Standardized catch rates for Gulf of Mexico Blacktip Sharks from the U.S. Pelagic longline logbook using generalized linear mixed models

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SEDAR29-WP-05

Date Submitted: 31 January 2012

Submitted January 31, 2012 SEDAR 29-WP-05

STANDARDIZED CATCH RATES FOR GULF OF MEXICO BLACKTIP SHARKS FROM THE US PELAGIC LONGLINE LOGBOOK USING GENERALIZED LINEAR MIXED MODELS

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ABSTRACT

An updated index of abundance was developed for blacktip shark (*Carcharhinus limbatus*) in the Gulf of Mexico from the US pelagic longline logbook program (1992-2010). Indices were calculated using a two-step delta-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately. Standardized indices with 95% confidence intervals are reported. The logbook time series showed an alternating trend, with an initial declining tendency to 1997, followed by an increase to a high peak in 2001, in turn followed by a marked decrease and a partial recovery to 2005, after which the series declined sharply. It is unclear whether the standardization procedure was successful at removing all extraneous effects unrelated to abundance.

KEYWORDS

Catch/effort, Commercial fishing, Long lining, Pelagic fisheries, Shark fisheries, By catch, Logbooks, Observer programs, Blacktip 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 blacktip sharks by Ortiz (2005) for SEDAR 11. Ortiz developed separate CPUE series for blacktip sharks in the Atlantic, Gulf of Mexico (GOM), and all areas combined from pelagic longline logbook data for the period 1992-2004. In this document, the GOM standardized CPUE series is updated with data up to 2010 for potential inclusion into SEDAR 29.

2. MATERIALS AND METHODS

2.1 Data

The pelagic longline fleet is required to report catch through logbooks. Each report includes the catch in numbers of all caught tuna and tuna-like species and general fishery operational variables on a set-by-set basis. The pelagic longline fleet also has an observer program in existence since 1992 that monitors the fishing activities of the fleet, recording detailed information on fishing operations, gear characteristics and deployment, and environmental and biological information from all longline catch, including sharks. However, blacktip sharks have seldom been observed in that program (n=169 in 1992-2010), with only 69 specimens reported from the GOM. Thus, a CPUE time series could not be developed from the pelagic longline observer program.

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).

Although data from US pelagic longline logbooks are available since 1986, no records for blacktip sharks appear until 1992, when logbooks became mandatory. The analysis of logbook data thus covers the period 1992-2010. Geographically, we restricted the analysis to area 2 (GOM), which accounts for ca. 57% of all observations for blacktip sharks (**Fig. 2**).

Based on methodology used in Brooks et al. (2005) and several other ICCAT (International Commission for the Conservation of Atlantic Tunas) publications (e.g., see Cortés [2009] for a recent publication), the following factors were considered in the analyses: year, quarter (January-March, April-June, July-September, October-December), gear (bottom longline or pelagic longline), and presence or absence of light sticks. Additionally, nominal catch rates (catch per 1000 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. Although swordfish has traditionally been the main target species of the US pelagic longline fleet, tunas are also targeted. We also considered the first-order interactions year*quarter and year*gear. Nominal catch rates were defined in all cases as catch (the sum of animals kept, released alive or discarded dead) per 1000 hooks.

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. 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 (GLMM) 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 positive observations data, and for the lognormal estimates, a back-transformed log bias correction was applied (Lo et al. 1992).

3. RESULTS

Factors retained for the proportion of positive sets were Tqr, year, gear, and year*gear; and for the positive catches, the factors Tqr, gear, year, Sqr, year*gear, and year*quarter were retained (**Table 1**). The explanatory variable "Tqr", a proxy for targeting tunas explained the majority of the deviance for both proportion positives and positive catches (**Appendix table 1**). The estimated annual mean CPUE and CV values are given in **Table 2**. The updated index does not track very well that developed by Ortiz (2005), probably because different factors were used for statistical standardization. Both indices, however, showed a generally declining trend during most of the 1990s. In the Ortiz (2005) index there was a recovery in 2000, followed by another decline in the early 2000s. In the present analysis, the index increased from 1997 to a high peak in 2001, after which it declined precipitously to 2004, climbed back in 2005, and declined thereafter till the most recent year of data, 2010 (**Fig. 3**). Both indices showed similar levels of decline with respect to the starting year of observations, 1992. The nominal series showed fluctuations of smaller magnitude. Diagnostic plots showed somewhat of a pattern towards negative residuals in the 1990s and positive residuals in the 2000s for the proportion positive but no very apparent trend in the residuals of the positive catches (**Fig. 4**).

4. DISCUSSION

The standardized CPUE time series showed an alternating trend, with an initial declining tendency to 1997, followed by an increase to a high peak in 2001, which in turn was followed by a marked decrease and a partial recovery to 2005, after which the series again declined sharply. The nominal series had fluctuations of smaller magnitude, with the largest peak in 2006 and a smaller peak in 2001. The updated index presented herein did not show the marked decline up to 2004 from the Ortiz (2005) index, but both indices had very wide confidence intervals. Differences in the two indices are likely due to the use of different explanatory variables and specification of the levels of those variables.

Sharp interannual changes in relative abundance, such as the peak in 2001 in the standardized index, are inconsistent with the biology of most sharks, whose stock abundance would be expected to fluctuate relatively little from year to year. It is unlikely that management measures, such as quota reductions, may have had any effect on the catch rates of blacktip sharks because pelagic longline fisheries do not target this species and catch rates used here are based on total catch (the sum of animals kept, discarded dead and released alive). One potential explanation for the 2001 peak could be increased local availability as a result of a larger portion of the stock moving through the area in that particular year. However, since blacktip sharks are mostly a coastal species, this index may not be particularly adequate to capture relative abundance of the Gulf of Mexico stock. Indeed, only 69 blacktip sharks were reported in the Gulf of Mexico from the pelagic longline observer program during 1992-2010, which casts doubt on the adequateness of the logbook database for estimating blacktip shark relative abundance.

Several issues that may affect the pelagic longline logbook dataset have been previously documented, notably species identification, misreporting, and changes in reporting practices (see Burgess et al. [2005], Cortés et al. [2007], SEDAR [2009], and references therein for a more extensive discussion). From an identification perspective, blacktip sharks are easily confused with their congeners, spinner sharks (*C. brevipinna*), but can also be confused with other species, such as the silky shark (*C. falciformis*). Misidentification of blacktip sharks and resulting misreporting, changes in reporting practices as a result of the implementation of several logbook programs, and perhaps a tendency to under-report bycatch over time as fishers develop a growing perception that those reports result in increasingly restrictive management measures may all have affected the index, especially in more recent years where the most substantial declines were found. Other factors, such as hook size and type, were not included in the analysis because they have not been reported consistently in the logbooks, but may have affected catch rates of blacktip sharks. Fishing depth was indirectly taken into account in our analysis by using proxies for fishers targeting swordfish or tunas, but we did not differentiate between different species of tunas being targeted.

Nominal effort, catches, and CPUE of blacktip sharks declined from beginning to end of the time series (**Fig. 2 bottom panel; Fig. 3, top panel**). Disaggregation in time and space reveals that effort intensified in 1996-2000 with respect to 1992-1995, and the range of operation of the fleet contracted in 2001-2005, and especially in 2006-2010, with respect to previous periods (**Fig. 5**). Catches progressively declined throughout these periods, but especially the range where catches took place (**Fig. 6**). Average catch in 1992-1995 was 4-fold that in 1996-2000 and 2001-2005 and an order of magnitude higher than in 2006-2010. Nominal CPUE also declined, with the range of positive catches declining more drastically throughout these periods (**Fig. 7**). Thus, it appears that catches declined more rapidly than effort, resulting in a decreasing catch rate throughout the time period considered.

Although the GLMM fit to the data attempted to remove the impact of multiple factors and interactions predicting whether blacktip sharks are caught at all (proportion positives) or the degree to which they are caught (CPUEs of positive catches), the index obtained may still not account for all factors affecting relative abundance and thus may not necessarily reflect the true relative abundance of this species in the Gulf of Mexico.

Acknowledgments

We thank John Walter for extracting the data used in these analyses.

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Table 1. Factors retained in the model of proportion of positive sets and positive catch of GOM blacktip shark for U.S. pelagic longline logbook data.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	83370	31168	-15584
Final model TQR YEAR GEAR YEAR*GEAR	83331	25523	-12761

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	3844	5668	-6203
Final model TQR GEAR YEAR SQR YEAR*GEAR YEAR*QUARTER	3748	4548	-5778

Table 2. Estimates of mean annual CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for GOM blacktip shark from the U.S. pelagic longline logbook data.

Year	Standardized CPUE	CV	Nominal CPUE
1992	0.501	0.729	1.790
1993	0.962	0.720	1.894
1994	0.526	0.727	1.728
1995	0.628	0.724	1.825
1996	0.389	0.768	1.718
1997	0.330	0.770	1.423
1998	0.370	0.821	1.297
1999	0.590	0.796	1.531
2000	0.594	0.805	1.451
2001	1.868	0.742	2.175
2002	0.903	0.831	1.465
2003	0.716	0.809	1.248
2004	0.276	1.205	1.048
2005	0.755	0.852	1.832
2006	0.667	0.818	2.713
2007	0.408	0.935	1.219
2008	0.172	0.988	0.635
2009	0.188	0.996	0.390
2010	0.030	1.839	0.421

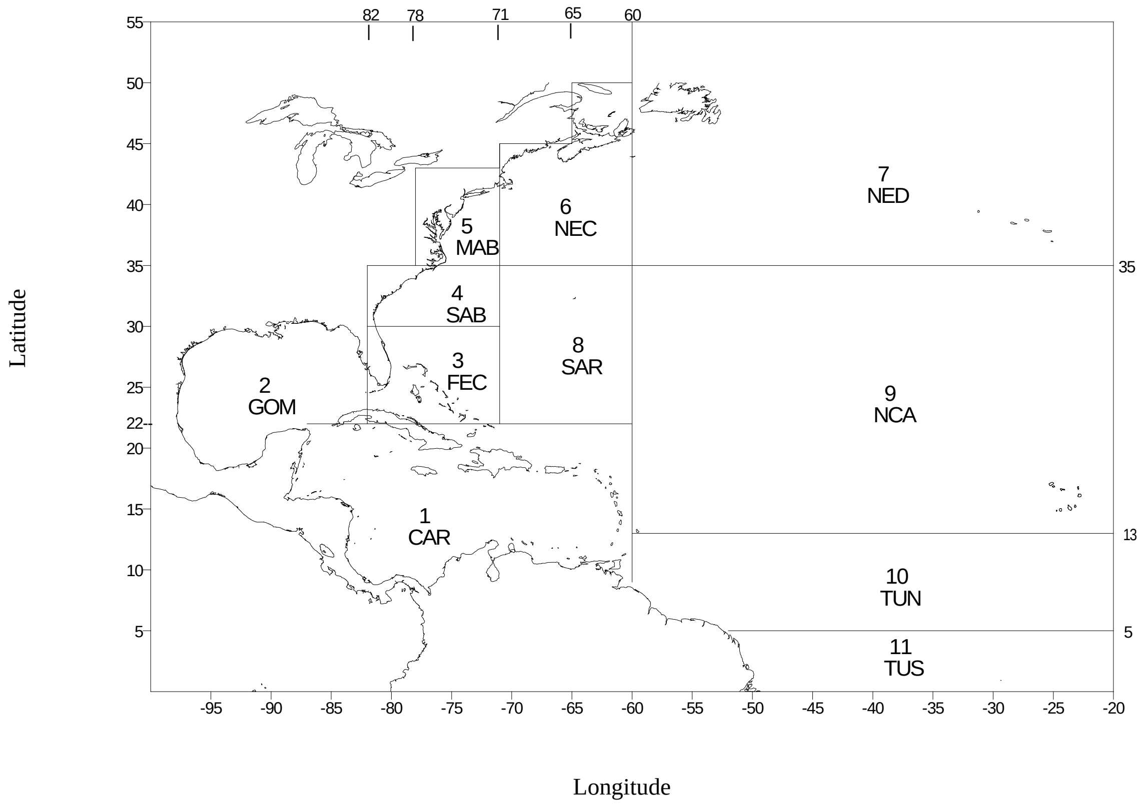
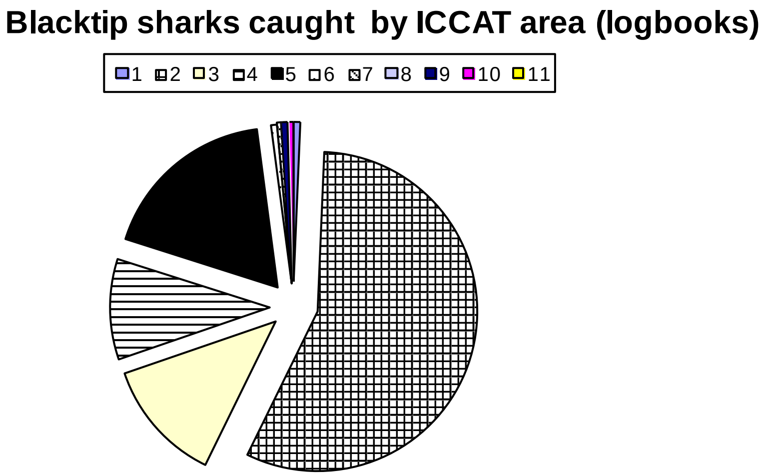


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean; 2) Gulf of Mexico; 3) Florida East Coast; 4) South Atlantic Bight; 5) Mid Atlantic Bight; 6) Northeast Coastal; 7) Northeast Distant; 8) Sargasso; 9) North Central Atlantic; 10) Tuna North; 11) Tuna South.



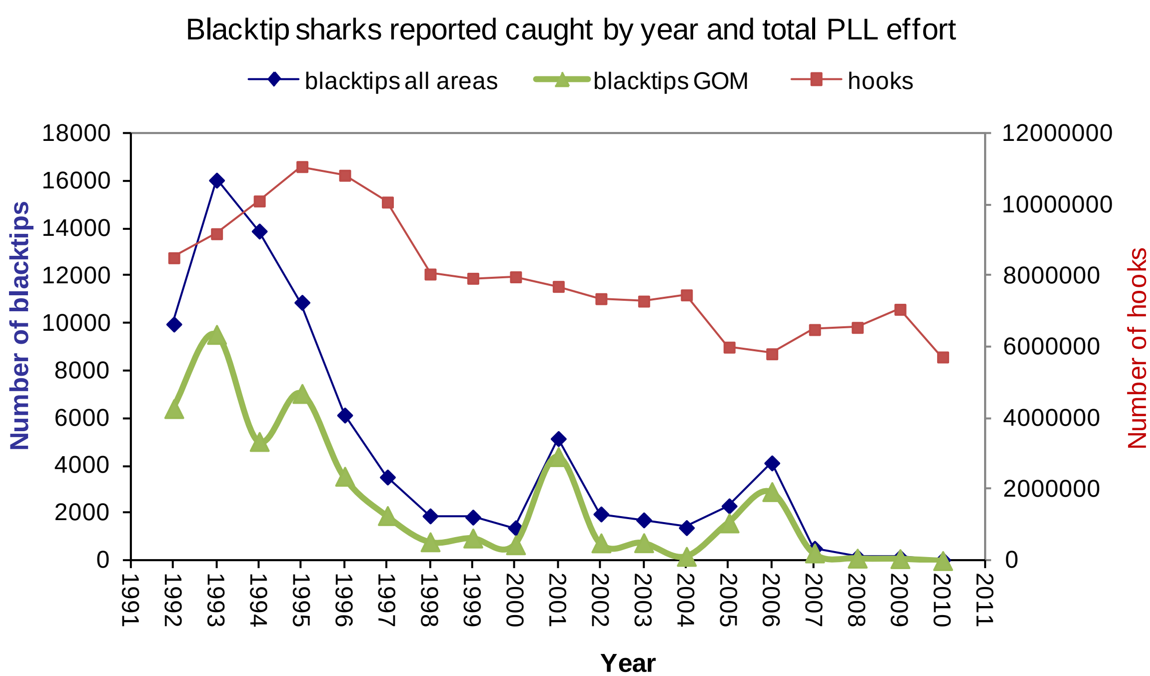
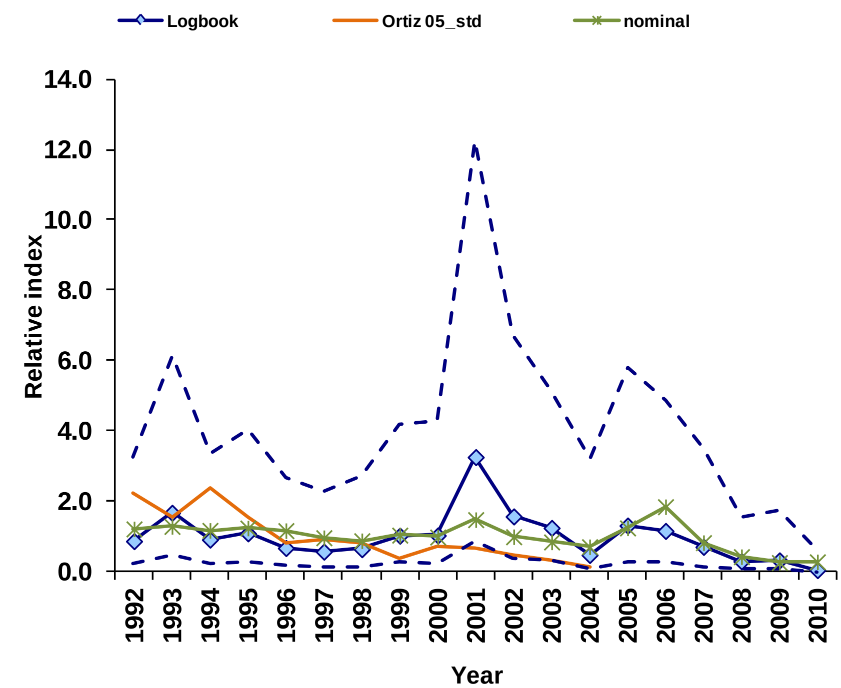


Figure 2. Blacktip sharks caught by ICCAT area as reported in the pelagic longline logbook (top panel). Blacktip sharks caught by year in all areas and in the Gulf of Mexico relative to total effort.



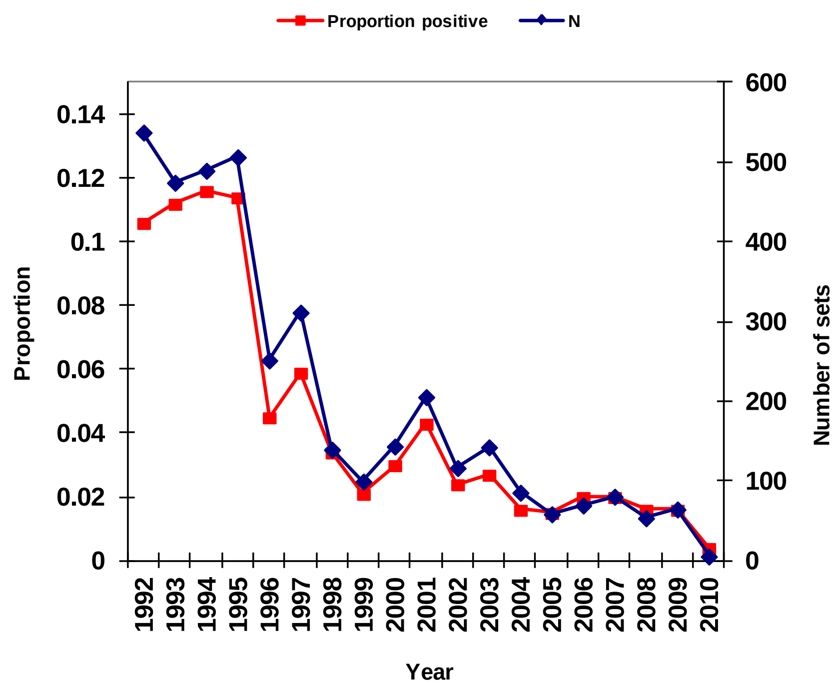


Figure 3. Standardized CPUE (in number) and 95% confidence intervals for blacktip shark from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

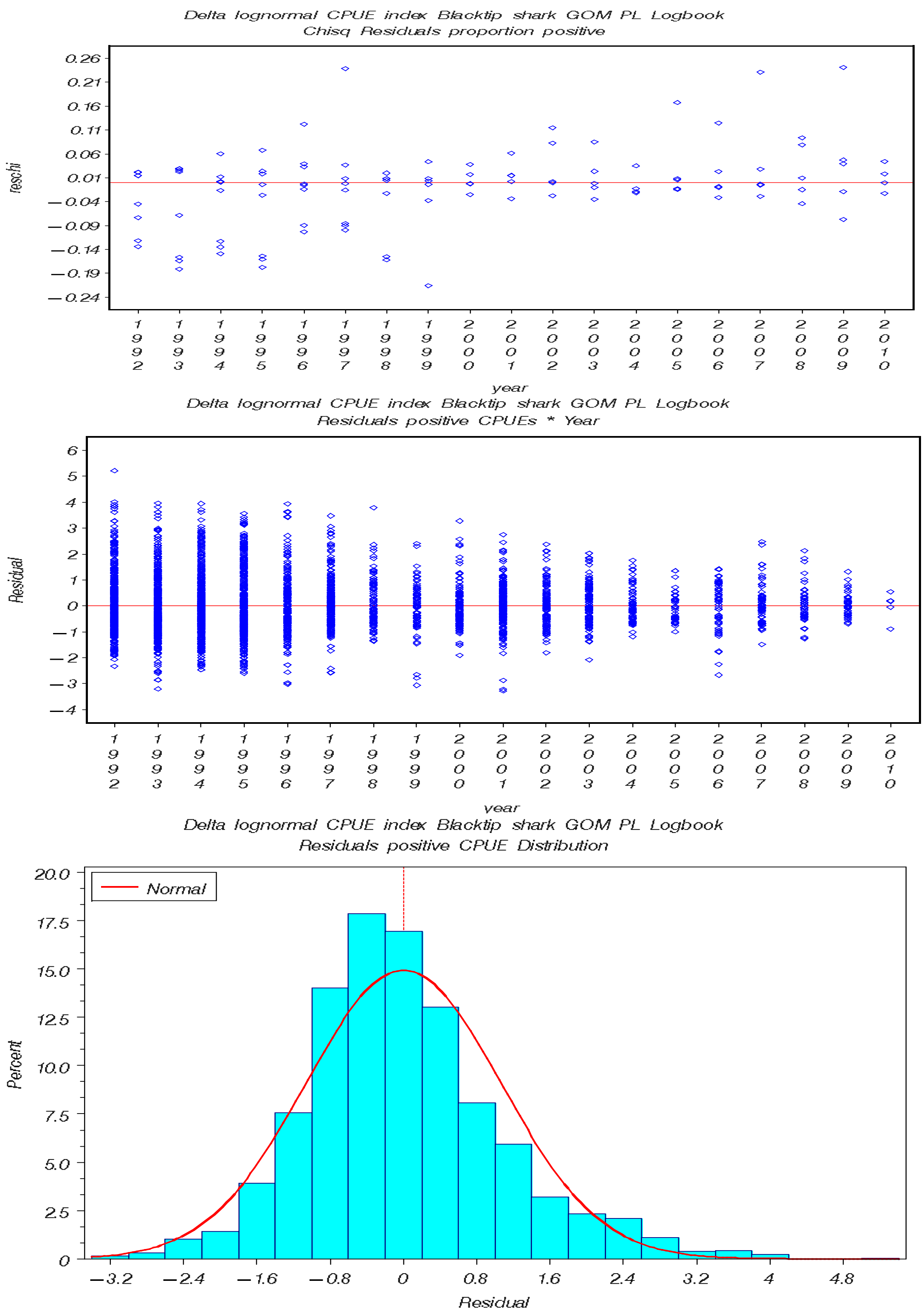


Figure 4. Diagnostic plots of CPUE model from US logbook data for GOM blacktip sharks. Top: residuals of proportion positive sets; middle: residuals of positive catches; bottom: residual positive catch frequency distribution.

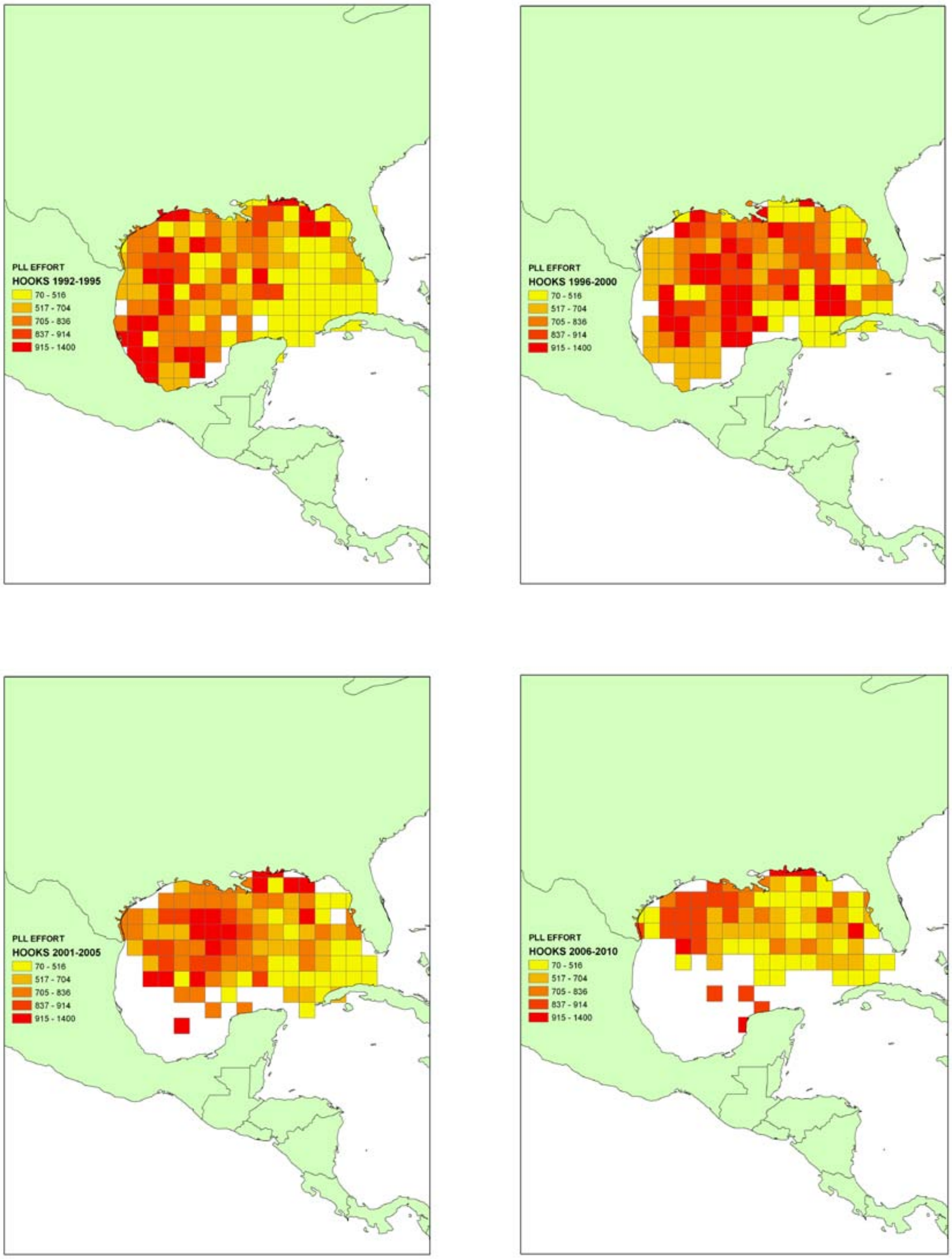


Figure 5. Cumulative effort (hooks deployed) of blacktip sharks in the Gulf of Mexico by 1 degree lat-long reported in the pelagic longline logbook database for 1992-2010.

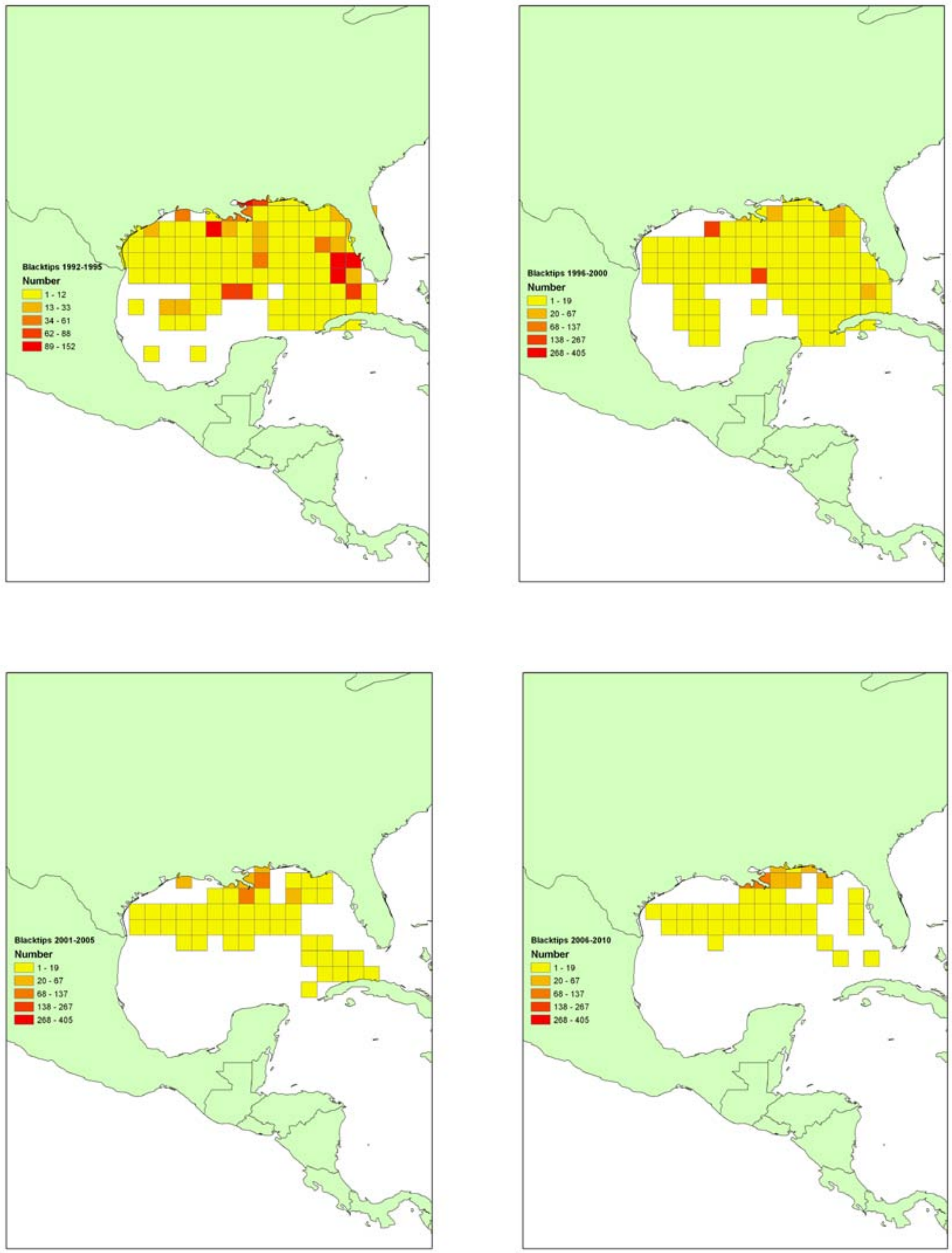


Figure 6. Cumulative catch (numbers) of blacktip sharks in the Gulf of Mexico by 1 degree lat-long reported in the pelagic longline logbook database for 1992-2010.

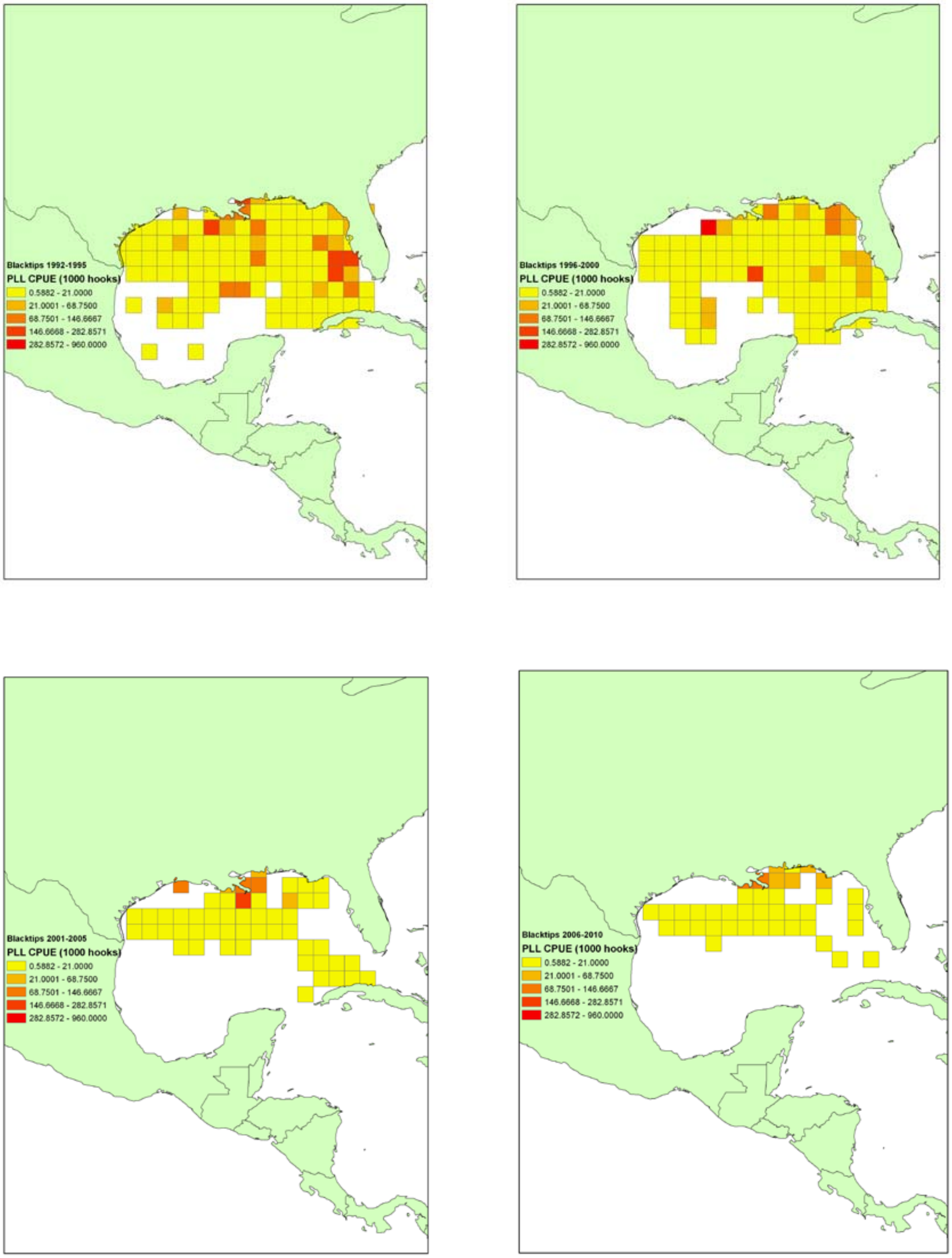


Figure 7. Average nominal catch rates of blacktip sharks in the Gulf of Mexico by 1 degree lat-long reported in the pelagic longline logbook database for 1992-2010.

Appendix table 1. Deviance analysis table of explanatory variables in the delta lognormal model for GOM blacktip shark catch rates (number of fish per 1000 hooks) from the US pelagic longline fishery logbook. Percent of total deviance refers to the deviance explained by the model; p value is the Chi-square probability between consecutive models.

Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
Null		31168			
Tqr	3	28199	2969	52.6%	< 0.001
Tqr Year	18	26613	1586	28.1%	< 0.001
Tqr Year Gear	1	26110	503	8.9%	< 0.001
Tqr Year Gear Year*Gear	1	25523	587	10.4%	< 0.001

Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
Null		7716			
Tqr	3	5668	2048	64.6%	< 0.001
Tqr Gear	1	5390	278	8.8%	< 0.001
Tqr Gear Year	18	5230	160	5.1%	< 0.001
Tqr Gear Year Sqr	3	5145	85	2.7%	< 0.001
Tqr Gear Year Sqr Year*Gear	1	4733	412	13.0%	< 0.001
Tqr Gear Year Sqr Year*Gear Year*Quarter	3	4548	185	5.8%	< 0.001