Commercial Bottom Longline Vessel Standardized Catch Rates of Blacktip Sharks in the United States Gulf of Mexico, 1996-2010, with targeting determined using logistic regression

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Introduction

Handline, electric and hydraulic reel (bandit rig), and longline landings and fishing effort of commercial vessels operating in the Gulf of Mexico and U.S. South Atlantic have been 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 in the Gulf of Mexico and in 1992 in the US South Atlantic with the objective of a complete census of coastal fisheries permitted vessel activity, however in Florida 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 bottom longline catch per unit effort (CPUE) data were used to construct a standardized abundance index for blacktip sharks in the Gulf of Mexico. Blacktip shark data were sufficient to include the years 1996-2010 in a index of abundance. Although fishing effort and landings from 1990-1995 were reported to the coastal logbook program, shark species identification problems were found in those data (Brown, 2002) and a large proportion of shark landings were identified as unclassified shark prior to 1996 (Heinemann and Poffenberger, 2002). The proportion of unclassified sharks decreased after 1995 and the proportion of blacktip and sandbar sharks increased coincidentally (Brown, 2002). Due to the large number of non species-specific identifications, data reported prior to 1996 were excluded from this analysis.

Methods

Available Data

For each fishing trip, the coastal logbook database included a unique trip identifier, the landing date, fishing gear deployed, areas fished (Figure 1), number of days at sea, number of crew, gear specific fishing effort, species caught and weight of the landings. Fishing effort data available for longline gear included number of sets fished, number of hooks fished per set, and length of the longline fished. Confusion regarding how to report the number of hours fished (i.e., as total hours fished or hours fished per set) has prevented the use of those data in any analysis. Multiple areas fished and multiple gears fished may be recorded 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 (i.e., subregion, as defined below) and one gear fished (longline) 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 (some reporting delays were longer than one year) likely resulted in less reliable effort data. Landings data, however, may have been reliable even with lengthy reporting delays if trip ticket reports were referenced by the reporting fisher.

Clear outliers in the data, e.g. values falling outside the 99.5 percentile of the data, were excluded from the analyses. These included longline data from trips reporting fishing more than 24 sets per day or fishing less than 50 or more than 3,000 hooks per set. Data from trips with reported crews of more than six or trips of more than 19 days at sea were also excluded from the analyses. Approximately 70 percent of longline trips were retained for analyses following all data filtering. Data were also filtered to remove trips reported during the many closed large coastal shark fishing seasons.

Blacktip shark 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 presumptive blacktip shark habitat. Such an approach was necessary because fishing location was 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 blacktip sharks 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 blacktip 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 blacktip sharks occurring when the species was actually absent (false positives) while also minimizing incorrect predictions of blacktip sharks absence when the species was actually present (false negatives). Figure 2 provides species-specific regression coefficients from the analysis. The magnitude of the coefficients indicates the predictive impact of each species.

Index Development

A single Gulf of Mexico index was constructed using filtered coastal logbook commercial longline data. Longline catch rate was calculated as weight of blacktip sharks per hook fished:

CPUE = pounds of blacktip sharks/(number of sets fished*number of hooks per set)

Six factors were considered as possible influences on the proportion of trips that landed blacktip sharks and on the catch rate of blacktip sharks. An additional factor, number of hooks fished, was examined for its affect on the proportion of positive trips. Spatially, the analyses were limited to the areas defined below. 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	15	1996-2010
Subregion	4	Stat areas 1-3, 4-7, 8-12, 13-21 see Figure 1
Crew (crew1)*	3	1-2, 3, 4+ crew members
Days at sea (seadays)*	4	1, 2, 3, 4+ days
Longline length (length1)*	4	<6, 6-7.9, 8-11.5, >11.5 miles
Distance between hooks (hk_dist)*	4	<53, 53-65.9, 66-84.2, >84.2 feet
Hooks fished (hooks1)*[1]	4	<800, 800-1,400, 1,401-2,250, >2,250 hook hours

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

The delta lognormal model approach (Lo et al. 1992) was used to construct a standardized index of abundance. This method combines separate general linear model (GLM) analyses of the proportion of successful trips (trips that landed blacktip sharks) and the catch rates on successful trips to construct a single standardized CPUE index. Parameterization of each model was accomplished using a GLM analysis (GENMOD; Version 8.02 of the SAS System for Windows © 2000. SAS Institute Inc., Cary, NC, USA).

For the 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) where log(CPUE)=ln(pounds of blacktip sharks/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 ≥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 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 cpue of the series.

Results and Discussion

The CFLP effort and landings data were trip based, therefore, species-specific CPUE calculated for trips by vessels that change the species targeted during a trip will be erroneous. Such change in targeting may occur due to a vessel reaching a trip limit for a species. Blacktip shark trip limits, under the broader large coastal shark trip limits, were in effect throughout the time series of available CFLP data. Trip limit effects were examined by determining the percentage of large coastal shark landings to total landings for each trip included in the analysis. Only 5.65 percent of the all trips (154 of 2,725 trips) reported landings of less than 75 percent large coastal sharks. This suggests that trip limits had little effect on CPUE calculations; i.e., once a trip limit was reached the trip ended without a change in targeting.

The final model of the Gulf of Mexico data set for the binomial on proportion positive trips (PPT) and the lognormal on CPUE of successful trips were:

PPT[1] = Subregion + Year + Distance Between Hooks

LOG(CPUE) = Subregion + Days at Sea + Longline Length + Year + Distance Between Hooks + Year*Subregion + Year*Longline Length + Year*Distance Between Hooks + Subregion*Longline Length + Year*Days at Sea + Longline Length*Distance Between Hooks

The linear regression statistics for fixed effects and the analyses of the mixed model formulations of the final models are summarized in Table 1.

Relative nominal CPUE, number of trips, proportion positive trips, and relative abundance indices are provided in Table 2. The proportion of positive trips increased over the time series from 0.55 to 0.95. The number of trips identified as targeting blacktip sharks dropped in 2007 to less than one third the trips in 2006, presumably due to regulatory changes. Yearly mean cpue ranged from a low of approximately 0.5 in 1996 to approximately 1.3 pounds per hook fished during six of nine years during the period 1999-2007. Mean cpue decreased during the final three years of the time series. Coefficients of variation (CV) for both indices were low (0.24-0.29) from 1996-2008; but were higher (0.35-0.41) in the final two years of the series, likely due to small sample size.

Plots of the proportion of positive trips per year, nominal cpue, 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 3-6. The proportion of positive trips was high during the final year of the time series, however, the small sample sizes during the final two years may be of greater concern. No obvious patterns were apparent in the residual plots, although there were outliers among those data (Figures 4a-c, 6a-e). The frequency distributions log(CPUE) were somewhat negatively skewed (Figures 5a), although the lack of fit was typical for fisheries dependent data and the data appeared to be appropriate for the analysis.

The delta-lognormal abundance index, along with 95% confidence intervals, is shown in Figure 7. Blacktip sharks standardized catch rates for commercial longline vessels were variable and without trend over much of the period 1999-2007. During the initial three years of the time series, yearly mean CPUE increased. Yearly mean CPUE during the final three years (2008-2010) were similar to those from 1996-1998. Plots of an index (continuity index) constructed following the methods of SEDAR 11 (McCarthy and Abercrombie, 2005; McCarthy, 2010) and the index described here (2012 index) are provided in Figure 8. The SEDAR 11 method defined blacktip targeted trips as those reported from vessels with catch rates above the 80^{th} percentile of large coastal shark CPUE averaged across all years. Plotted confidence intervals were those calculated for the 2012 index. The two indices were broadly similar (r^2=0.605), with the continuity index mean yearly CPUEs usually within the 95 percent confidence intervals of the 2012 index. As with any fishery dependent index of abundance, changes in catchability may mask true trends in population abundance.

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McCarthy, K. and D. Abercrombie. 2005. Standardized catch rates of large coastal sharks from the United States bottom longline fishery during 1996-2004. LCS05/06-DW-30-V2.

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Table 1. Linear regression statistics for the GLMs on proportion positive trips (**A**) and catch rates on positive trips (**B**) of blacktip sharks for vessels reporting longline landings from the Gulf of Mexico. Analysis of the mixed model formulations of the positive trip model (**C**). 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	14	182	67.42	4.82	<.0001	<.0001
subregion	3	182	109.99	36.66	<.0001	<.0001
hk_dist1	3	182	13.73	4.58	0.0033	0.0041

B.

Type 3 Tests of Fixed Effects

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	14	38	15.46	1.10	0.3475	0.3852
subregion	3	38	138.20	46.07	<.0001	<.0001
seadays	3	39	109.47	36.49	<.0001	<.0001
length1	3	38	52.67	17.56	<.0001	<.0001
hk_dist1	3	40	26.83	8.94	<.0001	0.0001
*subregion*length1*	9	1779	35.53	3.95	<.0001	<.0001
*length1*hk_dist1*	9	1779	23.14	2.57	0.0059	0.0061

Table 1. Continued

C.

Catch Rates on Positive Trips	*-2 REM Log likelihood*	*Akaike's Information Criterion*	*Schwartz's Bayesian Criterion*	*Likelihood Ratio Test*	*P*
year + subregion + seadays + length1 + hk_dist1	5902.8	5904.8	5910.4	-	-
*year + subregion + seadays + length1 + hk_dist1 + year*subregion*	5871.2	5875.2	5879.2	31.6	<0.0001
*year + subregion + seadays + length1 + hk_dist1 + year*subregion + year*length1*	5842.2	5848.2	5854.3	29.0	<0.0001
*year + subregion + seadays + length1 + hk_dist1 + year*subregion + year*length1 + year*hk_dist1*	5824.7	5832.7	5840.8	17.5	<0.0001
*year + subregion + seadays + length1 + hk_dist1 + year*subregion + year*length1 + year*hk_dist1 + subregion*length1*	5799.4	5807.4	5815.5	25.3	<0.0001
*year + subregion + seadays + length1 + hk_dist1 + year*subregion + year*length1 + year*hk_dist1 + subregion*length1 + year*seadays*	5793.8	5803.8	5813.9	5.6	0.0180
*year + subregion + seadays + length1 + hk_dist1 + year*subregion + year*length1 + year*hk_dist1 + subregion*length1 + year*seadays + length1*hk_dist1*	5784.0	5794.0	5804.1	9.8	0.0017

Table 2. Gulf of Mexico longline relative nominal CPUE, number of trips, proportion positive trips, and standardized abundance index for blacktip sharks constructed using commercial longline data.
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YEAR	Normalized Nominal CPUE	Trips	Proportion Successful Trips	Standardized Index	Lower 95% CI (Index)	Upper 95% CI (Index)	CV (Index)
1996	0.508	186	0.548	0.495	0.283	0.866	0.285
1997	0.598	161	0.602	0.580	0.341	0.989	0.271
1998	0.728	147	0.565	0.778	0.446	1.358	0.284
1999	1.262	200	0.765	1.272	0.760	2.130	0.262
2000	1.291	166	0.717	1.338	0.791	2.265	0.268
2001	0.670	216	0.606	0.929	0.551	1.565	0.266
2002	0.789	297	0.687	0.967	0.593	1.578	0.248
2003	1.112	311	0.826	1.309	0.815	2.101	0.240
2004	1.406	240	0.821	1.341	0.828	2.172	0.245
2005	0.813	278	0.752	1.000	0.616	1.623	0.246
2006	0.959	299	0.799	1.284	0.790	2.089	0.247
2007	1.004	84	0.905	1.280	0.758	2.160	0.266
2008	0.679	90	0.800	0.593	0.334	1.052	0.293
2009	0.701	31	0.710	0.997	0.503	1.977	0.353
2010	2.481	19	0.947	0.837	0.379	1.846	0.412

Figure 1. Coastal Logbook defined fishing areas.

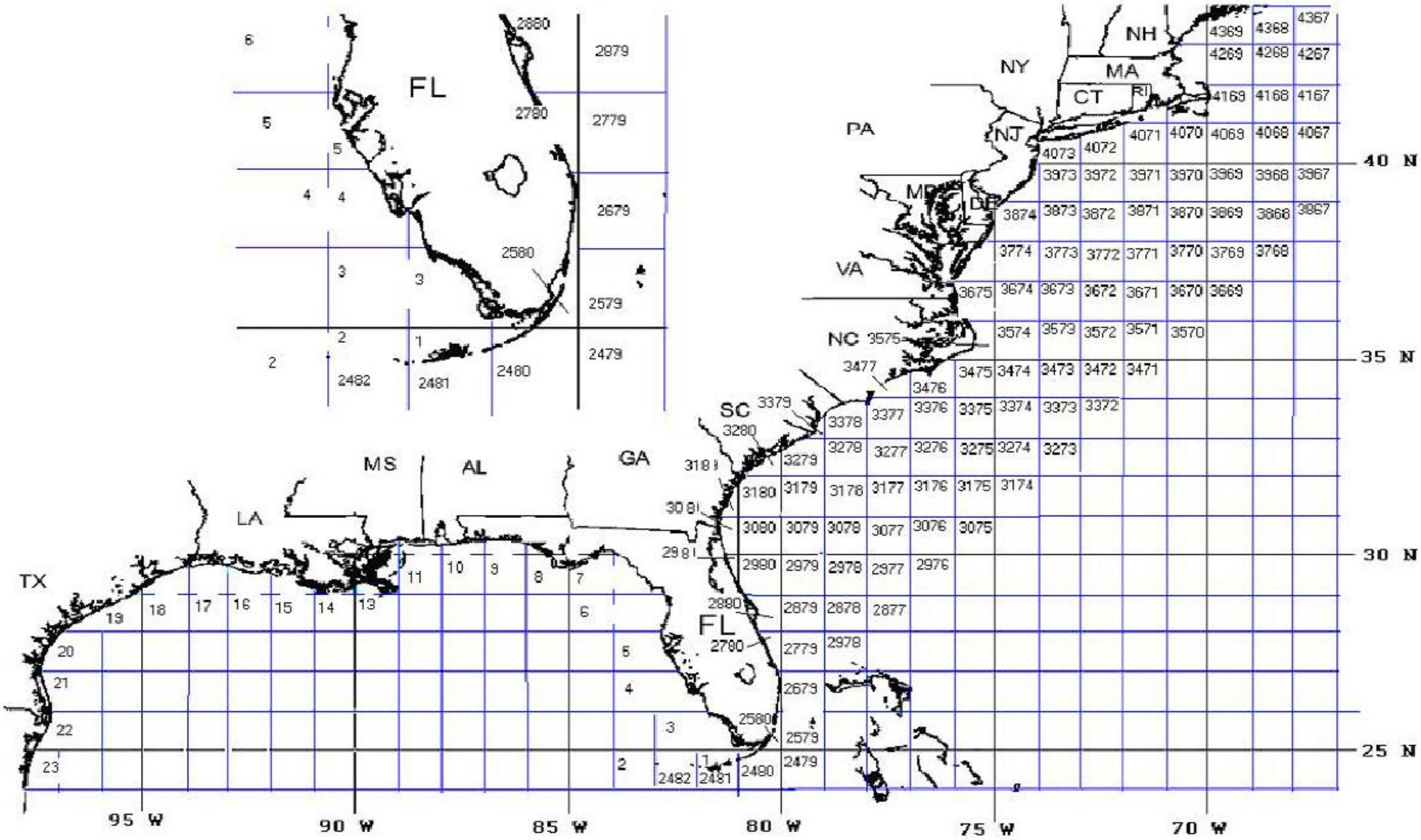


Figure 2. Regression coefficients from the Gulf of Mexico Stephens & MacCall analyses. Positive coefficients signify species that had positive associations with the target species. The magnitude of the coefficients indicates the predictive impact of each species. The value for "non co-occurring" is the 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 commercial longline trips in the Gulf of Mexico.

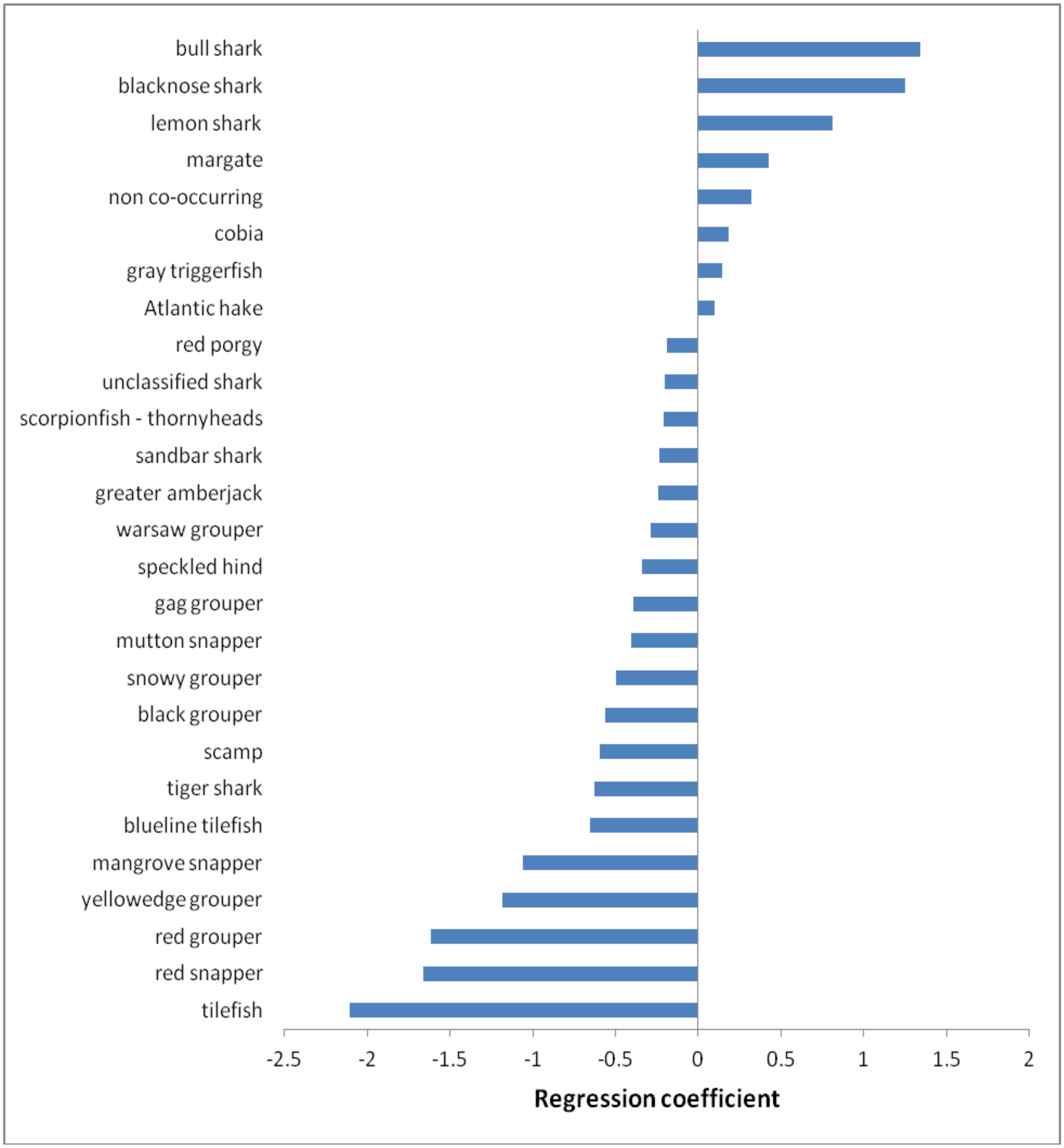


Figure 3. Gulf of Mexico blacktip sharks commercial longline data annual trends in **A.** the proportion of positive trips and **B.** nominal CPUE.

A. **B.**

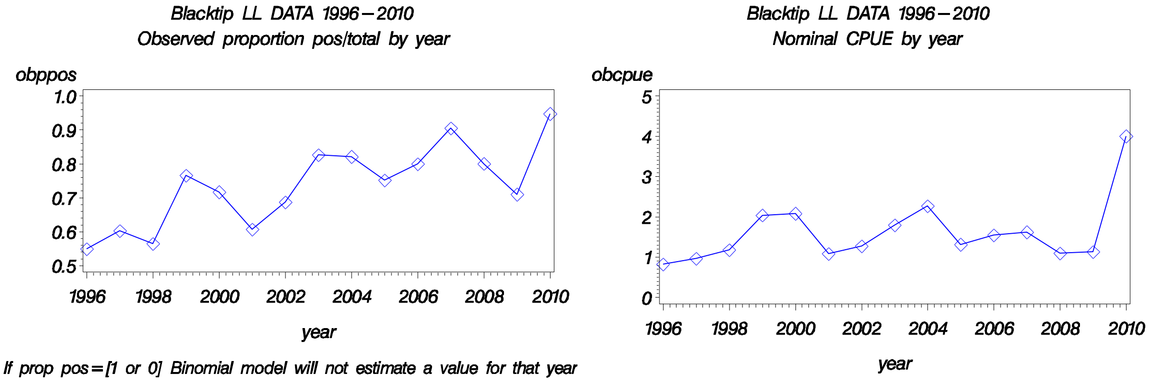
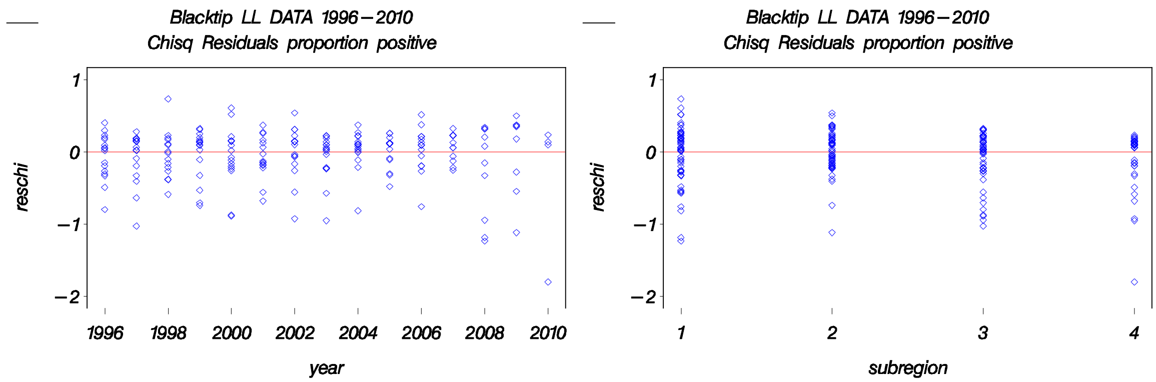


Figure 4. Diagnostic plots for the binomial component of the blacktip sharks commercial longline Gulf of Mexico model: **A**. the Chi-Square residuals by year, **B**. the Chi-Square residuals by subregion, and **C**. the Chi-Square residuals by distance (feet) between hooks (hk_dist1).

A. **B.**



C.

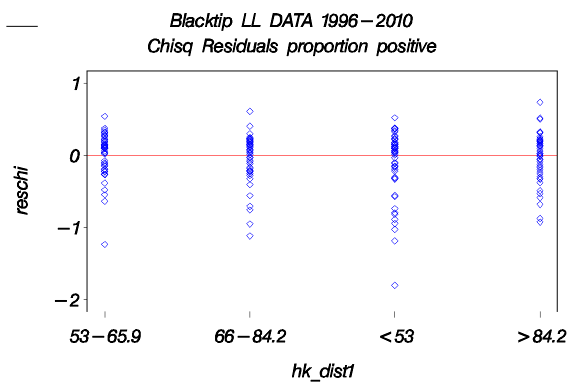
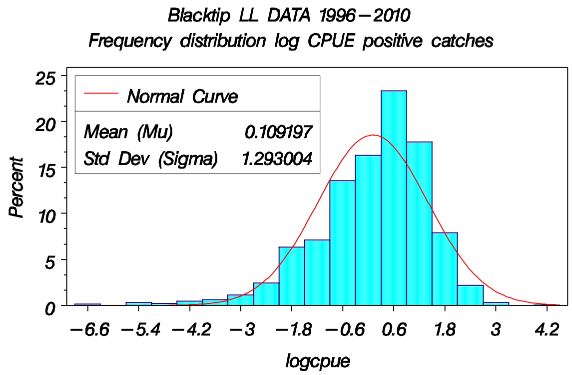


Figure 5. Diagnostic plots for the lognormal component of the Gulf of Mexico blacktip shark commercial longline model: **A.** the frequency distribution of log(CPUE) on positive trips, **B.** the cumulative normalized residuals (QQ-Plot) from the lognormal model. The red line is the expected normal distribution.

A.



B.

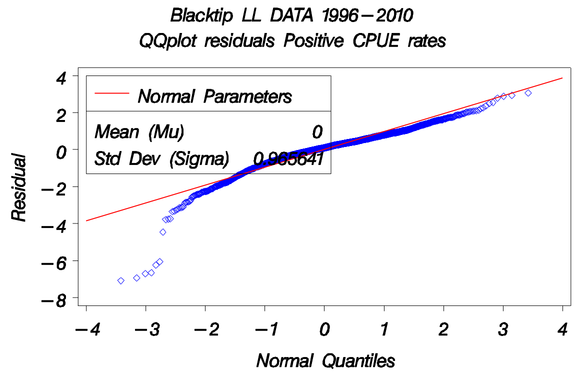
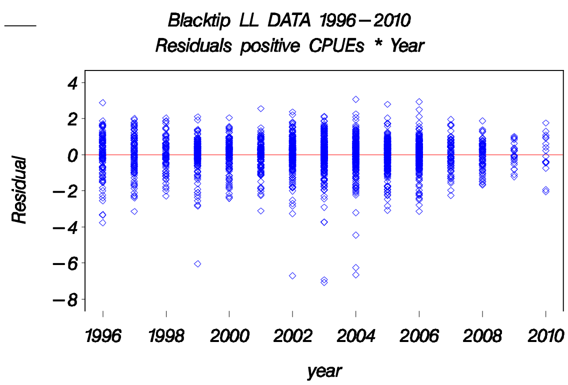
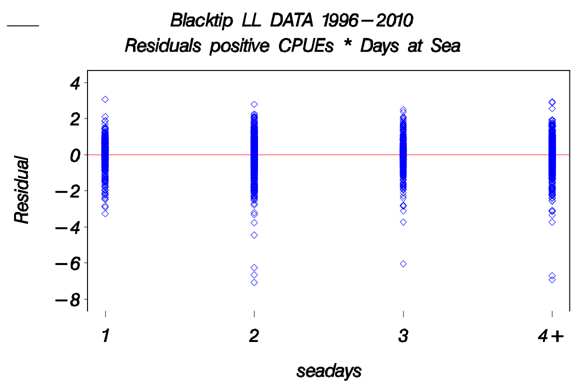


Figure 6. Diagnostic plots for the lognormal component of the Gulf of Mexico blacktip sharks commercial longline model: **A**. the Chi-Square residuals by year; **B**. the Chi-Square residuals by days at sea (seadays); **C**. the Chi-Square residuals by subregion, **D**. the Chi-Square residuals by length of the longline fished (length1), and **E**. the Chi-Square residuals by distance (feet) between hooks (hk_dist1).

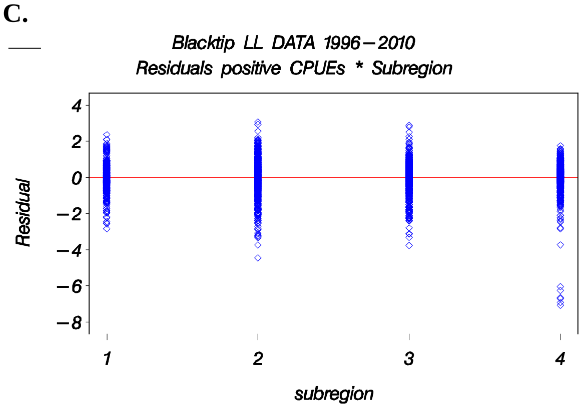
A.



B.



C.



D.

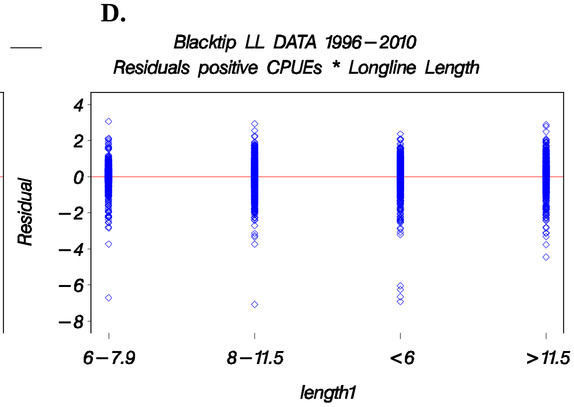


Figure 6. Continued.

E.

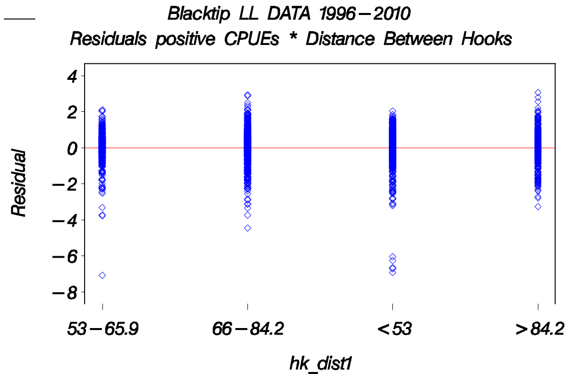


Figure 7. Blacktip shark Gulf of Mexico nominal CPUE (solid circles), standardized CPUE (open diamonds), and upper and lower 95% confidence limits of the standardized CPUE estimates (dashed lines) for commercial vessels fishing bottom longlines.

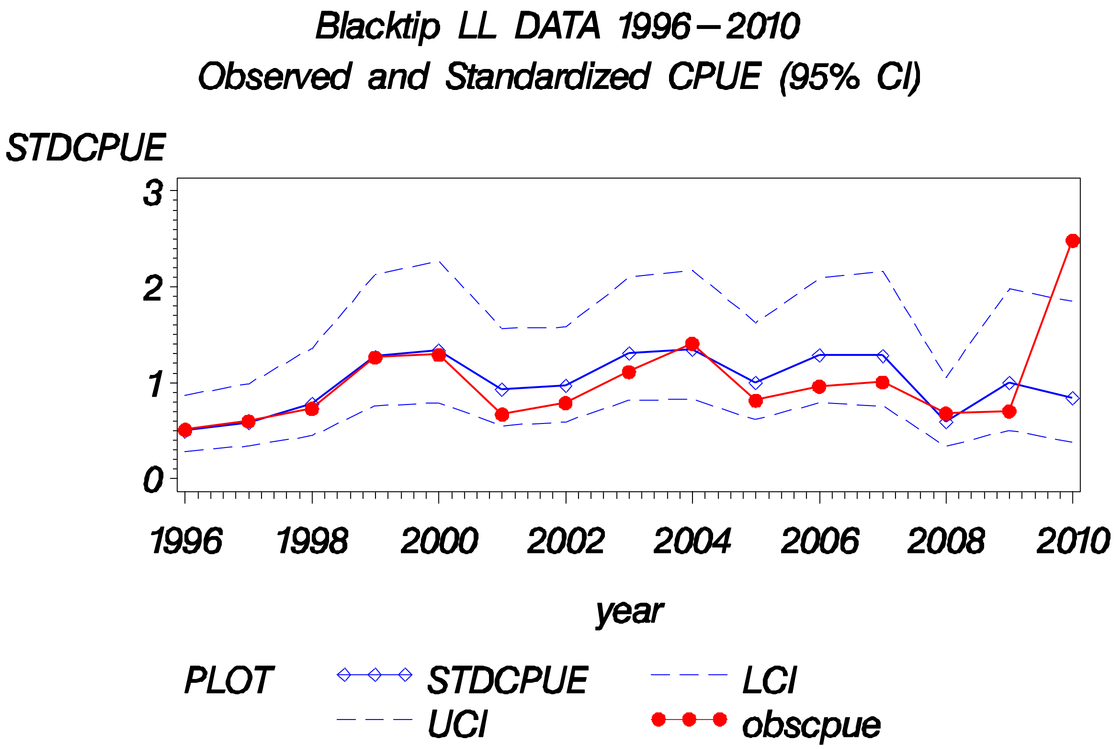


Figure 8. Comparison of the 2012 index (constructed using the Stephens and MacCall technique to subset the data) with the SEDAR 11 continuity index (data subset by including only those trips reported from vessels with catch rates above the 80th percentile of large coastal shark CPUE averaged across all years; see McCarthy and Abercrombie, 2005). Confidence intervals of the 2012 index (Stephens and MacCall data subsetting) are also provided.