Standardized abundance indices of sandbar shark from the Pelagic Longline Observer Program, 1992-2025

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SEDAR101-DW-08

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Introduction

In 1992, the National Marine Fisheries Service (NMFS) initiated scientific sampling of the U.S. large pelagic fisheries longline fleet, as mandated by the U.S. Swordfish Fisheries Management Plan and subsequently the Atlantic Highly Migratory Species Fishery Management Plan (1998). Scientific observers were placed aboard vessels participating in the Atlantic pelagic longline fishery. Relative abundance indices from data collected by observers have been previously developed and used in a variety of assessments of pelagic species primarily under the auspices of the International Commission for the Conservation of Atlantic Tunas (ICCAT). Herein, we develop an abundance time series for scalloped shark based on these data.

Methods

<u>*Data*</u>

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 (Figure 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).

<u>*Catch rate analysis*</u>

A data set was developed based on the observer programs as described in Beerkircher et al. (2002) and Cortes et al. (2007). Indices were developed for sandbar shark in the northwest Atlantic Ocean.

For the purposes of analysis, several categorical and continuous variables were considered based on Cortes et al. (2007):

<u>Categorical</u>

- "Year"
  1992-2025
- "Target"
  BET, DOL, MIX, SHX, SWO, TUN, YFT
- "Fishing Area"
  CAR, FEC, GOM, MAB, NCA, NEC, NED, SAB, SAR, TUN, TUS, UNK
- "Season"
  Winter = January-March
  Spring = April-June
  Summer = July-September
  Fall = October-December
- "Bait": primary bait used
  ARTIF HERRI MACKE OTHER SARDI SCAD SQUID
- "Hook type": the hook that was used by the majority of the set
  CIRCLE, J HOOK, UNKNOW

- "Were lightsticks used"
  Yes, no

<u>Continuous</u>

- Mean Depth=(bottom_depth_minimum+bottom_depth_maximum/2)
- Mean Hook Depth=(mean_hook=(hook_depth_minimum+hook_depth_maximum/2)
- Soak time= time the gear is set and retrieved

Following previous methods in multiple SEDARs and Cortes et al. (2007), the proportion of sets that caught sharks (when at least one shark was caught) was modeled assuming a binomial distribution with a logit link function. Positive catches were modeled using a dependent variable of the natural logarithm of CPUE expressed as:

$$CPUE=\log [(\text{sharks kept}+\text{sharks released})/(\text{number of hooks}/1{,}000)]$$

Two modeling approaches when developing standardized indices of relative abundance. The first modeling approach to model sandbar shark catch rates was performed with generalized linear models with fixed effect factors (GLM; McCullagh and Nelder, 1989). Each factor was ranked from greatest to least reduction in deviance per degree of freedom when compared to the null model with no factors (e.g., Ortiz & Arocha 2004, Cortés et al., 2007; Cass-Calay & Schmidt 2009). The factor with the greatest reduction in deviance was then incorporated into the model providing the effect was significant at $p<0.05$ based on a Chi-Square test and was reduced by at least 5% from the less complex model (Ortiz and Arocha 2004; Forrestal et al. 2019). The process was continued until no factors met the criterion for incorporation into the final model. Regardless of its level of significance, year was retained in all models.

The fixed factors determined through the GLM modelling procedure were then modeled using a generalized linear mixed model (GLMM) with the variables year and sampling strategy as random variables to account for repeated observations within sampling year and fixed areas and that all years and fixed areas are not sampled at the same rate. Only first-order interactions were considered due to the potential to overparameterize the model. Model goodness-of-fit was evaluated using -2 Residual Log-Likelihood (RLL), Bayesian information criterion (BIC), Akaike's information criterion (AIC). Model validation used residuals diagnostics, quantile-quantile plots and the distribution of transformed CPUE with graphical checks.

The standardized CPUE values were calculated as the product of the expected probability of a non-zero catch and the expected conditional catch rate for sets that had a non-zero catch. The expected probability and expected conditional catch rate were the least square means of the factor year from each of the two sub-models that constituted an analysis using the Delta model approach (Lo et al., 1992). GLM and GLMM analysis was conducted using the PROC GENMOD and PROC GLIMMIX procedure in the SAS statistical computer software (ver 9.4). All standardized CPUEs were estimated using a SAS macro, GLIMMIX (glmm800MaOB.sas: Russ Wolfinger, SAS Institute Inc.) and the PROC MIXED procedure.

Results and Discussion

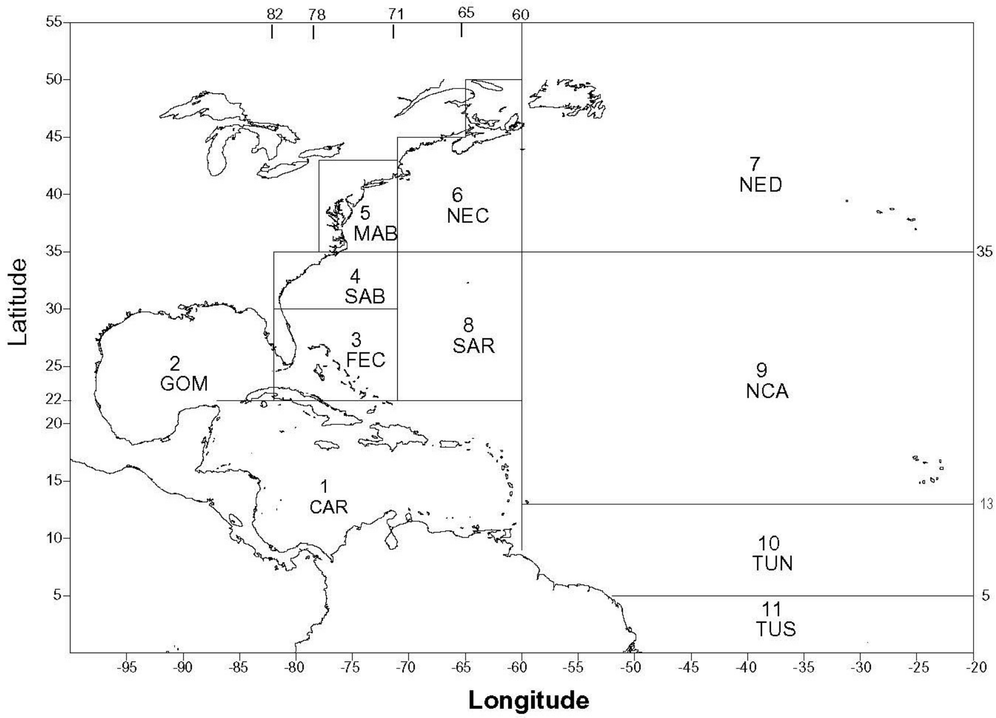


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean Sea (CAR), 2) Gulf of Mexico (GOM), 3) Florida East coast (FEC), 4) South Atlantic Bight (SAB), 5) Mid-Atlantic Bight (MAB), 6) New England coastal (NEC), 7) Northeast distant waters (NED or Grand Banks), 8) Sargasso Sea (SAR), 9) North Central Atlantic (NCA), 10) Tuna North (TUN), and 11) Tuna South (TUN).

The proportion of positive sets (i.e. at least one shark was caught) was 2.6%. The stepwise construction of the models is summarized in Table 1 and final models determined through generalized linear mixed model are in Table 2. The index statistics can be found in Table 3. The delta-lognormal abundance index is shown in Figure 2. The retrospective analysis of removing the last year of the index for 5 years is in Figure 3. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 4).

Table 1. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear model formulations of the proportion of positive and positive catches for sandbar shark.

Proportion positive-Binomial error distribution						
FACTOR	**AIC**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL		0.2459				
YEAR	4259.6	0.2379	3.253	3.253	149.11	<.0001
YEAR+						
SEASON	4009.8	0.2233	9.191	5.937	255.77	<.0001
MEAN_DEPTH	4016.4	0.2239	8.947		245.17	<.0001
FISHING_AREA	4127.8	0.2293	6.751	Negative of Hessian not positive definite		
TARGET	4263.0	0.2296	6.629		50.15	<.0001
WERE_LIGHT_SICKS_USED	4299.1	0.2321	5.612		4.12	0.0424
SOAK	4303.0	0.232	5.531		0.14	0.7038
BAIT	4212.5	0.2346	4.595		59.12	<.0001
MEAN_HOOK_DEPTH	4251.2	0.2373	3.497		10.36	0.0013
HOOK_TYPE	4258.2	0.2376	3.375		5.38	0.0678
YEAR+SEASON+						
MEAN_DEPTH	3811.6	0.2049	16.673	7.483	237.63	<.0001
BAIT	4004.0	0.215	12.566		55.13	<.0001
TARGET	4006.1	0.2152	12.485		53.06	<.0001
MEAN_HOOK_DEPTH	4021.5	0.2165	11.956		27.64	<.0001
WERE_LIGHT_SICKS_USED	4049.2	0.218	11.346		0	0.9608
SOAK	4048.2	0.218	11.346		0.98	0.3214
YEAR+SEASON+MEAN_DEPTH+						
BAIT	3791.4	0.2032	17.365	0.691	32.13	<.0001
TARGET	3798.6	0.2036	17.202		24.98	0.0003
MEAN_HOOK_DEPTH	3807.3	0.2046	16.795		6.25	0.0124

Positive catches-Lognormal error distribution						
FACTOR	**AIC**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL		0.7926				
YEAR	1236.8	0.7434	6.207	6.207	64.55	0.0008
YEAR+						
TARGET	1196.2	0.6756	14.762	8.554	50.64	<.0001
MEAN_DEPTH	1194.9	0.6826	13.878		42.35	<.0001
BAIT	1217.5	0.7055	10.989		31.28	<.0001
FISHING_AREA	1223.3	0.7141	9.904		25.54	0.0003
SEASON	1222.9	0.7177	9.450		19.89	0.0002
HOOK_TYPE	1225.9	0.7237	8.693		14.88	0.0006
SOAK	1233.4	0.737	7.053		5.37	0.0205
WERE_LIGHT_SICKS_USED	1235.8	0.7405	6.573		2.97	0.0849
MEAN_HOOK_DEPTH	1236.9	0.7421	6.371		1.95	0.1629
YEAR+TARGET+						
SEASON	1179.3	0.6482	18.219	3.457	22.88	<.0001
SOAK	1179.3	0.648	18.219		22.88	<.0001
FISHING_AREA	1184.1	0.6512	17.840		24.05	0.0005
MEAN_DEPTH	1177.3	0.6513	17.827		19.46	<.0001
HOOK_TYPE	1191.8	0.667	15.859		8.31	0.0157
BAIT	1200.6	0.6742	14.938		7.59	0.2701

Table 2. Analyses of Delta-lognormal mixed model formulations for sandbar shark catch rates from the Pelagic Longline Fishery. RLL= -2 Residual Log-Likelihood, BIC=Bayesian information criterion, AIC= Akaike's information criterion. Final model selected is in bold

Error structure	Model	RLL	BIC	AIC
Binomial	**YEAR+SEASON+MEAN_DEPTH**	**96010.4**	**96019.9**	**96012.4**
	YEAR*SEASON	96345.2	96355	96349.2
	YEAR*MEAN_DEPTH	97989.9	97997.0	97993.9
Lognormal	YEAR+TARGET+SEASON	1635.4	1641.9	1637.4
	YEAR*TARGET	**1610.7**	**1620.3**	**1614.7**
	YEAR*SEASON	1626.2	1635.4	1630.2

Table 2 The standardized index (number of sharks per 1,000 hooks per year/mean of the index) of relative abundance, the upper (UCL) and lower (UCL) 95% confidence limits and coefficients of variation (CV) for sandbar shark for the Pelagic Longline Fishery.

Year	N	Relative Index	LCL	UCL	CV
1992	318	4.463	1.912	10.420	0.44
1993	817	2.266	1.217	4.220	0.32
1994	645	1.743	0.844	3.598	0.37
1995	696	1.086	0.521	2.267	0.38
1996	361	1.008	0.370	2.748	0.53
1997	458	1.458	0.609	3.488	0.46
1998	287	0.710	0.214	2.348	0.66
1999	430	0.794	0.303	2.079	0.51
2000	475	0.436	0.155	1.222	0.55
2001	403	0.432	0.136	1.368	0.63
2002	348	0.043	0.005	0.373	1.49
2003	554	0.034	0.004	0.293	1.49
2004	644	0.711	0.301	1.676	0.45
2005	552	0.275	0.088	0.861	0.62
2006	570	0.434	0.151	1.245	0.57
2007	949	0.440	0.172	1.122	0.50
2008	1213	0.488	0.229	1.037	0.39
2009	1384	0.586	0.291	1.179	0.36
2010	887	0.308	0.117	0.810	0.51
2011	888	0.413	0.172	0.991	0.46
2012	951	0.810	0.368	1.782	0.41
2013	1486	0.681	0.356	1.302	0.33
2014	1234	0.392	0.169	0.911	0.44
2015	1142	0.736	0.346	1.567	0.39
2016	1228	0.921	0.486	1.747	0.33

2017	901	2.217	1.173	4.191	0.33
2018	731	1.455	0.607	3.489	0.46
2019	506	0.440	0.147	1.320	0.59
2020	380	0.746	0.193	2.883	0.76
2021	415	2.255	0.989	5.141	0.43
2022	500	0.992	0.472	2.084	0.38
2023	524	2.584	1.260	5.301	0.37
2024	429	1.406	0.632	3.128	0.42
2025	331	0.238	0.050	1.143	0.92

Figure 2. Standardized (index_mean) index and nominal (obcpue) of abundance for sandbar shark. The dashed lines are the 95% confidence limits for the standardized index. Each index has been divided by the mean of the index.

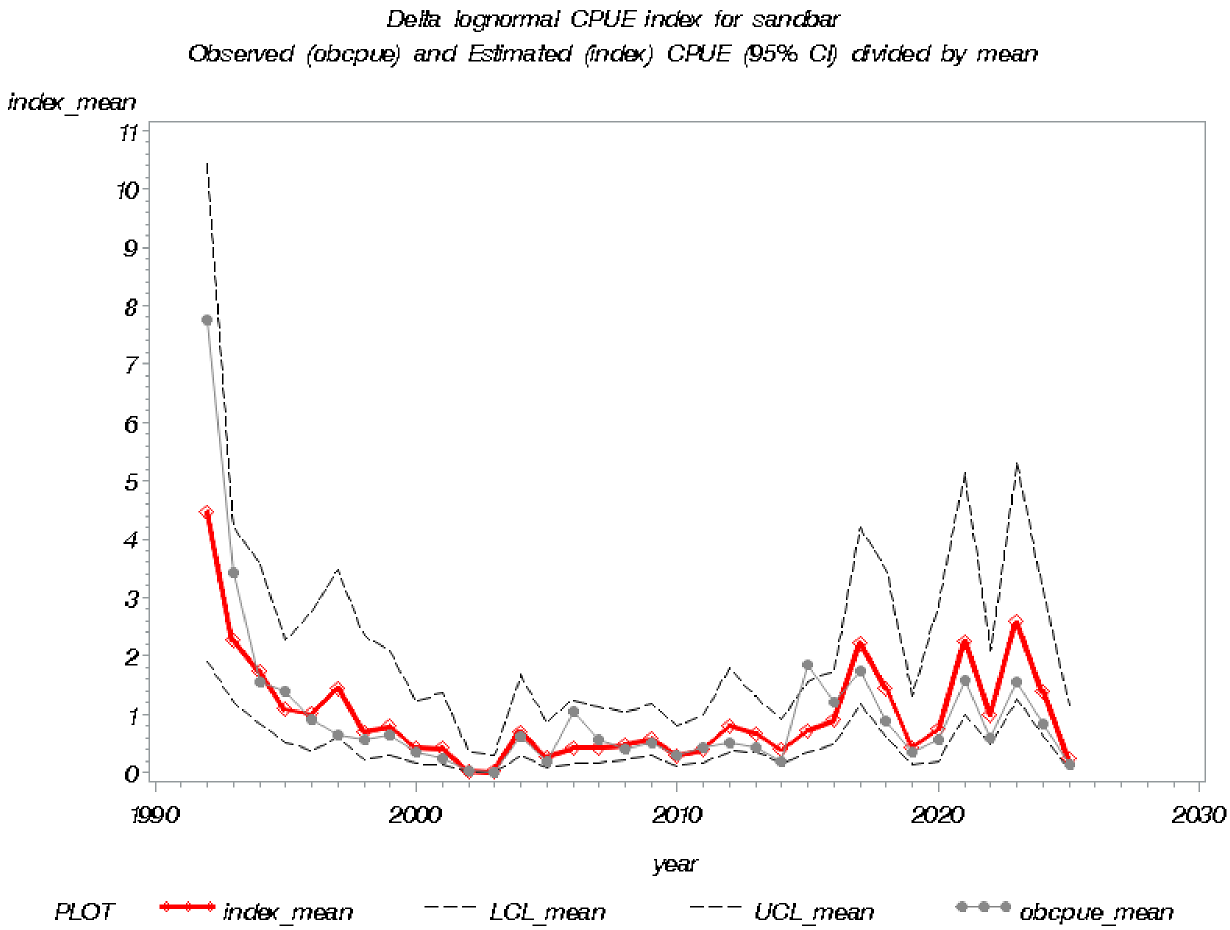


Figure 3. Retrospective analysis of the pelagic longline index of abundance for sandbar shark.

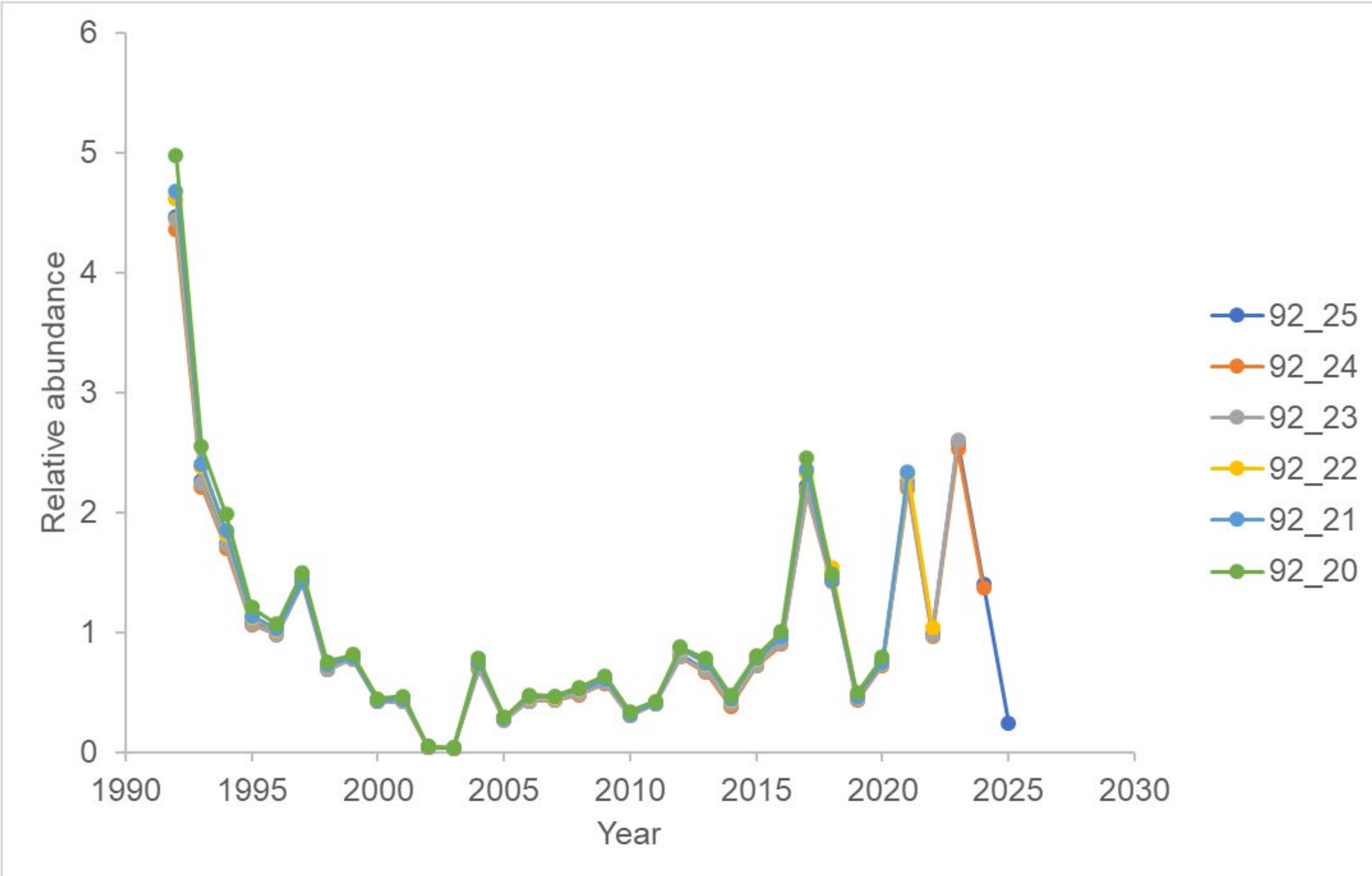
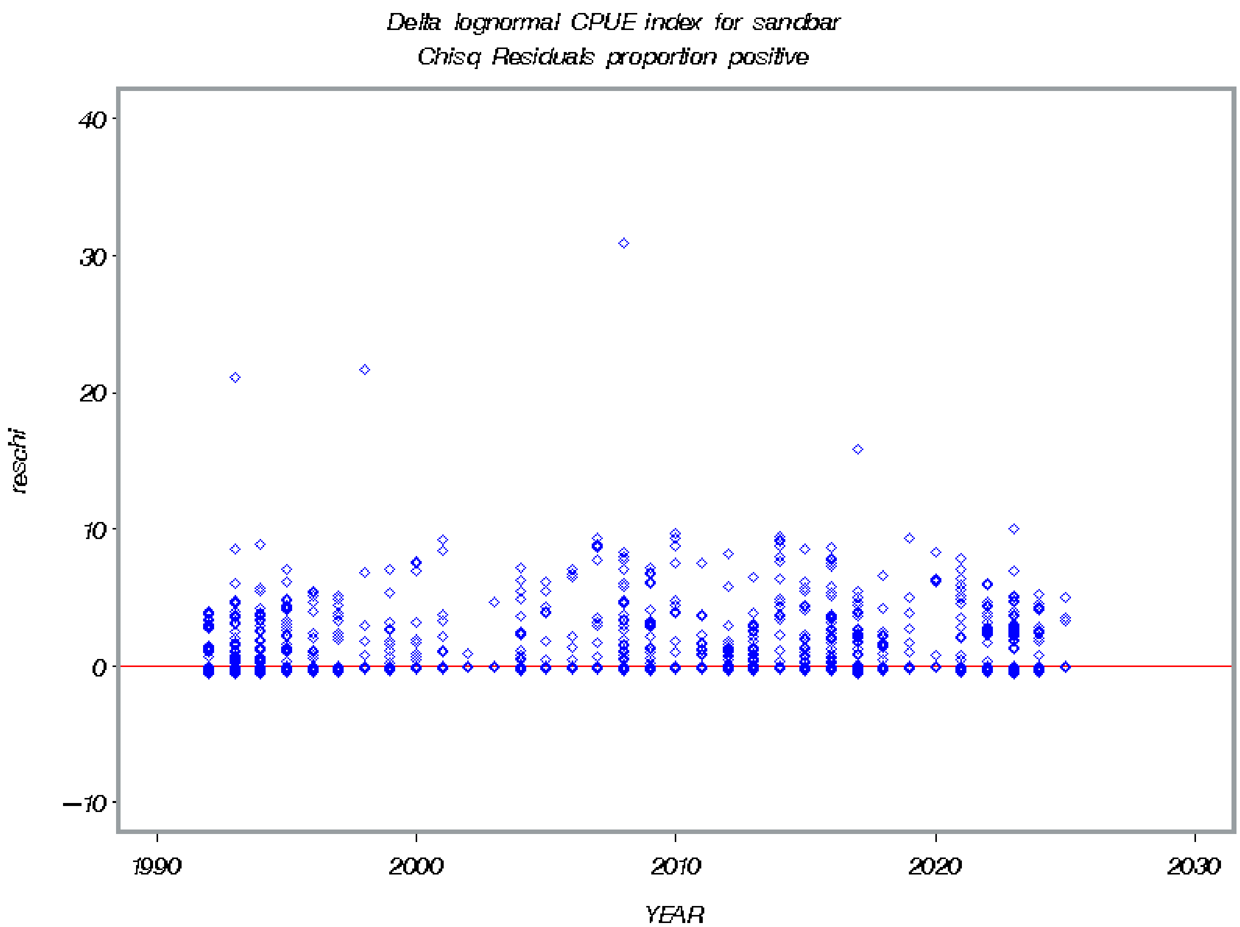
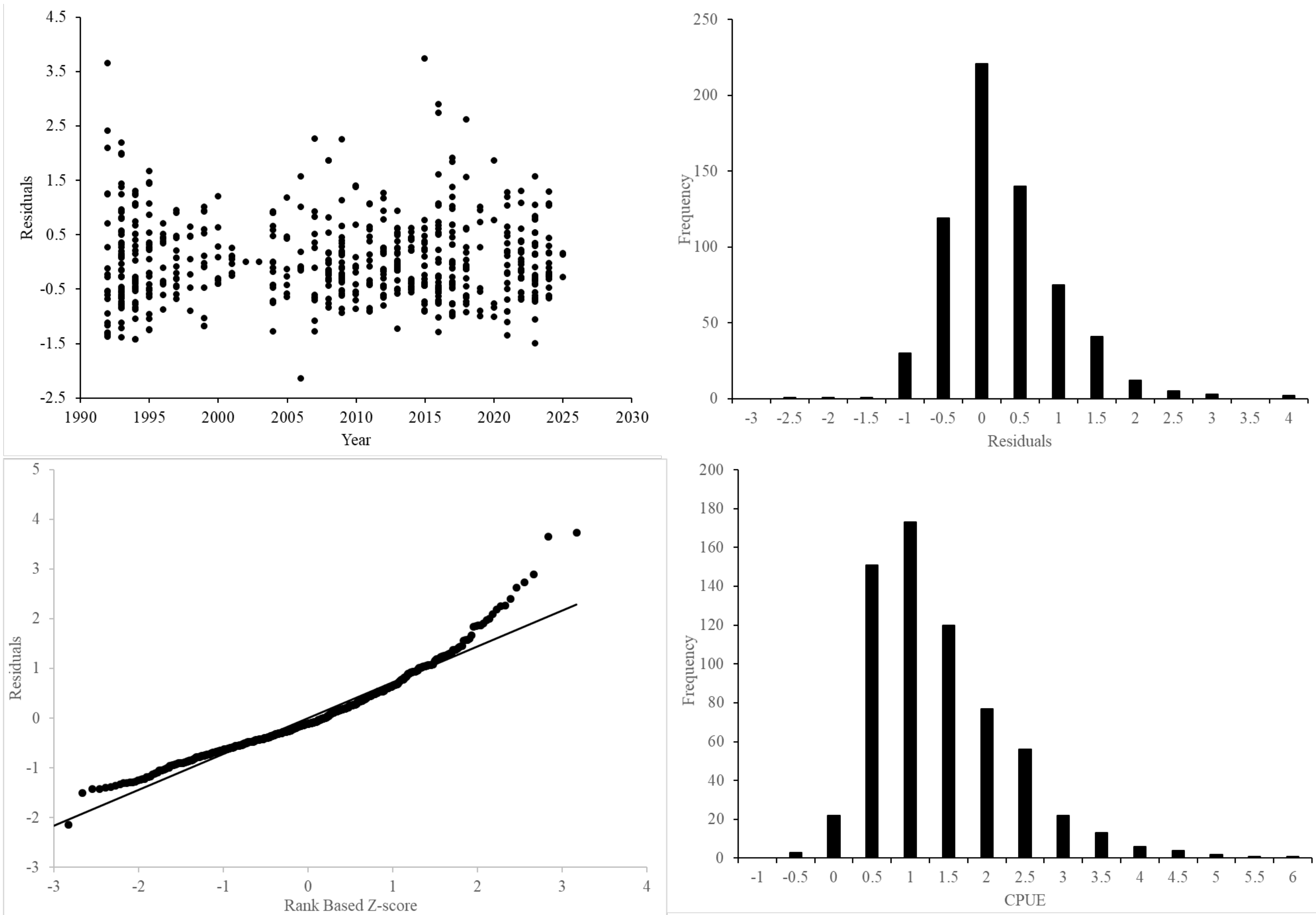


Figure 4. Diagnostic plots of the model outputs for sandbar shark.




Residuals
Year
Frequency
Residuals
Residuals
Rank Based Z-score
Frequency
CPUE