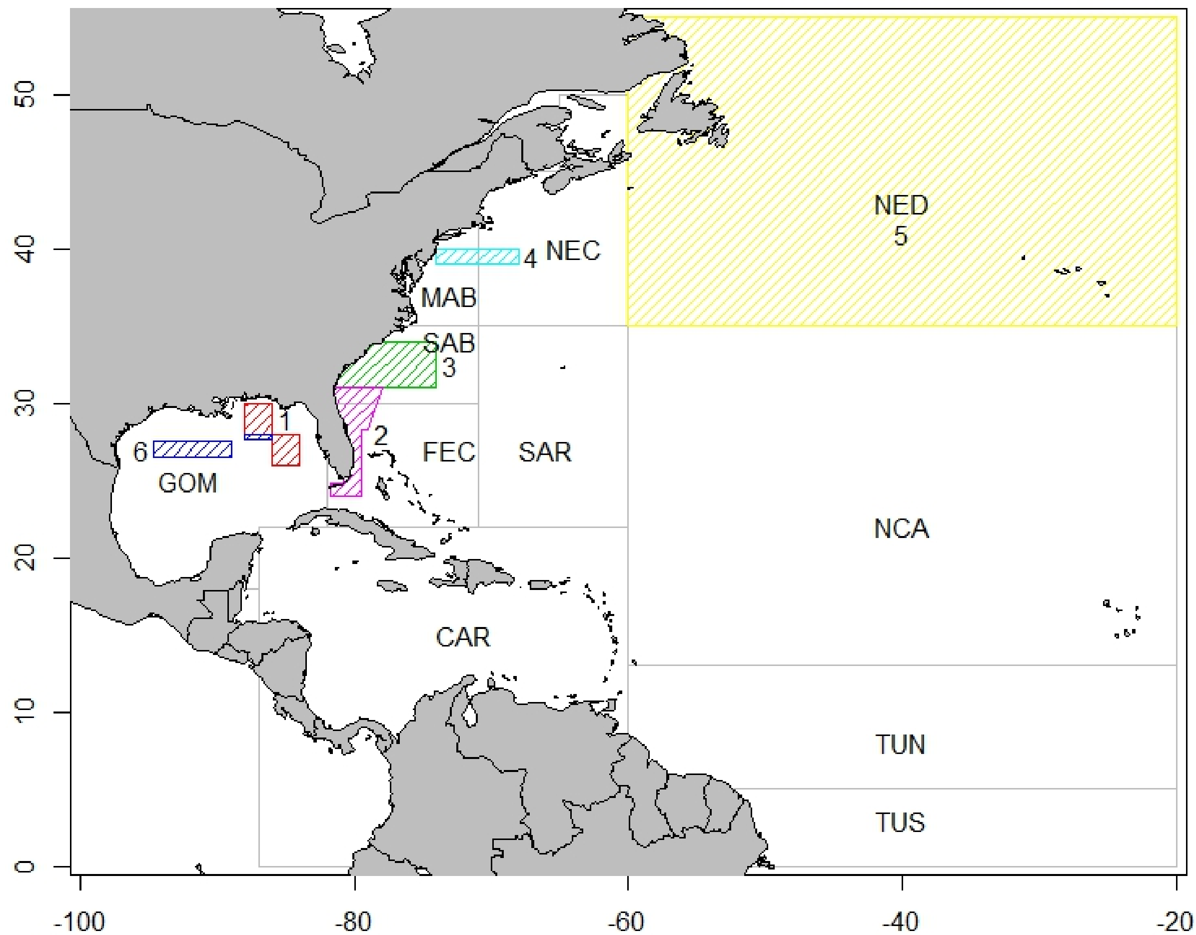
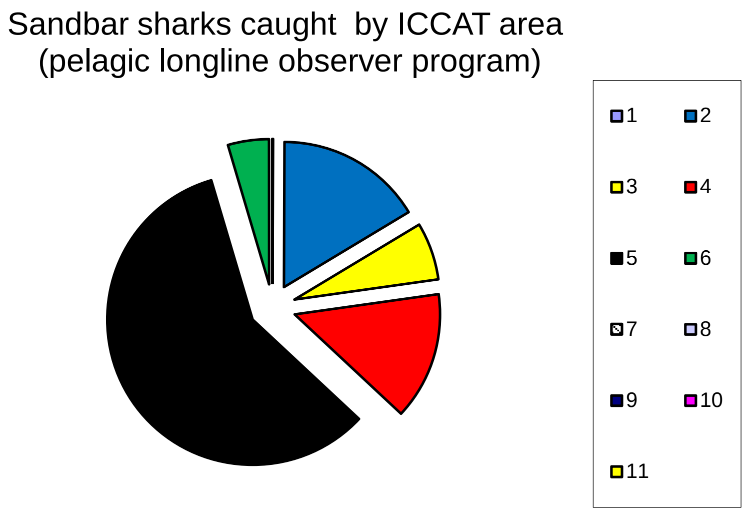


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: CAR=Caribbean (area 1); GOM=Gulf of Mexico (area 2); FEC=Florida East Coast (area 3); SAB=South Atlantic Bight (area 4); MAB=Mid-Atlantic Bight (area 5); NEC=Northeast Coastal (area 6); NED=Northeast Distant (area 7); SAR=Sargasso (area 8); NCA=North Central Atlantic (area 9); TUN=Tuna North (area 10); TUS=Tuna South (area 11). Time-area closures are as follows: 1) DeSoto Canyon; 2) Florida East Coast; 3) Charleston Bump; 4) Bluefin tuna Northeast Atlantic; 5) Grand Banks; 6) Bluefin tuna spring Gulf of Mexico



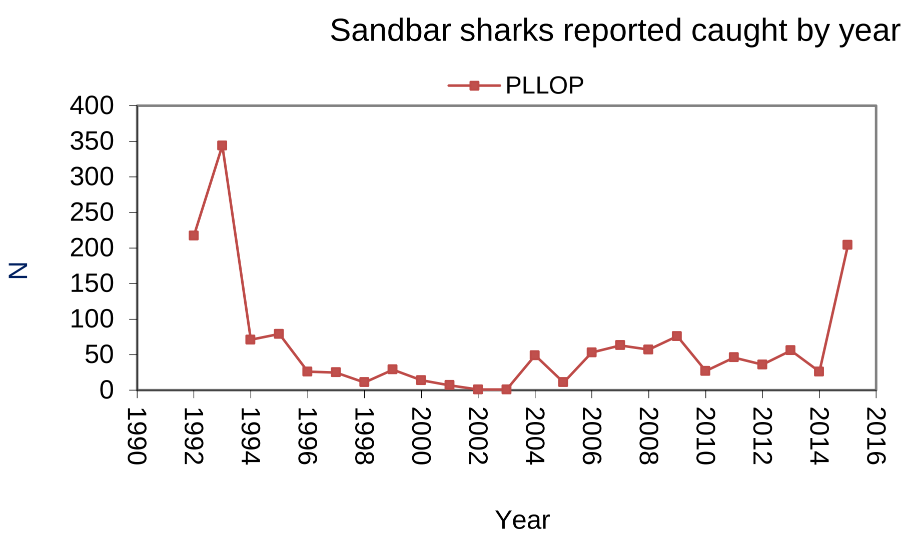


Figure 2. Sandbar sharks caught by area and year as reported in the pelagic longline observer program. Sandbar sharks caught by year in all areas combined are shown in the bottom panel.

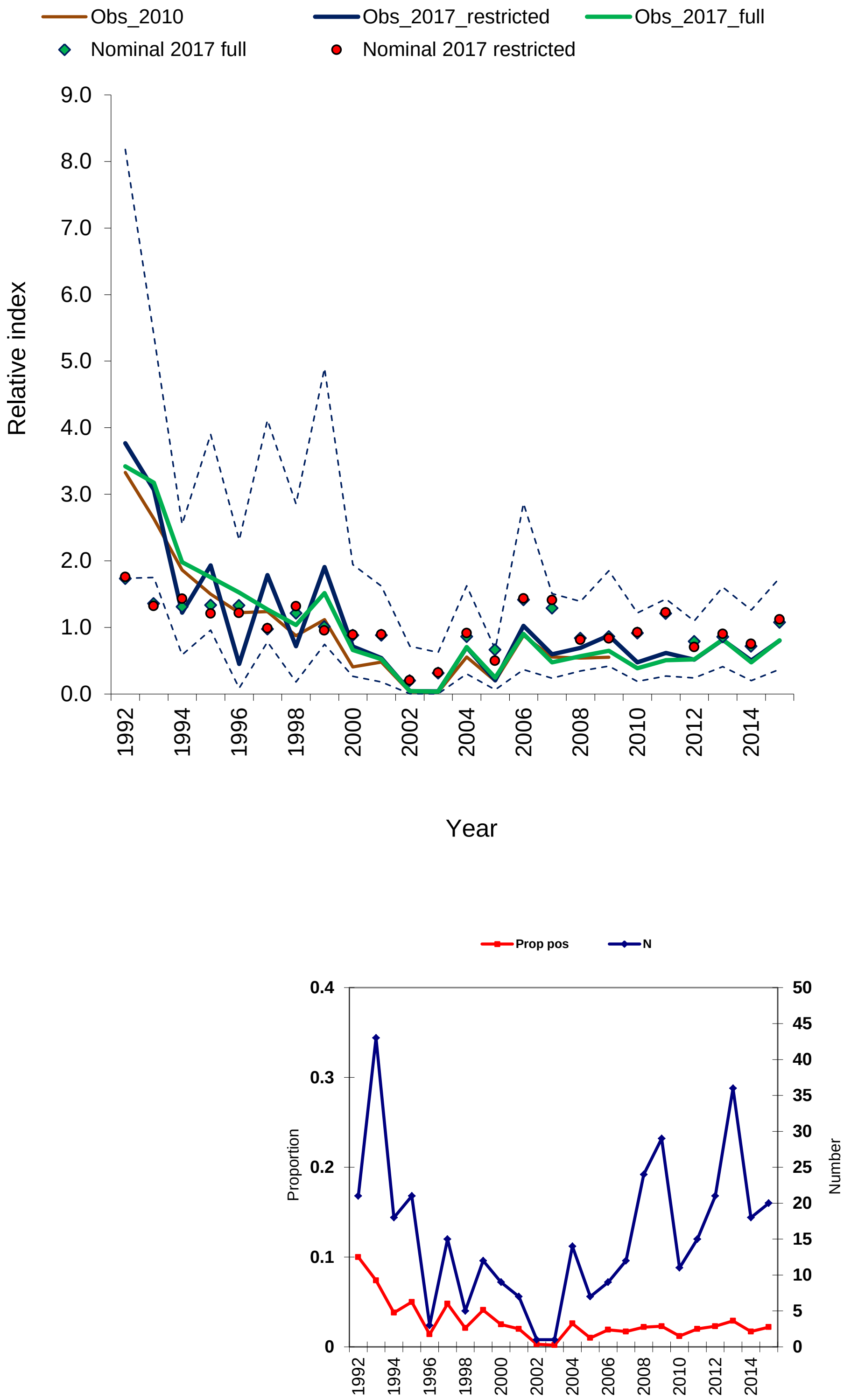


Figure 3. Standardized CPUE (in numbers) and 95% confidence intervals for sandbar shark from the pelagic longline observer program. The lower panel shows the proportion and number of positive sets for the restricted analysis.

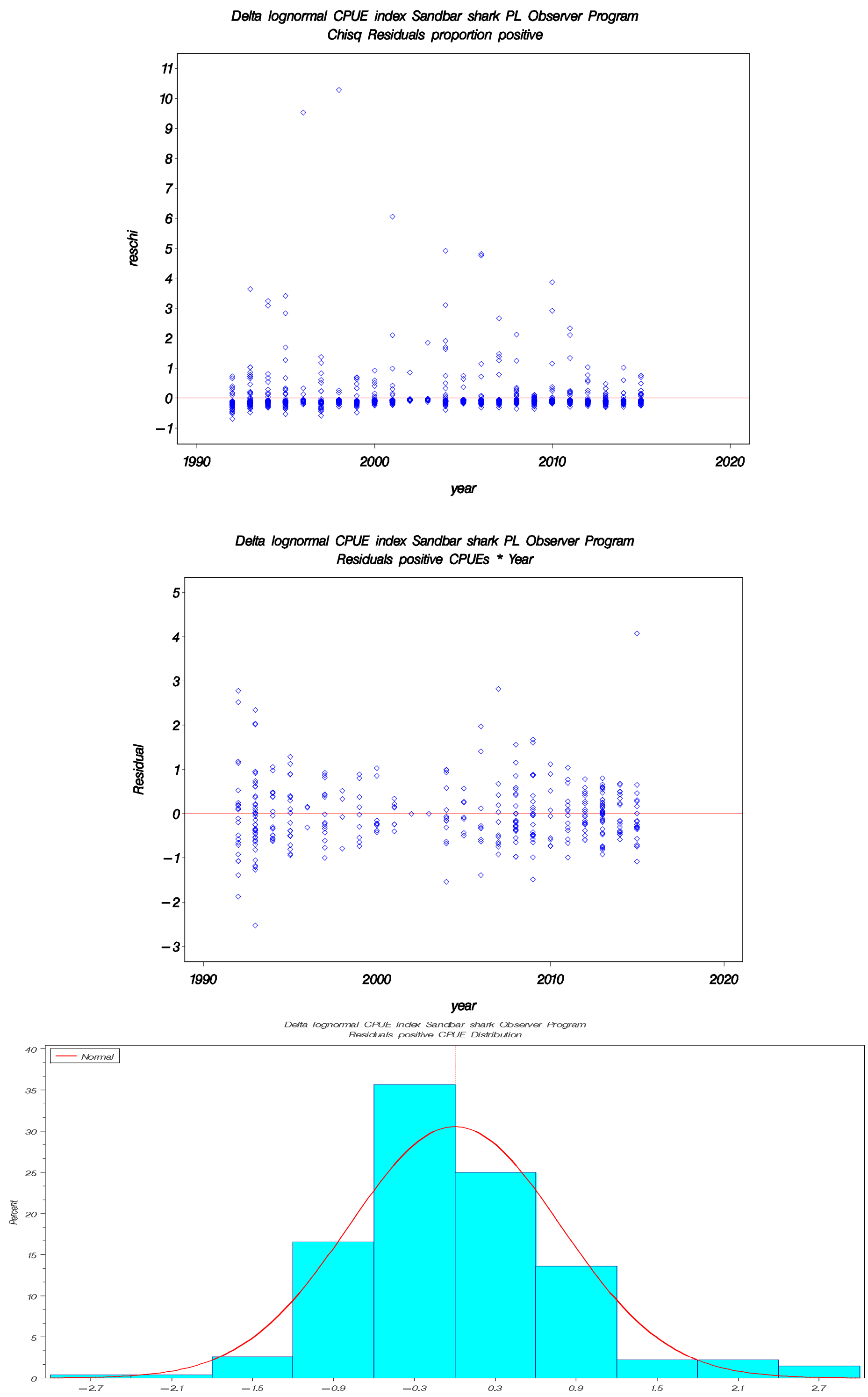


Figure 4. Diagnostics plots of CPUE model from pelagic longline observer program for sandbar shark (restricted analysis). Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: frequency distribution of residuals positive catch.

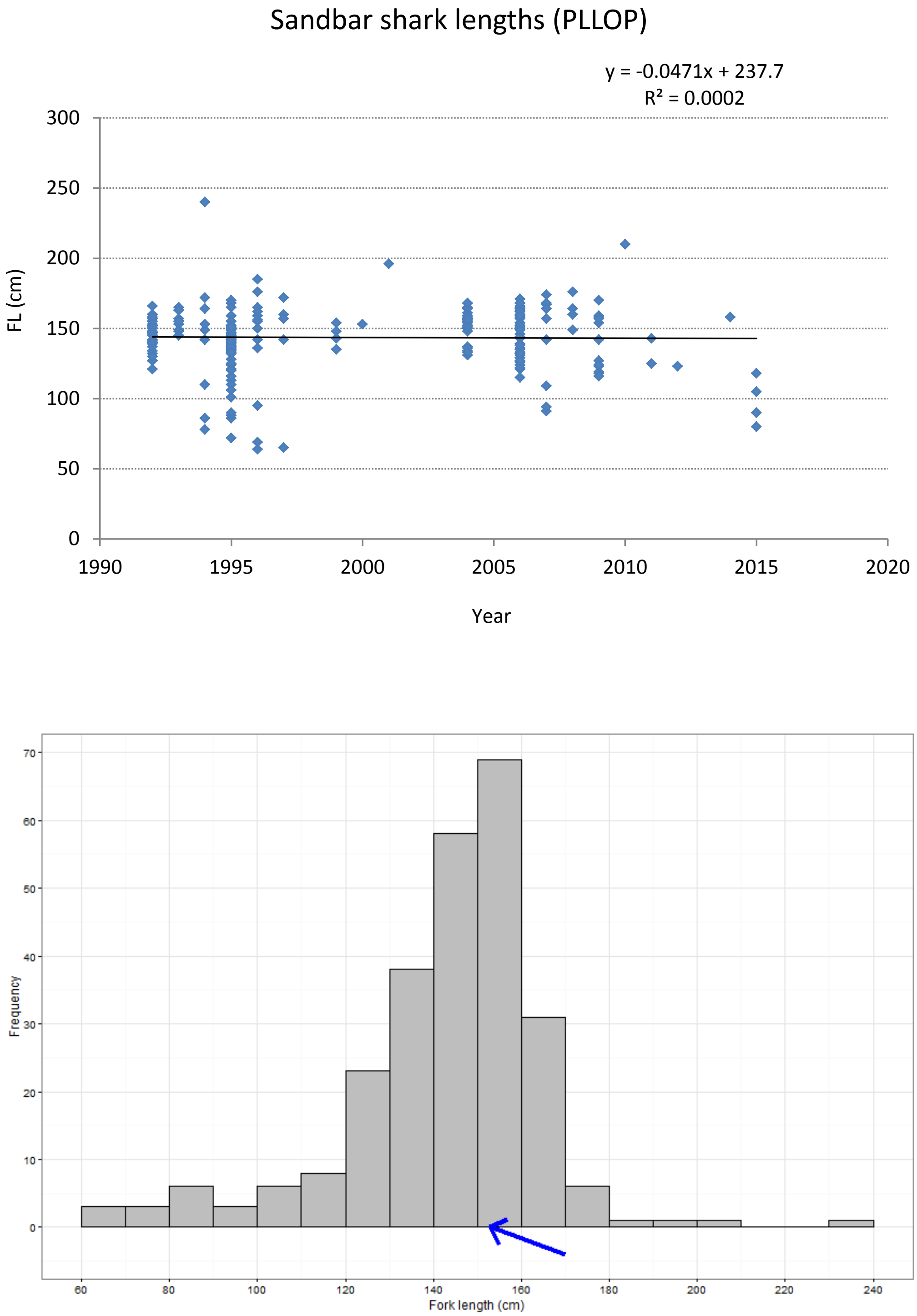


Figure 5. Observed individual fork lengths (FL, cm) by year (top panel) and histogram of all observed lengths combined (bottom panel) of sandbar sharks from the pelagic longline observer program. The arrow indicates approximate median length at maturity.