Standardized catch rates of blacktip sharks, *Carcharhinus limbatus*, from the NOAA Northeast Fisheries Science Center coastal shark bottom longline survey.

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Standardized catch rates of blacktip sharks, *Carcharhinus limbatus*, from the NOAA Northeast Fisheries Science Center coastal shark bottom longline survey

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Summary

This document details blacktip shark catches from the Northeast Fisheries Science Center (NEFSC) coastal shark bottom longline survey conducted by the Apex Predators Program from 1996-2018. Data from this survey were used to examine the trends in relative abundance of blacktip sharks in the waters off the east coast of the United States. The majority (72%) of the catch was mature males and the proportion of sets with positive catch (at least one blacktip shark caught) was 26%. Catch per unit effort (CPUE) in number of sharks per 100 hook hours were examined for each year of the bottom longline survey, 1996, 1998, 2001, 2004, 2007, 2009, 2012, 2015, and 2018. The CPUE was standardized using generalized linear models in a two-step delta-lognormal approach that models the proportion of positive catch with a binomial error distribution separately from the positive catch, which is modeled using a lognormal distribution. The standardized CPUE results from the NEFSC longline survey show an increasing trend in blacktip shark relative abundance across survey years from 1996 to 2018.

Introduction

The Northeast Fisheries Science Center (NEFSC) coastal shark bottom longline survey is conducted by the Apex Predators Program, Narragansett Laboratory, Narragansett, RI. The primary objective of this survey is to conduct a standardized, systematic survey of the shark populations off the US Atlantic coast to provide unbiased indices of the relative abundance for species inhabiting the waters from Florida to the Mid-Atlantic. It also provides an opportunity to tag sharks as part of the NEFSC Cooperative Shark Tagging Program and to collect biological samples and data used in analyses of life history characteristics (age, growth, reproductive biology, trophic ecology, etc.) and other research of sharks in US coastal waters.

Methods

Sampling Gear and Data Collection

The NEFSC Coastal Shark Survey (1996-2018) covers the US continental shelf waters from Florida to Delaware in depths of 9-80 m. The survey uses a fixed station design with stations generally located approximately 30 nm apart except where the continental shelf narrows off Cape Hatteras, NC (Fig. 1). Standard sampling gear consists of a 300 hook 'Florida' commercial style bottom longline. This gear consists of a 940 lb test monofilament mainline with 12 foot (3.6 m) gangions composed of 730 lb test monofilament with a longline clip at one end and a 3/0 shark hook at the other. Gangions (referred to hereafter simply as 'hooks') baited with chunks of spiny dogfish are attached to the mainline at 60-70 ft (21 m) intervals; 5 lb (2.3 kg) weights are attached every 15 hooks and a bullet float and 15 lb (6.8 kg) weights are placed at 50 hook intervals. A 20 ft (6 m) staff buoy ('high flyer') equipped with radar reflectors and flashers (at night) is attached to a poly ('tag') buoy by a 12 ft (3.6 m) line. The poly buoy is then attached to the mainline and there is a set of these to mark each end of the mainline. To ensure that the gear fishes on the bottom, 20 lb (9.1 kg) weights are placed at the beginning and end of the mainline after a length of line 2-3 times the water depth is deployed.

Once set, the gear is fished for three hours with approximately six hours from start of setting to completion of haulback. The mainline covers from 2.0 to 5.5 nm, with an average of 3.7 nm. Fishing takes place at all times of the day. Number of sets completed per day varies from one to three with an average of 2.5 sets per day. The number of sets is dependent on distance between stations, weather conditions, and the length of time to complete previous sets during the day.

Data is recorded at the beginning and end of each set and haul, when available these data consist of: number of hooks, time, location, surface and bottom temperature and salinity, depth, air temperature, wind direction and strength, and sea state. For all surveys, catch data recorded at each station include, at a minimum: species, sex and length.

Data Analysis

Catch per unit effort (CPUE) for each set is defined as the number of sharks per 100 hook hours. The CPUE was standardized using a delta-lognormal generalized linear model, which models the proportion of positive sets separately from the positive catch. Factors considered as potential influences on CPUE were: year (1996, 1998, 2001, 2004, 2007, 2009, 2012, 2015), month (April, May), area (1 = <33.8 ^{o} latitude, 2 = 33.8 to 35.7 ^{o} latitude, 3 = > 35.7 ^{o} latitude), depth (<20, 20-29, 30-39, 40-49, 50+ m), and surface water temperature (<21, 21+ deg C). The proportion of sets with positive catch values was modeled assuming a binomial distribution with a logit link function and the positive catch sets were modeled assuming a lognormal distribution.

Models were fit in a stepwise forward manner adding one potential factor at a time after initially running a null model with no factors included. Each potential factor was ranked from greatest to least reduction in deviance per degree of freedom when compared to the null model. The factor resulting in the greatest reduction in deviance was then incorporated into the model provided the effect was significant at $\alpha = 0.05$ based on a Chi-Square test, and the deviance per degree freedom was reduced by at least 1% from the less complex model. This process was continued until no additional factors met the criteria for incorporation into the final model. The factor "year" was kept in all final models, regardless of its significance, to allow for calculation of indices. All models in the stepwise approach were fitted using the SAS GENMOD procedure (SAS Institute, Inc.). The final models were then run through the SAS GLIMMIX macro to allow fitting of the generalized linear models using the SAS MIXED procedure (Wolfinger, SAS Institute, Inc). The standardized indices of abundance were based on the year effect least square means determined from the combined binomial and lognormal components.

Results and Discussion

A total of 663 blacktip sharks were caught during 557 longline sets from 1996 to 2018. The size range of blacktip sharks caught by year is displayed in Figure 2 with the majority (72%) of the catch as mature males. The proportion of sets with positive catch (at least one blacktip shark caught) was 26%. The stepwise construction of each model and the resulting statistics are detailed in Table 1. The proportion of positive catch sets was influenced by year, area, and depth and the positive catch sets were influenced by year and depth. Diagnostic plots for the binomial model reveal that the model fit is acceptable (Figure 3). The residual plots for the lognormal model show a pattern indicating increasing variability across categories (Figure 4). The year plot exhibits heteroscedasticity, meaning in this case that the residuals for the positive catch get larger over time, which is not evident in the variance of the index values during the later years of the survey time series. Given the low values estimated during this time for the CVs, a measure sometimes used to weight the index values in the assessment, these values are likely underestimated.

This type of residual pattern (heteroscedasticity) often indicates a variable is missing. Since station was not used in the original model development a separate run was conducted with this variable and it was rejected during the first stage of model development: binomial model would not converge and lognormal model not did not reduce deviance from the null model and was not significant based on a Chi-Square test. Some areas/stations had reduced annual sampling coverage due to logistical constraints; therefore, a year*area and year*station interaction term were introduced separately into the model with random effects with little improvement to the model and diagnostics. Area and station were also included separately as random effects in the model with little improvement. Additionally, the year residuals from the final model were extracted and included as a variable within the model resulting in no improvement. Disregarding the established model development procedures used in this working paper, station was included as a variable in the final lognormal model. This inclusion improved the year residuals (Figure 5), but negated the affect depth had on the model. Using year and station alone corrects for the heteroscedasticity, making the annual index CV's credible, but does not change the survey trend. The resulting indices of abundance based on the year effect least square means, associated statistics and nominal indices for the original and new model are reported in Tables 2 and 3 and are plotted by year in Figures 6 and 7, respectively. Nominal and standardized CPUE results from the NEFSC longline survey show an increasing trend in blacktip shark relative abundance across survey years from 1996 to 2018.

Table 1. Results of the stepwise procedure for development of the catch rate model for blacktip sharks. %DIF is the percent difference in deviance/DF between each model and the null model. Delta% is the difference in deviance/DF between the newly included factor and the previous entered factor in the model. L is the log likelihood.

PROPORTION POSITIVE-BINOMIAL ERROR DISTRIBUTION

FACTOR	DF	DEVIANCE	DEVIANCE/DF	%DIFF	DELTA%	CHISQ	PR>CHI
NULL	231	420.7477	1.8214				
YEAR	223	320.8954	1.4390	20.9948		99.85	<.0001
AREA	228	352.0511	1.5441	15.2246		68.70	<.0001
TEMP	228	363.2119	1.5930	12.5398		57.54	<.0001
DEPTH	228	369.9958	1.6228	10.9037		50.75	<.0001
MONTH	230	420.6054	1.8287	-0.4008		0.14	0.7061
YEAR +							
AREA	220	266.5302	1.2115	33.4852	12.4904	54.37	<.0001
DEPTH	220	279.4365	1.2702	30.2624	9.2676	41.46	<.0001
TEMP	220	283.4208	1.2883	29.2687	8.2739	37.47	<.0001
YEAR + AREA +							
DEPTH	217	227.4041	1.0479	42.4673	8.9821	39.13	<.0001
TEMP	217	258.8077	1.1927	34.5174	1.0322	7.72	0.0521
	123	92.1672	0.7493	58.8613	16.3940	23.03	0.0413

FINAL MODEL: YEAR + AREA + DEPTH

Akaike's information criterion 407.1

Schwartz's Bayesian criterion 409.5

(-2) Res Log liklihood 405.0

Type 3 Test of Fixed Effects

	YEAR	DEPTH	AREA
Significance (Pr>Chi) of Type 3 test of fixed effects for each factor	<.0001	<.0001	<.0001
DF	8	3	2
CHI SQUARE	52.21	26.09	23.41

POSITIVE CATCHES-POISSON ERROR DISTRIBUTION

FACTOR	DF	DEVIANCE	DEVIANCE/DF	%DIFF	DELTA%	CHISQ	PR>CHI
NULL	145	147.8004	1.0193				
YEAR	137	110.2671	0.8049	21.0340		42.70	<.0001
DEPTH	142	139.9852	0.9858	3.2866		7.93	0.0474
MONTH	144	146.9466	1.0205	-0.1177		0.85	0.3577
AREA	143	145.9325	1.0205	-0.1177		1.86	0.3952
TEMP	141	145.6401	1.0329	-1.3342		1.41	0.7040
YEAR +							
DEPTH	134	102.6146	0.7658	24.8700	3.8360	10.50	0.0148

FINAL MODEL: YEAR + DEPTH

Akaike's information criterion 375.9

Schwartz's Bayesian criterion 378.8

(-2) Res Log liklihood 373.9

Type 3 Test of Fixed Effects

	YEAR	DEPTH
Significance (Pr>Chi) of Type 3 test of fixed effects for each factor	<.0001	0.0186
DF	8	3
CHI SQUARE	48.80	9.99

Table 2. Original analyses: proportion positive (binomial) = year + area + depth, and positive catch (lognormal) = year + depth. Blacktip shark number of sets per year (n obs), number of positive sets per year (obs pos), proportion of positive sets per year (obs ppos), nominal cpue as sharks per hook (obs cpue), resulting estimated cpue from the delta-lognormal model (est cpue), the lower 95% confidence limit for the est cpue (LCL), the upper 95% confidence limit for the est cpue (UCL), and the coefficient of variation for the estimated cpue (CV).

year	n obs	obs pos	obs ppos	obs cpue	est cpue	LCL	UCL	CV
1996	87	4	0.0460	0.0036	0.0052	0.0010	0.0274	0.9953
1997								
1998	87	17	0.1954	0.0249	0.0391	0.0160	0.0953	0.4692
1999								
2000								
2001	84	13	0.1548	0.0135	0.0206	0.0074	0.0569	0.5440
2002								
2003								
2004	67	17	0.2537	0.0232	0.0305	0.0125	0.0748	0.4719
2005								
2006								
2007	22	1	0.0455	0.0020	0.0018	0.0002	0.0215	1.8850
2008								
2009	49	12	0.2449	0.0317	0.0277	0.0096	0.0804	0.5720
2010								
2011								
2012	48	22	0.4583	0.1360	0.1267	0.0611	0.2626	0.3770
2013								
2014								
2015	49	25	0.5102	0.1760	0.1426	0.0725	0.2804	0.3481
2016								
2017								
2018	53	35	0.6604	0.3126	0.3024	0.1859	0.4921	0.2470

Table 3. New analyses: proportion positive (binomial) = year + area + depth, and positive catch (lognormal) = year + station. Blacktip shark number of sets per year (n obs), number of positive sets per year (obs pos), proportion of positive sets per year (obs ppos), nominal cpue as sharks per hook (obs cpue), resulting estimated cpue from the delta-lognormal model (est cpue), the lower 95% confidence limit for the est cpue (LCL), the upper 95% confidence limit for the est cpue (UCL), and the coefficient of variation for the estimated cpue (CV).

year	n obs	obs pos	obs ppos	obs cpue	est cpue	LCL	UCL	CV
1996	92	4	0.0435	0.0034	0.0032	0.0006	0.0173	1.0173
1997								
1998	89	17	0.1910	0.0243	0.0315	0.0126	0.0786	0.4825
1999								
2000								
2001	85	13	0.1529	0.0134	0.0131	0.0046	0.0373	0.5612
2002								
2003								
2004	69	17	0.2464	0.0226	0.0310	0.0124	0.0775	0.4841
2005								
2006								
2007	22	1	0.0455	0.0020	0.0008	0.0001	0.0091	1.9006
2008								
2009	49	12	0.2449	0.0317	0.0263	0.0086	0.0804	0.6062
2010								
2011								
2012	48	22	0.4583	0.1360	0.1218	0.0581	0.2555	0.3836
2013								
2014								
2015	50	25	0.5000	0.1725	0.1485	0.0751	0.2938	0.3513
2016								
2017								
2018	53	35	0.6604	0.3126	0.3183	0.1957	0.5176	0.2468

Figure 1. Survey Stations

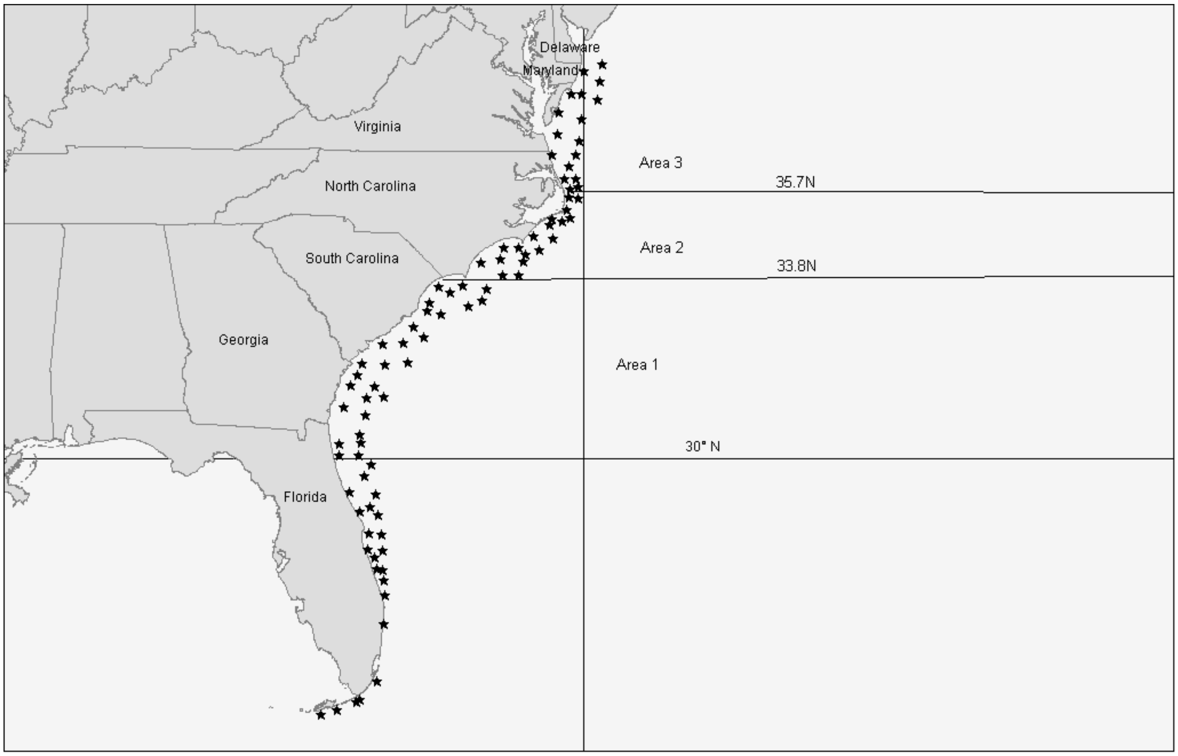


Figure 2. Fork lengths (cm) of blacktip sharks caught by year

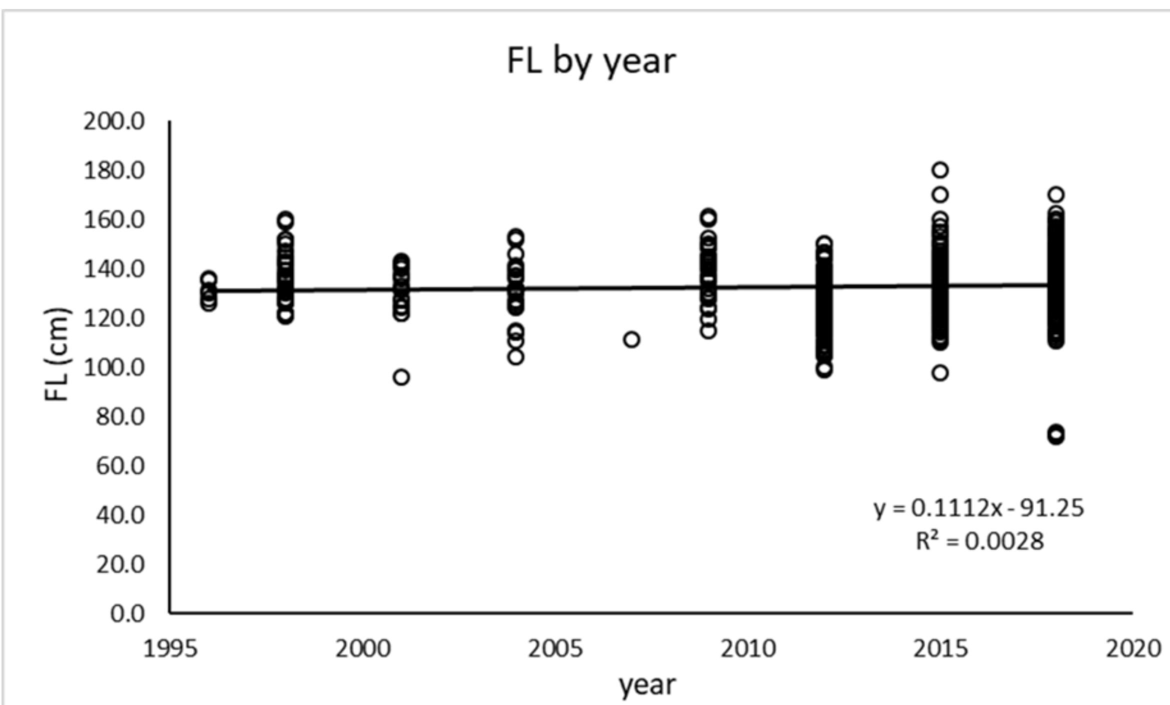
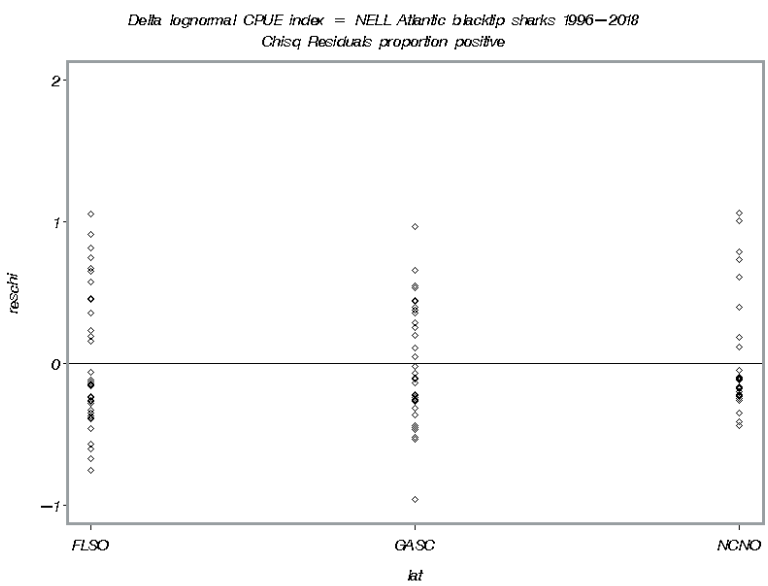
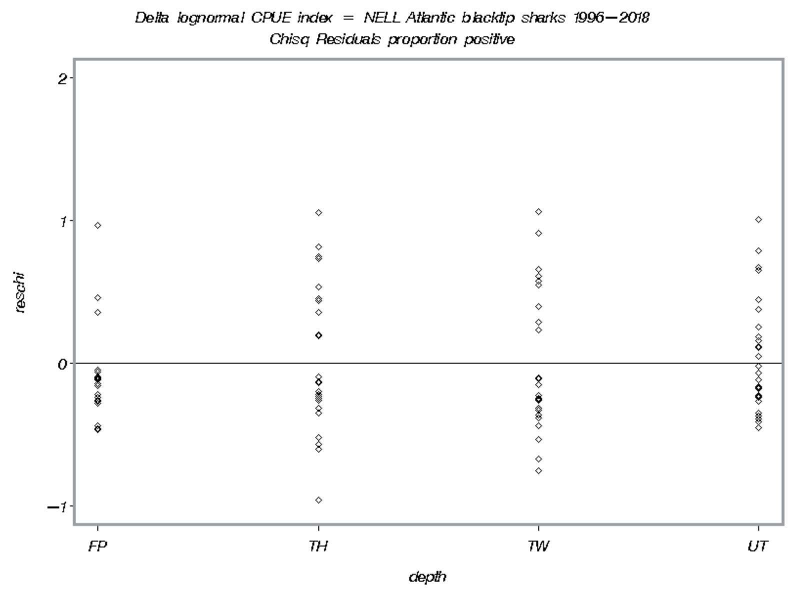


Figure 3. Blacktip shark model diagnostic plots for the binomial component.





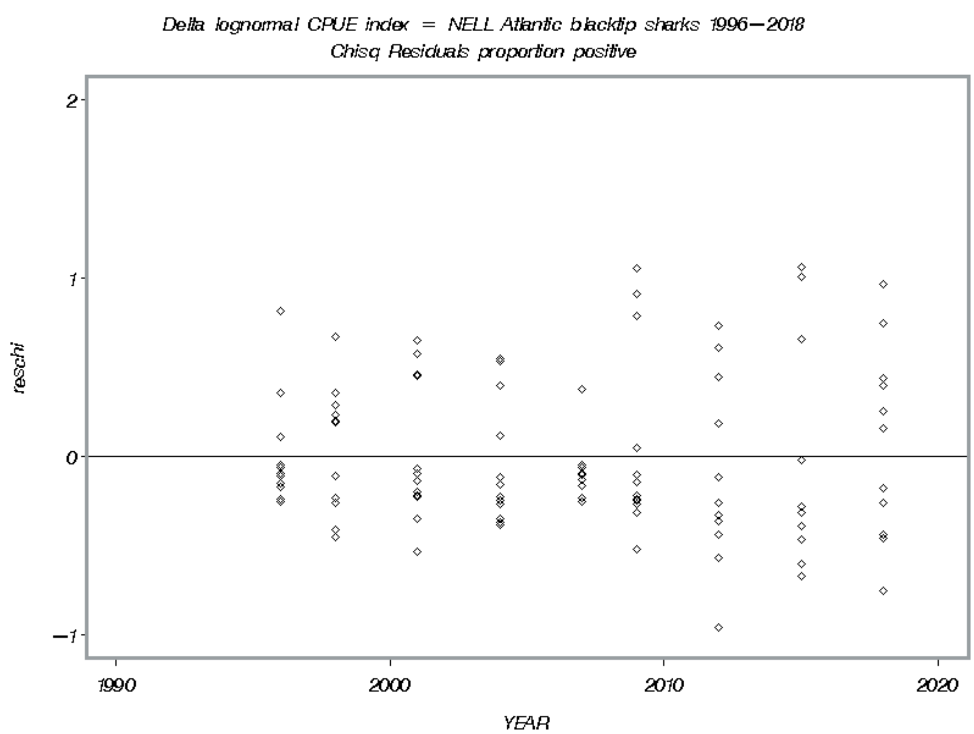


Figure 4. Original model: positive catch = year + depth. Blacktip shark model diagnostic plots for the lognormal component.

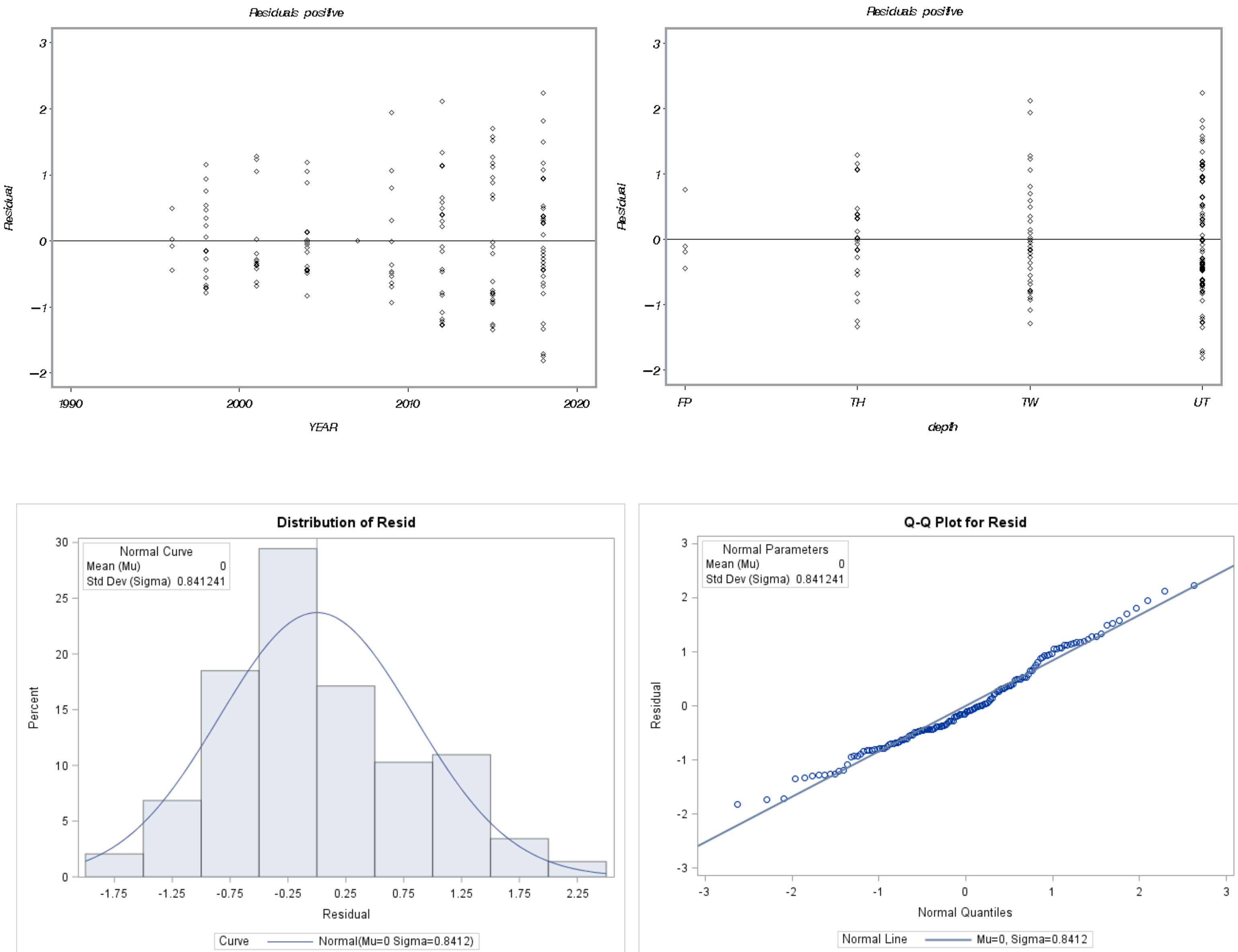


Figure 5. Original model: positive catch = year + depth. Blacktip shark model diagnostic plots for the lognormal component.

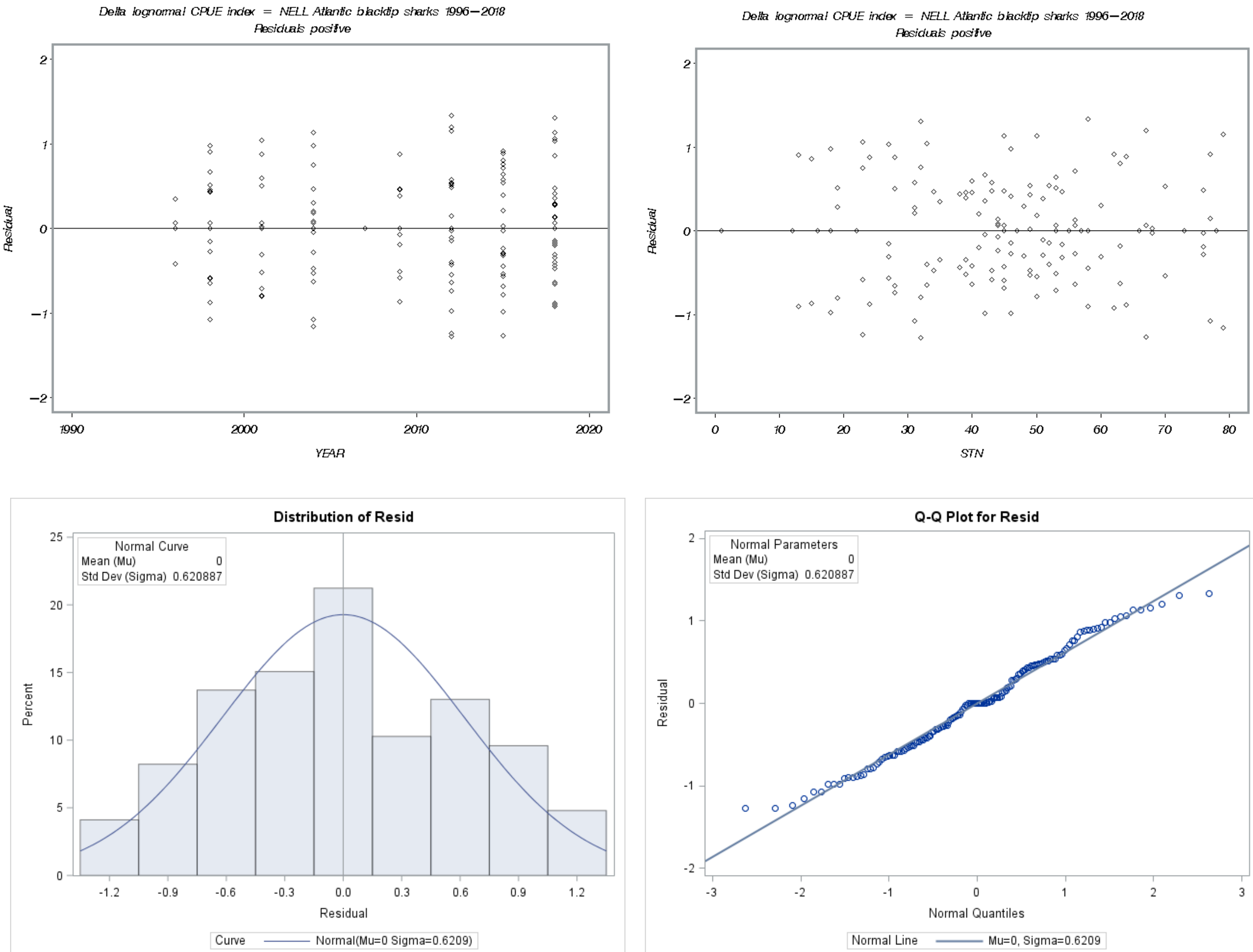


Figure 6. Original model: proportion positive (binomial) = year + area + depth, and positive catch (lognormal) = year + depth. NEFSC longline survey blacktip shark observed and standardized indices with 95% confidence limits.

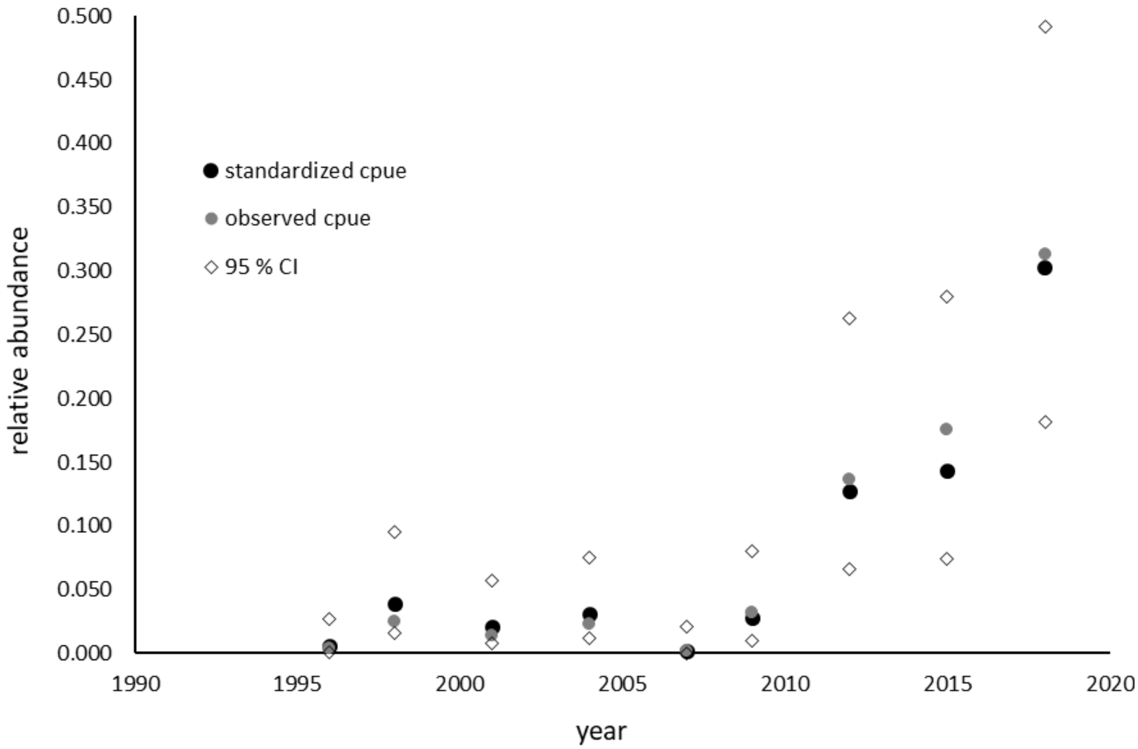


Figure 7. New model: proportion positive (binomial) = year + area + depth, and positive catch (lognormal) = year + station. NEFSC longline survey blacktip shark observed and standardized indices with 95% confidence limits.