Index of Abundance of Sandbar Shark (*Carcharinus plumbeus*) in the Southeast Region, 1992-2007, From United States Commercial Fisheries Longline Vessels

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Introduction

Handline, electric reel (bandit rig), and longline landings and fishing effort of commercial vessels operating in the Gulf of Mexico (GOM) and U.S. south Atlantic are reported to the National Marine Fisheries Service (NMFS) through the Coastal Fisheries Logbook Program (CFLP, conducted by the NMFS Southeast Fisheries Science Center). The program collects landings and effort data by fishing trip from vessels that are federally permitted to fish in a number of fisheries managed by the Gulf of Mexico and South Atlantic Fishery Management Councils. The coastal logbook program began in 1990 (Gulf of Mexico; 1992 south Atlantic) with the objective of a complete census of coastal fisheries permitted vessel activity, with the exception of Florida, where a 20% sample of vessels was selected to report. Beginning in 1993, reporting in Florida was increased to include all vessels permitted for Federally managed coastal fisheries.

The CFLP available catch per unit effort (CPUE) data were used to construct a standardized abundance index for sandbar shark (*Carcharinus plumbeus*). The index was constructed using data reported from commercial longline trips in the southeast region Texas to North Carolina. Sandbar shark data were sufficient to construct an index of abundance including the years 1992-2007.

Sandbar sharks were originally included with the Large Coastal Shark management group in the 1993 Federal Management Plan (FMP) for Sharks of the Atlantic Ocean for stock assessment and quota management purposes. In the 1999 FMP for Atlantic Tunas, Swordfish and Sharks, large coastal sharks were divided into two groups with sandbar sharks managed under the ridgeback sharks. In July 2008, Amendment 2 to the 2006 Consolidated Highly Migratory Species (HMS) FMP initiated a rebuilding plan for sandbar sharks which included separate quota monitoring of the species, the establishment of a Commercial Shark Research Fishery (of which the participants were the only fishers allowed to retain sandbar sharks), and prohibition of sandbar shark by any not involved in the shark research fishery.

Methods

Available Data

Data in the coastal logbook database included, for each fishing trip, a unique trip identifier, the landing date, fishing gear(s) deployed, areas fished (Figure 1), number of days at sea, number of crew, gear specific fishing effort, species caught, and weight of landings. Landings may be reported as whole weight or dressed weight by fishers. All weights were converted to whole weight (ww) prior to data analysis. Fishing effort data available for longline gear included number of sets and number of hooks fished per set. Due to reporting inconsistencies with number of hours recorded on the logbook forms, the number of hooks fished, as opposed to the number of hook hours, was used in this analysis for CPUE (catch per unit effort). Multiple areas and multiple gears fished may be reported for a single fishing trip. In such cases, assigning catch and effort to specific locations or gears was not possible; therefore, only trips which reported one area and one gear fished were included in these analyses.

Data were further restricted to include only those trips with landings and effort data reported within 45 days of the completion of the trip. Reporting delays beyond 45 days are unlikely to effect the reliability of landings data as this information may be retrieved from trip ticket reports; however lengthy delays in recording are likely to result in decreased reliability of reported fishing effort. Eliminating reports submitted more than 45 days after the completion of a trip resulted in approximately 77% of the longline trips being retained for analyses.

Clear outliers in the dataset of large coastal sharks fished with longline gear, e.g. values falling outside the 99.5 percentile of the data, were excluded from the analyses. These included data from trips reporting more than 12 sets per day, fewer than 30 hooks per set, more than 3,000 hooks per set, longline lengths less than 1 mile, and longline lengths more than 20 miles. Data from trips that reported crews of more than 5 or trips of more than 16 days at sea were also excluded.

Management measures, specifically closed seasons, required that additional data be excluded from the analyses. Closed seasons generally occurred yearly from April to June and from September to December beginning in 1993 due to quota restrictions. Data from closed seasons were excluded from the analyses. Trip limit restrictions did not exist for sandbar shark until 2008 with the inception of the shark research fishery. Trip limits are specific to each vessel and owner (listed on the individual's Shark Research Permit). Trip limits, along with a reduced number of vessels/captains, likely changed catchability of sandbar shark after 2007 (particularly 2008); therefore, data for the analyses were restricted to the years 1992-2007. No minimum size restrictions were in effect for sandbar shark for the years of the analyses.

Although reports of unknown sharks have historically been reported, particularly large numbers of unknown sharks were reported in 1993,1994, and 1995. A corresponding decrease in the number of sharks reported as sandbar shark (and other shark species) was observed.

Large coastal sharks fishing trips were identified using a data subsetting technique (modified from Stephens and MacCall, 2004) intended to restrict the data set to trips with fishing effort in sandbar shark habitat. Such an approach was necessary because fishing location is not reported to the CFLP at a spatial scale adequate to identify targeting based upon the habitat where the fishing occurred. The modified Stephens and MacCall method was an objective approach in which a logistic regression was applied to estimate the probability that sandbar shark could have been encountered given the presence or absence of other species reported from the trip. As a function of the species reported from a trip, a score was assigned to the trip and that score was converted into the probability of observing sandbar sharks. Trips with scores above a critical value were included in the CPUE analysis. That critical value was set at the score that minimized the number of predictions of sandbar shark occurring when the species was actually absent (false positives) while also minimizing incorrect predictions of sandbar shark absence when the species was actually present (false negatives).

Small numbers of sandbar shark targeted trips were identified in statistical areas 12 through 22 (western GOM) and were excluded from the analyses. Data were also excluded from areas 2479, 2680, 2981, 3181, 3379, and 3576 (along the south Atlantic coast) also due to small sample sizes. Species-specific regression coefficients for sandbar shark are provided in Figure 2. The magnitude of the coefficients indicates the predictive impact of each species. The final data set included information from 5,693 trips.

Index Development

Longline catch rate was calculated as the weight of sandbar shark per hook fished:

CPUE = pounds of sandbar shark/(number of sets*number of hooks per set)

Nine factors were considered as possible influences on the proportion of trips that landed sandbar shark and on the catch rate of sandbar shark. An additional factor, number of hooks fished, was examined for its affect on the proportion of positive trips. In order to develop a well balanced sample design it was necessary to define categories within some of the factors examined:

Factor	Levels	Value
Year	16	1992 - 2007
Season	4	Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec
Subregion (subreg)*	6	Stat areas 1-4, 5-7, 8-11, 2480-2780, 2878-3180, 3277-3675 (*see Figure 1*)
Longline length (length_cat)*	2	<5, 5+ miles
Days at sea (away_cat)*	2	1-2, 3+ days
Crew (crew_cat)*	2	1-2, 3-5 crew members
Permit	2	Directed, Incidental
Vessel Length (veslen)*	4	<= 30, 31-40, 41-50, 50+ feet, Unknown
Distance between hooks (hookdist_cat)*	3	<=63, 63.1-85, >85.1 feet
Hooks fished (tothook_cat)*[1]	4	<501; 501-1,000; 1,001-2,000; 2,000+ hooks

* Names in parentheses appear in some figures and tables.
[1] Hooks fished was examined only for the proportion positive analyses.

For each general linear model (GLM) analysis of proportion positive trips, a type-3 model was fit, a binomial error distribution was assumed, and the logit link was selected. The response variable was proportion successful trips. During the analysis of catch rates on successful trips, a type-3 model assuming lognormal error distribution was examined. The linking function selected was "normal", and the response variable was log(CPUE). The response variable of longline data was calculated as: log(CPUE)=ln(pounds of sandbar shark /hooks fished). All 2-way interactions among significant main effects were examined. Higher order interaction terms were not examined.

A forward stepwise regression procedure was used to determine the set of fixed factors and interaction terms that explained a significant portion of the observed variability. Each potential factor was added to the null model sequentially and the resulting reduction in deviance per degree of freedom was examined. The factor that caused the greatest reduction in deviance per degree of freedom was added to the base model if the factor was significant based upon a Chi-Square test ($p<0.05$), and the reduction in deviance per degree of freedom was $\geq 1\%$. This model then became the base model, and the process was repeated, adding factors and interactions individually until no factor or interaction met the criteria for incorporation into the final model.

Once a set of fixed factors was identified, the influence of the YEAR*FACTOR interactions were examined. YEAR*FACTOR interaction terms were included in the model as random effects. Selection of the final mixed model was based on the Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion (BIC), and a chi-square test of the difference between the –2 log likelihood statistics between successive model formulations (Littell et al. 1996).

The delta lognormal model approach (Lo et al. 1992) was used to construct a standardized index of abundance. This method combines separate GLM analyses of the proportion of successful trips (trips that landed sandbar shark) and the catch rates on successful trips to construct a single standardized CPUE index. GLM analyses were used to identify any significant effects the above factors had on the proportion of positive sandbar shark trips and on the catch rate. Parameterization of each model was accomplished using a GLM procedure (GENMOD; Version 9.1 of the SAS System for Windows © 2000. SAS Institute Inc., Cary, NC, USA). The final delta-lognormal model was fit using a SAS macro, GLIMMIX (Russ Wolfinger, SAS Institute).

To facilitate visual comparison, a relative index and relative nominal CPUE series were calculated by dividing each value in the series by the mean value of the series.

Results and Discussion

The final models for the binomial on proportion positive trips (PPT) and the lognormal on CPUE of successful trips for sandbar shark were:

PPT = Year + Subreg + HookDist_cat + HooksFished + Subreg*HookDist_cat + Year*HookDist_cat

LOG(CPUE) = Year + Days at Sea + HooksFished + Subreg + Vessel Length + Subreg*Year + Year*Vessel Length + HookDist*Subregion

The linear regression statistics and analysis of the mixed model formulations of the final models are summarized in Table 1(A-D).

Relative nominal CPUE, number of trips, proportion positive trips, and standardized abundance index is provided in Table 2. The delta-lognormal abundance index developed for each species, with 95% confidence intervals, is shown in Figure 3. The annual trends in proportion of positive trips and the nominal CPUE are provided in Figure 4 (A-B).

The decrease in annual CPUE during 1993-1995 may be the direct result of a change in reporting. During those years, the number of sharks reported as “unclassified shark” increased substantially, while species-specific reports had a concomitant decline. Standardized annual CPUE may change markedly during 1993-1995 if a portion of the unclassified sharks could be categorized as sandbar shark. This may be accomplished by applying the ratio of sandbar sharks to all sharks recorded in the bottom longline observer data from the appropriate year-area combination.

Plots of frequency distributions of the proportion of positive trips, frequency distributions of log(CPUE) for positive catch, cumulative normalized residuals, and plots of chi-square residuals by each main effect for the binomial and lognormal models are shown in Figures 5-7. Those diagnostic plots indicate that the fit of the data to the lognormal and binomial models was acceptable. The frequency distribution of log(CPUE) data for each species were slightly skewed from the expected normal distribution. Those variations from the expected fit of the data were not sufficient to violate assumptions of the analyses. The percent positive sandbar shark trips ranged from approximately 13 to 86%. During the years 1993-95 (which correlate to the high reports of unknown sharks), proportion positive trips ranged from 13 to 33%, while the remainder of the data had proportions ranging from 69 to 86% positive trips. All were within the acceptable range required for the analysis.

Sandbar shark CPUE for longline vessels increased from 1994 until 1999 and were stable or slightly decreasing through 2007. It is possible that the misreported sandbar sharks as ‘unknown shark’ between 1993 and 1995 strongly influenced those observed lower rates. Coefficients of variation (CV) were in the range 0.20-0.58 for the entire time series, with a range 0.46 to 0.58 from 1993-1995 and a range of 0.20 to 0.25 for the remainder of the data set. Utilizing observer data from 1993 to 1995 those years to determine the proportions of sandbar sharks possibly reported as unknown sharks would likely increase the CPUE over those years.

Literature Cited

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D Wolfinger. 1996. SAS® System for Mixed Models, Cary NC, USA:SAS Institute Inc., 1996. 663 pp.

Lo, N.C., L.D. Jackson, J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

Stephens, A. and A. McCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research 70:299-310.

Figure 1. Coastal Logbook map with defined fishing (statistical) areas. The areas reported on coastal fisheries logbook forms include 1 through 22 for the Gulf of Mexico and grids 2479 through 3675 for the south Atlantic. No areas between 12 and 22 were included in the analyses. The area categories used in the index development are represented roughly by the ovals below.

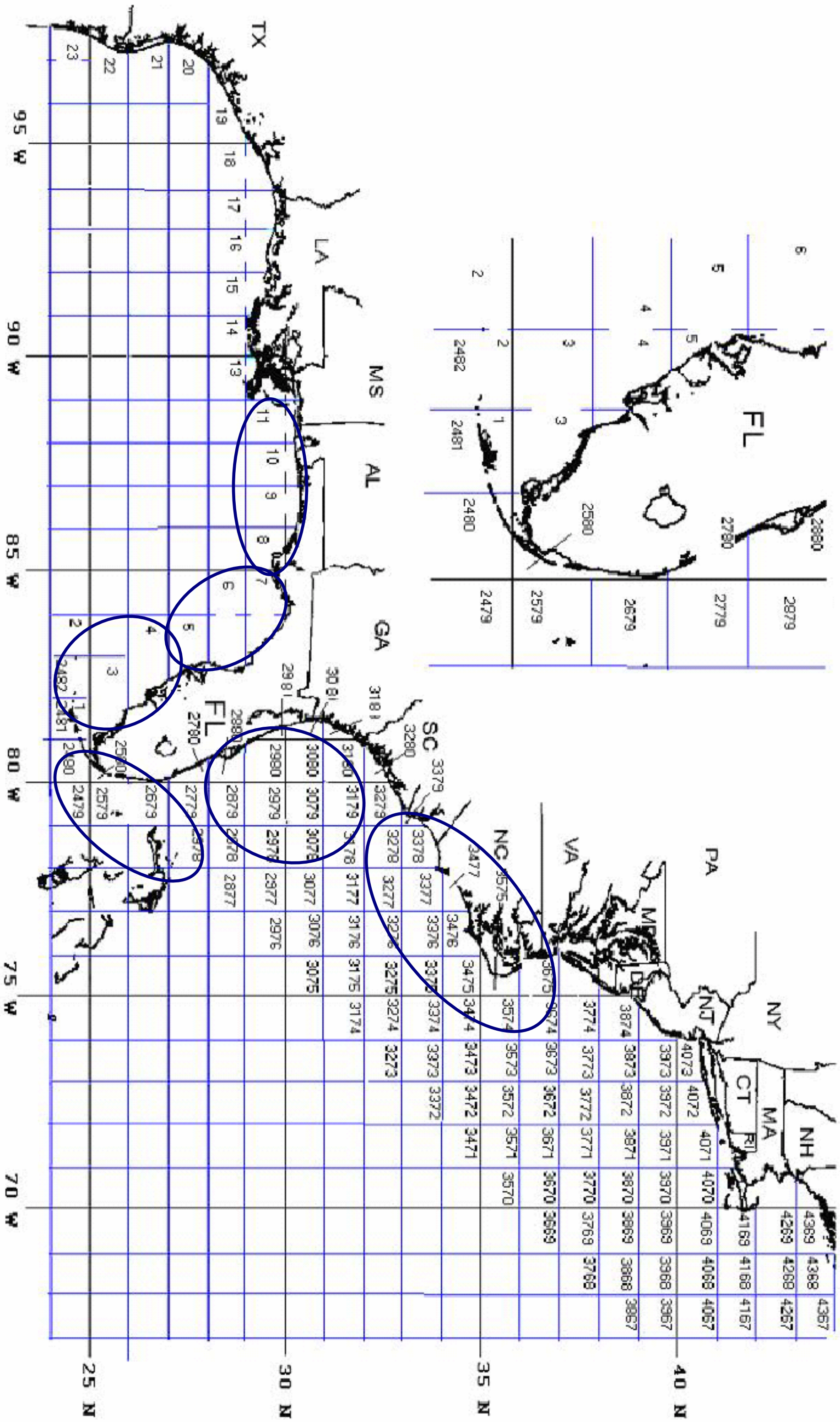


Figure 2. Regression coefficients from the Stephens & MacCall analyses. Positive coefficients signify species that had positive associations with the target species, sandbar shark. The magnitude of the coefficients indicates the predictive impact of each species. The value for “noncooccurring” is the regression intercept and denotes the probability a trip was fishing in the target species’ habitat, but did not report any of the listed species. Species included were reported on at least one percent of longline trips.

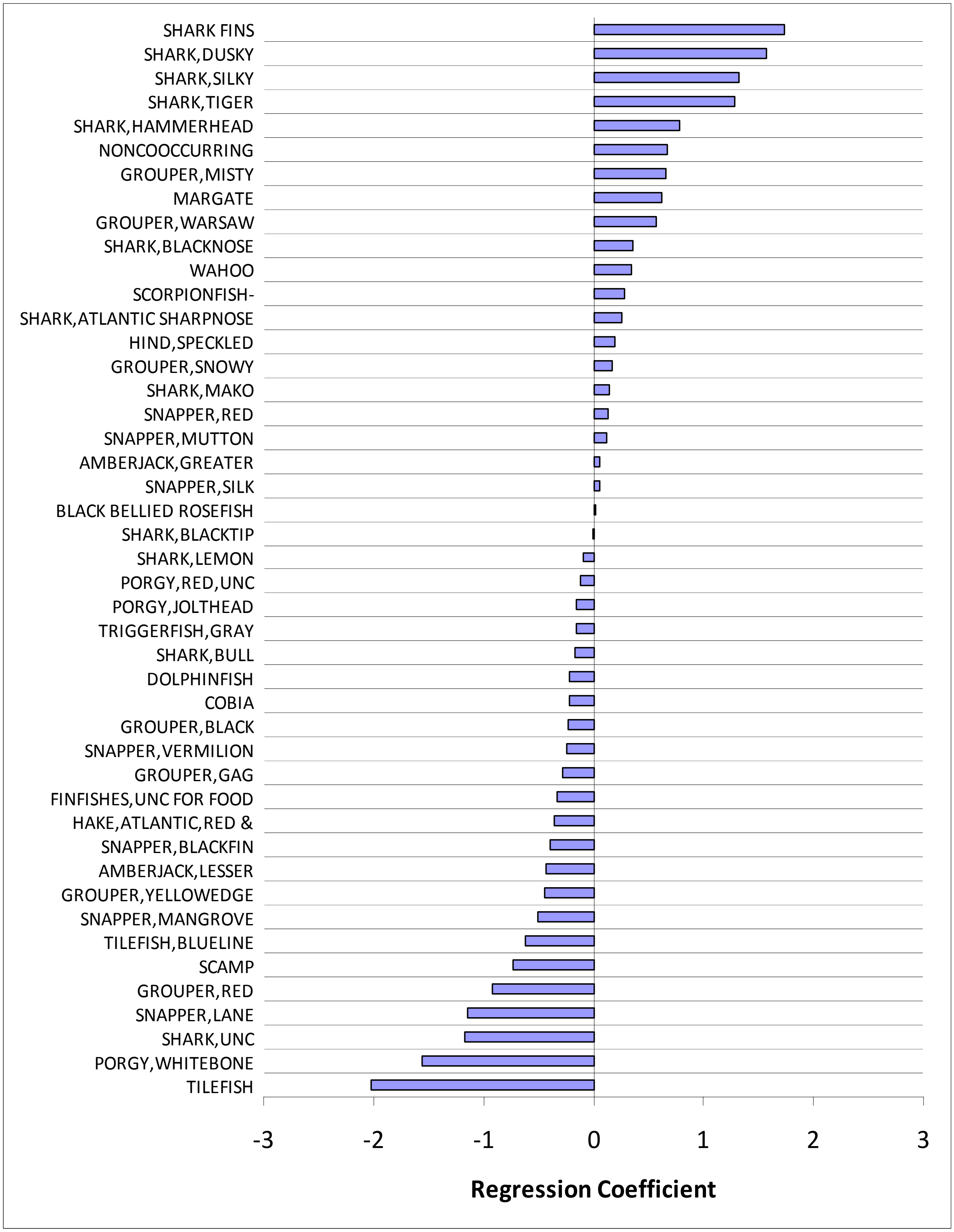


Table 1. (**A**) Linear regression statistics for the GLM models on proportion positive trips and (**B**) catch rates on positive trips for sandbar shark in the eastern Gulf of Mexico and south Atlantic for vessels reporting longline gear landings, 1992-2007. Analysis of the mixed model formulations of (**C**) the proportion positive and (**D**) the positive trip model. The likelihood ratio was used to test the difference of –2 REM log likelihood between two nested models. The final model is indicated with gray shading. See text for factor (effect) definitions.

A.

Type 3 Tests of Fixed Effects

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	15	30	132.56	8.84	<.0001	<.0001
SUBREG	5	765	83.32	16.66	<.0001	<.0001
HOOKDIST_CAT	2	30	52.18	26.09	<.0001	<.0001
TOTHOOK_CAT	3	765	40.75	13.58	<.0001	<.0001
*SUBREG*HOOKDIST_CAT*	10	765	46.81	4.68	<.0001	<.0001

B.

Type 3 Tests of Fixed Effects

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	15	42	15.71	1.05	0.4014	0.4302
AWAY_CAT	1	4111	247.52	247.52	<.0001	<.0001
HOOKDIST_CAT	2	4111	240.30	120.15	<.0001	<.0001
SUBREG	5	72	35.42	7.08	<.0001	<.0001
veslen	3	42	17.95	5.98	0.0005	0.0017
*HOOKDIST_CAT*SUBREG*	10	4111	58.77	5.88	<.0001	<.0001

C.

Proportion Positive	*-2 REM Log likelihood*	*Akaike's Information Criterion*	*Schwartz's Bayesian Criterion*	*Likelihood Ratio Test*	*P*
*YEAR + subreg + hookdist_cat + tothook_cat + subreg*hookdist_cat*	3291.0	3293.0	3297.7	-	-
*YEAR + subreg + hookdist_cat + tothook_cat + subreg*hookdist_cat + year*hookdist_cat*	3282.0	3286.0	3289.8	9.0	0.0027

D.

Catch Rates on Positive Trips	*-2 REM Log likelihood*	*Akaike's Information Criterion*	*Schwartz's Bayesian Criterion*	*Likelihood Ratio Test*	*P*
year + away_cat + hookdist_cat + subreg + veslen	13525.7	13527.7	13534.1	-	-
*year + away_cat + hookdist_cat + subreg + veslen + year*subreg*	13489.8	13493.8	13498.9	35.9	<0.0001
*year + away_cat + hookdist_cat + subreg + veslen + year*subreg + year*veslen*	13456.6	13462.6	13470.2	33.2	<0.0001
*year + away_cat + hookdist_cat + subreg + veslen + year*subreg + year*veslen + hookdist_cat*subreg*	13420.4	13426.4	13434.0	36.2	<0.0001

Table 2. Longline relative nominal CPUE, number of trips, proportion positive trips, and standardized abundance index for sandbar shark (1992-2007).

YEAR	Nominal CPUE	Trips	Proportion Successful Trips	Standardized Index	Lower 95% CI (Index)	Upper 95% CI (Index)	CV (Index)
1992	0.55484	90	0.75556	1.60053	0.97103	2.63814	0.25382
1993	0.43805	33	0.33333	0.67101	0.23947	1.88027	0.55134
1994	0.11301	90	0.13333	0.09340	0.03192	0.27334	0.57802
1995	0.22979	86	0.23256	0.22903	0.09486	0.55297	0.46301
1996	0.81793	404	0.76238	0.79333	0.52560	1.19744	0.20805
1997	1.09289	371	0.77898	0.99997	0.66072	1.51341	0.20944
1998	1.39800	391	0.86445	1.21031	0.80922	1.81021	0.20334
1999	1.52380	414	0.78019	1.44285	0.95468	2.18066	0.20872
2000	1.45335	377	0.81698	1.37091	0.90476	2.07723	0.21004
2001	1.55969	413	0.85230	1.23420	0.82166	1.85389	0.20555
2002	1.24229	566	0.78269	1.29117	0.86361	1.93039	0.20314
2003	1.12720	522	0.77203	1.15732	0.77085	1.73755	0.20530
2004	1.24089	503	0.75944	0.96834	0.64440	1.45512	0.20576
2005	0.96399	557	0.69479	1.00931	0.66690	1.52754	0.20944
2006	1.12135	688	0.72093	0.97472	0.65104	1.45933	0.20386
2007	1.12293	177	0.68927	0.95358	0.59012	1.54091	0.24345

Figure 3. Sandbar shark nominal CPUE (solid circles), standardized CPUE (open diamonds) and upper and lower 95% confidence limits of the standardized CPUE estimates (dashed lines) for vessels fishing longline gear.

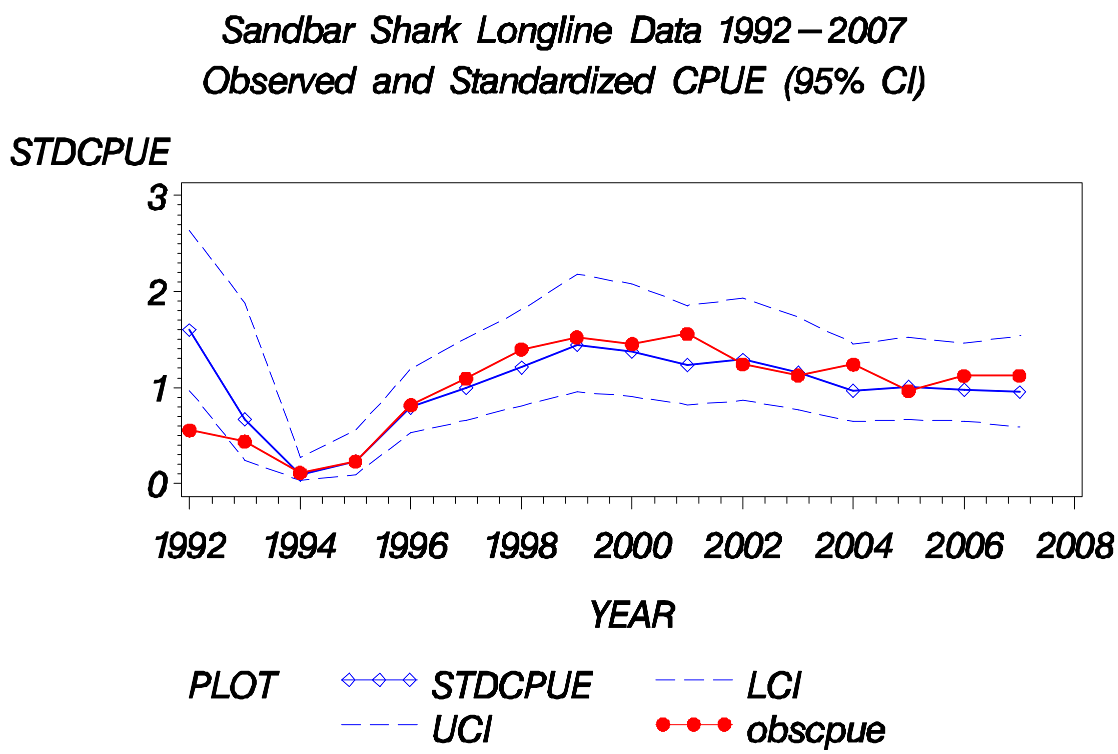
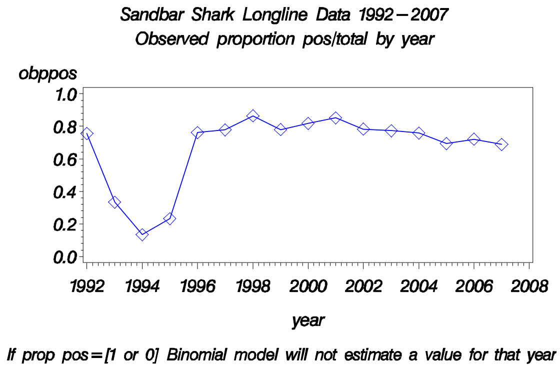


Figure 4. Annual trends in **A.** the proportion of positive trips and **B.** the nominal CPUE of 1992-2007 sandbar shark commercial longline data.

A.



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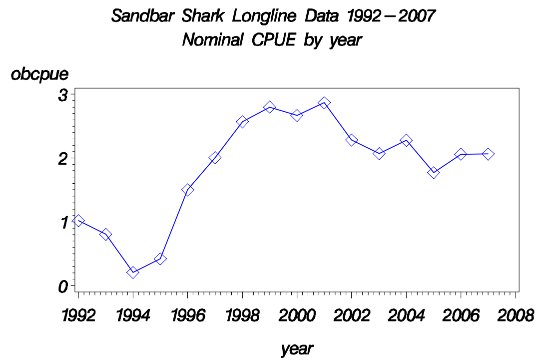
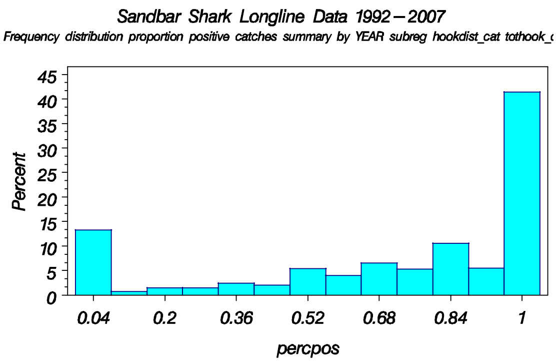


Figure 5. Diagnostic plots for the binomial component of the 1992-2007 sandbar shark commercial longline gear model: **A**. the frequency distribution of the proportion positive trips; **B**. the Chi-Square residuals by year; **C**. the Chi-Square residuals by subregion; **D**. the Chi-Square residuals by distance between hooks; and **E**. the Chi-Square residuals by total hooks fished.

A.



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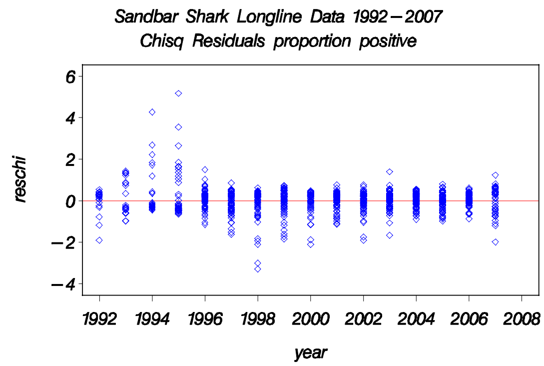

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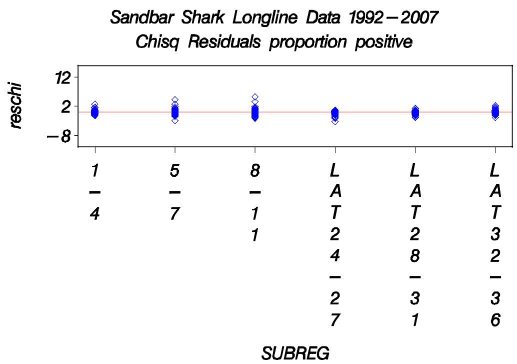

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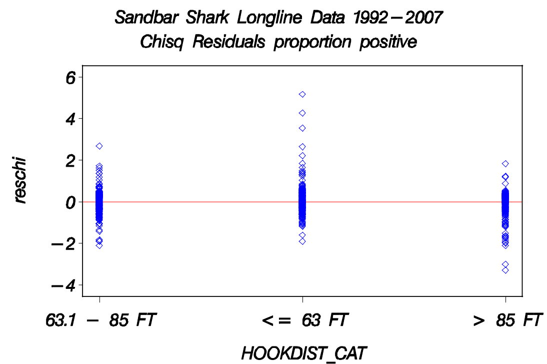

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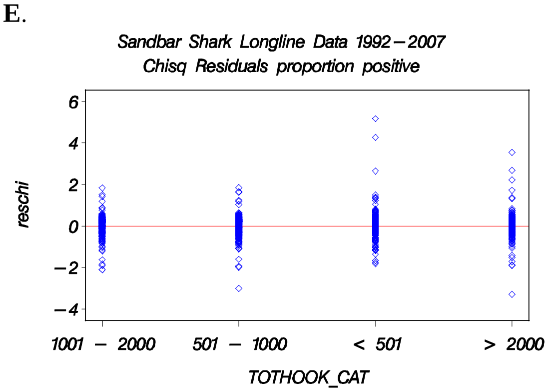
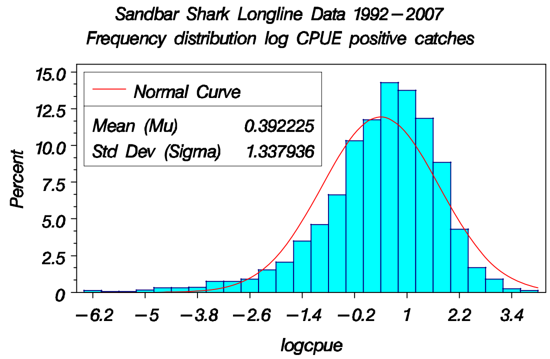


Figure 6. Diagnostic plots for the lognormal component of the 1992-2007 sandbar shark commercial longline gear model: **A.** the frequency distribution of log(CPUE) on positive trips, **B.** the cumulative normalized residuals (QQ-Plot) from the lognormal model. The red line is the expected normal distribution.

A.



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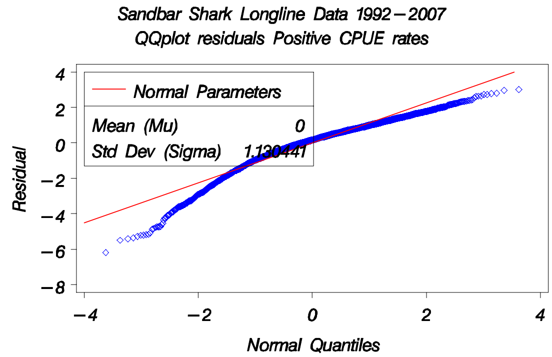
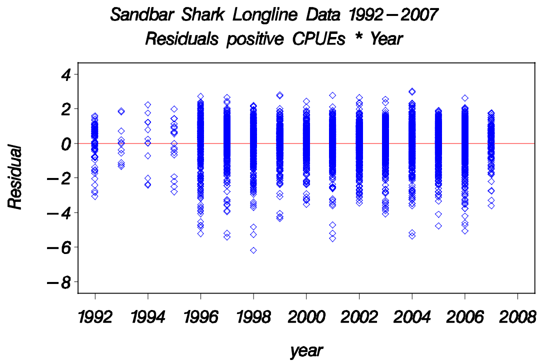


Figure 7. Diagnostic plots for the lognormal component of the 1992-2007 sandbar shark commercial longline gear model: **A**. the Chi-Square residuals by year; **B**. the Chi-Square residuals by subregion; **C**. the Chi-Square residuals by days at sea; **D**. the Chi-Square residuals by distance between hooks; and **E**. the Chi-Square residuals by vessel lengths.

A.



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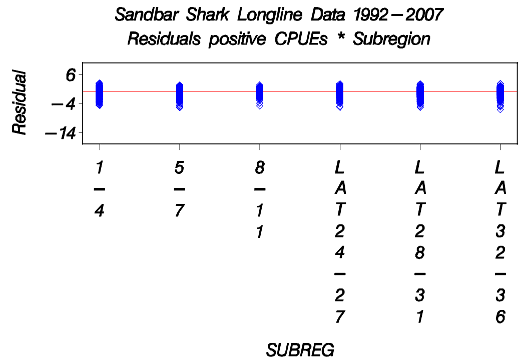

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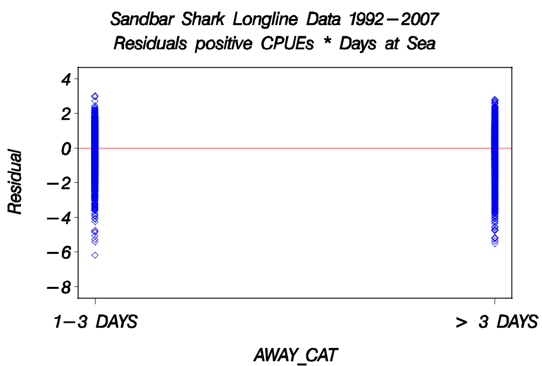

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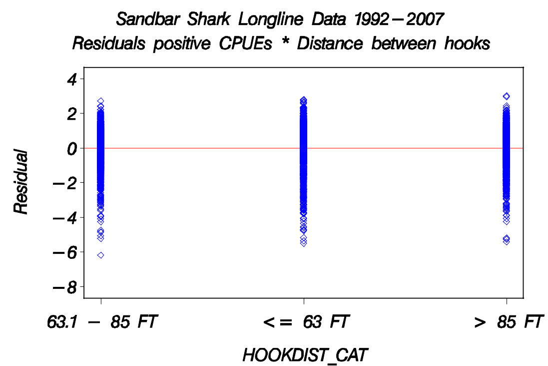

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