STANDARDIZED CATCH RATES FOR DUSKY AND SANDBAR SHARKS FROM THE US PELAGIC LONGLINE LOGBOOK AND OBSERVER PROGRAMS USING GENERALIZED LINEAR MIXED MODELS

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ABSTRACT

Updated indices of abundance were developed for dusky shark (*Carcharhinus obscurus*) and sandbar sharks (*Carcharhinus plumbeus*) from two commercial sources, the US pelagic longline logbook program (1992-2009) and the US pelagic longline observer program (1992-2009). 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. For dusky sharks, the logbook and observer time series showed a similar trend, marked by an initial decrease in the 1990s followed by a more stable trend in the 2000s. The trends form the two sources differed for sandbar sharks, with the logbook index showing a very sharp initial increase from 1994 to 1995 and a decreasing trend thereafter, whereas the observer index decreased from 1992 to 2003, after which it showed an upward trend.

KEYWORDS

Catch/effort, Commercial fishing, Long lining, Pelagic fisheries, Shark fisheries, By catch, Logbooks, Observer programs, Sandbar shark, Dusky shark

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1. INTRODUCTION

Relative abundance indices from the U.S. pelagic longline fishery targeting tuna and tuna-like species have been previously generated for dusky and sandbar sharks. Cortés et al. (2006) and Ortiz (2005) developed CPUE time series for dusky and sandbar sharks, respectively, from the pelagic longline logbook program covering the periods 1992-2003 and 1994-2004, respectively. In this document, those two series are updated with data up to 2009 and two new series of relative abundance are developed based on data from the pelagic longline observer program, which monitors the same fishery covered by the pelagic longline logbook program.

2. MATERIALS AND METHODS

2.1 Data

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 dusky sharks appear until 1992, whereas consistent records for sandbar sharks start in 1994. Thus, the analysis of logbook data covers the period 1992-2009 for dusky sharks and 1994-2009 for sandbar sharks. Geographically, areas 2 to 6 (2-6) account for 98% of the observations for dusky shark, thus the analysis was restricted to those areas for dusky shark to avoid an unbalanced design (Fig. 2). For sandbar shark, areas 2-6 account for 99.8% of the observations, but since the sample size for area 6 was considerably smaller than that of areas 2, 3, 4, and 5, the analysis was restricted to areas 2-5 and a sensitivity run was conducted with areas 2-6 (Fig. 3).

Data from the US pelagic longline observer program are available since 1992 and the analyses covered the period 1992-2009 for both species. The datasets for analysis were restricted to the same areas as used for logbooks, i.e., areas 2-6 for dusky shark (Fig. 2) and areas 2-5 for sandbar shark (Fig. 3) owing to the same sample size considerations mentioned above.

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 for both dusky and sandbar sharks: year, area, quarter (January-March, April-June, July-September, October-December), gear (bottom longline or pelagic longline; for the logbook analysis only), presence or absence of light sticks, and whether or not the data were part of experimental fishing (conducted in years 2000-2003 in the Northeast Distant area only). Additionally, nominal catch rates (catch per thousand 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. I also considered the following interactions: year*area, year*quarter, year*gear, gear*area, as well as the interactions between area and the nominal catch rate quartiles for tuna and swordfish (area*Tqr and area*Sqr). Nominal catch rates were defined in all cases as catch (the sum of animals kept, released alive or discarded dead) per 1000 hooks.

Trends in length of animals caught were also examined by using records of animals that were brought onboard and measured (fork length, measured in a straight line) by scientific observers form the pelagic longline observer program. No estimated lengths, sometimes recorded by observers, were used.

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. The year factor was always included because it is required for developing a time series. 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 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 input data, and for the lognormal estimates, a back-transformed log bias correction was applied (Lo et al. 1992).

3. RESULTS

Dusky sharks—In the analysis of the logbook data, factors retained for the dusky shark proportion of positive sets were area, year, gear, Tqr*area, and year*quarter; and for the positive catches, the factors Tqr, year, area, Sqr*area, year*area, year*quarter, year*gear, and Tqr*area were retained (Table 1). The estimated annual mean CPUE and CV values are given in Table 2. The updated index follows the same trend as that developed by Cortés et al. (2006), although the values for the two initial years of the series, 1992 and 1993, are offset. Since 2003, the series shows a somewhat decreasing trend, but the most substantial decrease in the time series occurred from 1992 to 1997 (Fig. 4). In all, the entire time series showed an 86% decline since 1992, corresponding to a mean instantaneous rate of change in abundance per year (r) of –0.114 (95% confidence interval [CI]:-0.295 to +0.066). This decline was largely driven by the fall from 1992 to 2001, after which the trend oscillated but remained fairly stable. In contrast, the nominal series showed a flatter trend, with a relative decline of 47% from beginning to end. Diagnostic plots showed somewhat of a pattern towards positive residuals in the proportion positive and some trend in the residuals of the positive catches, whose distribution was slightly skewed to the right of the normal distribution assumed by the model (Fig. 5).

In the analysis of the observer data, factors retained for the dusky shark proportion of positive sets were are, year, and Tqr*area; and for the positive catches, the factors year, area, Sqr, Tqr, year*area, year*quarter, and Sqr*area were retained (Table 3). The estimated annual mean CPUE and CV values are given in Table 4. The observer index followed a similar trend to the logbook index, but a more pronounced decline (95% decline since 1992, r=-0.176; 95% CI:-0.541 to +0.189) and larger interannual variation than the logbook index (Fig. 6). The nominal observer series showed a more moderate decline. The sharper interannual fluctuations in the observer index may be due to the smaller sample size (observer coverage on pelagic longline vessels averages ca. 4%). Note also that some of the lowest index values (2002-2003), when the proportion of positive sets was very low, correspond to some of the years of experimental fishing (2000-2003; Fig. 6). Diagnostic plots showed better agreement with model assumptions and less pattern in the residuals than in the logbook analysis (Fig. 7).

Sandbar sharks— In the analysis of the logbook data, factors retained for the sandbar shark proportion of positive sets were Tqr, gear, year, light, quarter, and year*quarter; and for the positive catches, the factors Sqr, Tqr, area, year, quarter, light, Sqr*area, year*quarter, year*area, Tqr*area, year*gear, and gear*area were retained (Table 5). The estimated annual mean CPUE and CV values are given in Table 6. The updated index followed the same general trend as that developed by Ortiz (2005), with the lowest value corresponding to the first year of data, 1994, which had the lowest number of positive observations of any year (n=100 or <1%). The index decreased from 2004 to 2008 and rebounded in 2009 (Fig. 8). In all, the entire time series showed a 10% increase since 1994 (r=+0.157, 95% CI:-0.287 to +0.602) driven by the abrupt increase from 1994 to 1995. Omitting 1994, or considering the period 1995-2009, the time series showed a declining trend (62% decrease) with less interannual variation. This decline matched that observed for the nominal series in 1994-2009, which showed a smoother trend than the standardized series (Fig. 8). The sensitivity run incorporating areas 2-6 (adding area 6 to the analysis) did not yield substantially different results (7% overall increase; r=+0.136, 95% CI:-0.259 to +0.531). Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 9).

In the analysis of the observer data, factors retained for the sandbar shark proportion of positive sets were year, area, quarter, Sqr*area, and Tqr*area; and for the positive catches, the factors Tqr, year, Sqr, area, Sqr*area, and year*quarter were retained (Table 7). The estimated annual mean CPUE and CV values are given in Table 8. The observer index showed a declining trend (83%) since 1992 (r=-0.106, 95% CI: -0.618 to 0.407), which can be decomposed into a decline from 1992 to 2003, followed by an increasing trend from 2003 to 2009 (Fig. 10). This latter trend opposes that estimated from the logbook data. With the exception of the jump from 1994 to 1995 in the logbook index, the observer index showed larger interannual variation compared with the logbook index in 1995-2009 (Fig. 10). As for dusky shark, the sharper interannual fluctuations in the observer index may be due to the smaller sample size. Also, some of the lowest index values (2002-2003), when the proportion of positive sets was very low (only 1 shark observed in each of those two years), correspond to some of the years of experimental fishing (2000-2003). Diagnostic plots showed some pattern towards positive residuals in the proportion positive and the distribution of positive CPUEs was slightly skewed to the right of the normal distribution assumed by the model (Fig. 11).

Trends in size

There was no trend in fork length over time for any of the two species. Sample sizes of measured animals were low in several years, particularly for sandbar sharks (Fig. 12).

4. DISCUSSION

Declines in relative abundance of dusky sharks estimated from the logbook and observer datasets were of similar magnitude and both indices followed similar trends. For sandbar sharks, the observer series showed a sharper decline than the logbook series, which initially increased from an unusually low value in the first year of data (1994) to 1995, after which it progressively decreased. The two series for sandbar shark showed opposing trends for more recent years, with the logbook index decreasing since 2004 and the observer index increasing since 2003.

The observer dataset has smaller sample sizes, leading to more uncertain trends and larger interannual variation than the logbook dataset. In contrast, the logbook dataset has much larger sample sizes, but several problems with species identification, misreporting, and changes in reporting practices have been previously identified (see Burgess et al. [2005], Cortés et al. [2007], SEDAR [2009], and references therein for a more extensive discussion). Sharp interannual changes in relative abundance are inconsistent with the biology of sandbar and dusky sharks as well as other large species of sharks, whose stock abundance would be expected to fluctuate little from year to year. It is unlikely that management measures, such as the dusky shark being placed on the prohibited species list in 2000 or quota reductions imposed on large coastal sharks, including the sandbar shark, may have had any effect on the catch rates of these species because pelagic longline fisheries do not target sandbar or dusky sharks and catch rates used here are based on total catch (the sum of animals kept, discarded dead and released alive).

Despite efforts to produce a balanced design for these analyses, for both logbook and observer datasets, the correlation between the proportion of positive sets and the magnitude of the index suggests that low proportions of positive sets tended to produce low index values and vice versa. Although the GLMMs fit to the models attempted to remove the impact of a large number of factors and interactions predicting whether dusky and sandbar sharks are caught at all (proportion positives) or the degree to which they are caught (CPUEs of positive catches), the indices obtained may still not account for all factors affecting relative abundance and thus may not necessarily reflect the true relative abundance of these two species.

Acknowledgments

I 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 **dusky shark** for U.S. pelagic longline logbook data.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	186484	83370	-41685
Final model AREA YEAR GEAR TQR*AREA YEAR*QUARTER	186392	70969	-35485

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	10956	12733	-16370
Final model TQR YEAR AREA SQR*AREA YEAR*AREA YEAR*QUARTER YEAR*GEAR TQR*AREA	10768	9770	-14919

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

Year	Standardized CPUE	CV	Nominal CPUE
1992	1.239	0.274	1.854
1993	1.209	0.273	1.841
1994	0.653	0.273	1.366
1995	0.573	0.275	1.417
1996	0.49	0.278	1.391
1997	0.423	0.282	1.471
1998	0.448	0.288	1.404
1999	0.385	0.285	1.329
2000	0.372	0.289	1.198
2001	0.212	0.307	0.907
2002	0.224	0.323	0.847
2003	0.419	0.295	1.263
2004	0.417	0.299	1.324
2005	0.183	0.305	1.128
2006	0.359	0.311	1.063
2007	0.258	0.344	0.997
2008	0.144	0.352	0.834
2009	0.177	0.353	0.974

Table 3. Factors retained in the model of proportion of positive sets and positive catch of **dusky shark** for U.S. pelagic longline observer program data.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	9994	5297	-2648
Final model AREA YEAR TQR*AREA	9958	4261	-2131

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	743	740	-1054
Final model YEAR AREA SQR TQR YEAR*AREA YEAR*QUARTER SQR*AREA	602	357	-787

Table 4. Estimates of mean annual CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for dusky shark from the U.S. pelagic longline observer program data.

Year	Standardized CPUE	CV	Nominal CPUE
1992	2.279	0.274	2.167
1993	1.06	0.218	1.296
1994	1.724	0.217	1.491
1995	0.689	0.258	1.168
1996	0.676	0.29	1.426
1997	0.309	0.353	0.891
1998	0.805	0.296	1.868
1999	0.217	0.392	0.850
2000	0.454	0.307	1.220
2001	0.196	0.373	0.924
2002	0.096	0.889	0.401
2003	0.058	0.632	0.500
2004	0.314	0.311	1.120
2005	0.254	0.297	0.910
2006	0.454	0.284	0.919
2007	0.182	0.32	0.801
2008	0.126	0.425	0.576
2009	0.114	0.294	0.522

Table 5. Factors retained in the model of proportion of positive sets and positive catch of **sandbar shark** for U.S. pelagic longline logbook data.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	160763	65872	-32936
Final model TQR GEAR YEAR LIGHT QUARTER YEAR*QUARTER	160694	47161	-23580

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	8387	18055	-15117
Final model SQR TQR AREA YEAR QUARTER LIGHT SQR*AREA YEAR*QUARTER YEAR*AREA TQR*AREA YEAR*GEAR GEAR*AREA	8213	9488	-12419

Table 6. Estimates of mean annual CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for **sandbar shark** from the U.S. pelagic longline logbook data.

Year	Standardized CPUE	CV	Nominal CPUE
1994	0.106	0.379	3.308
1995	2.276	0.294	2.705
1996	2.23	0.293	2.427
1997	1.467	0.302	2.541
1998	1.58	0.307	2.267
1999	1.884	0.306	2.395
2000	1.931	0.305	2.440
2001	1.694	0.312	2.405
2002	1.714	0.316	2.718
2003	1.5	0.315	2.679
2004	1.731	0.306	1.979
2005	1.338	0.318	2.082
2006	1.231	0.323	2.332
2007	0.747	0.334	1.667
2008	0.675	0.368	1.116
2009	0.817	0.361	1.267

Table 7. Factors retained in the model of proportion of positive sets and positive catch of **sandbar shark** for U.S. pelagic longline observer program data.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	9994	5297	-2648
Final model YEAR AREA QUARTER SQR*AREA TQR*AREA	9958	4261	-2131

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	743	740	-1054
Final model TQR YEAR SQR AREA SQR*AREA YEAR*QUARTER	602	357	-787

Table 8. Estimates of mean annual CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for **sandbar shark** from the U.S. pelagic longline observer program data.

Year	Standardized CPUE	CV	Nominal CPUE
1992	0.816	0.318	1.885
1993	0.646	0.209	1.395
1994	0.457	0.231	1.345
1995	0.368	0.289	1.480
1996	0.300	0.382	1.364
1997	0.304	0.336	0.998
1998	0.215	0.516	1.246
1999	0.274	0.407	0.934
2000	0.100	0.455	0.765
2001	0.118	0.482	0.906
2002	0.008	1.969	0.206
2003	0.007	1.97	0.322
2004	0.136	0.355	1.071
2005	0.048	0.477	0.679
2006	0.216	0.43	1.452
2007	0.136	0.368	1.324
2008	0.132	0.281	0.874
2009	0.135	0.279	0.882

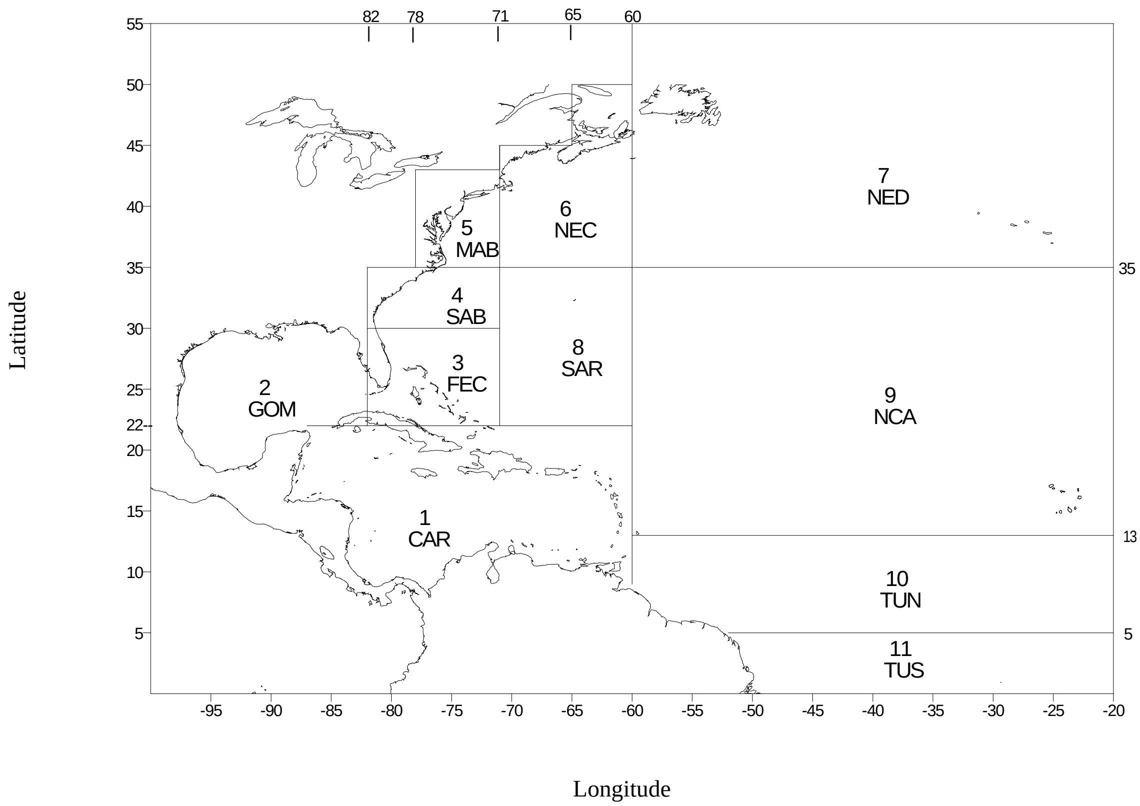
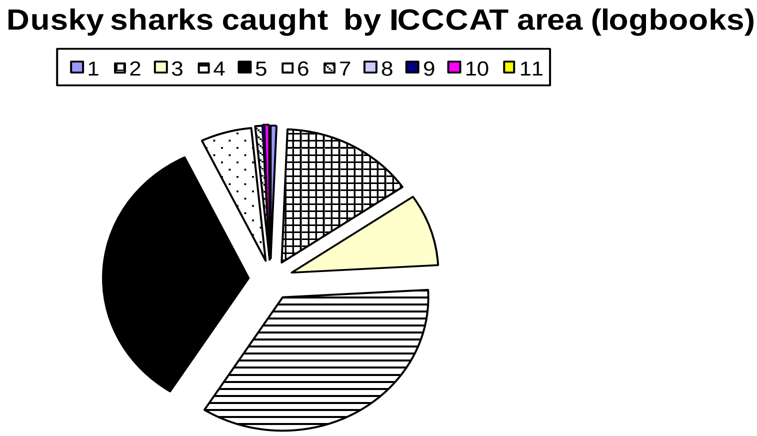
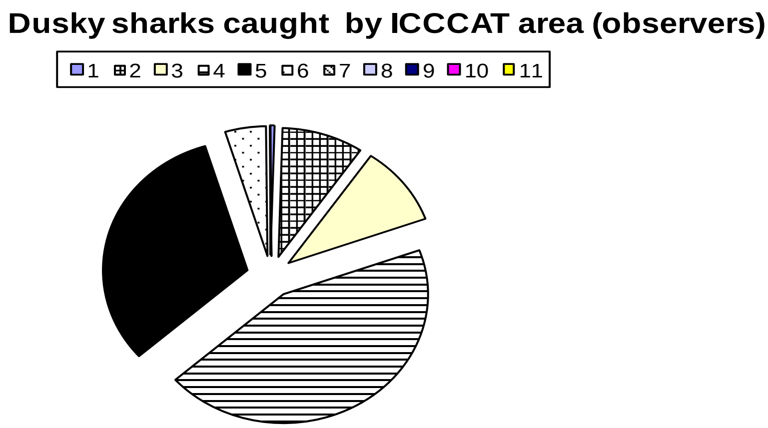


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean; 2) Gulf of Mexico; 3) Florida East Coast; 4) South Atlantic Bight; 5) Mid Atlantic Bight; 6) Northeast Coastal; 7) Northeast Distant; 8) Sargasso; 9) North Central Atlantic; 10) Tuna North; 11) Tuna South.





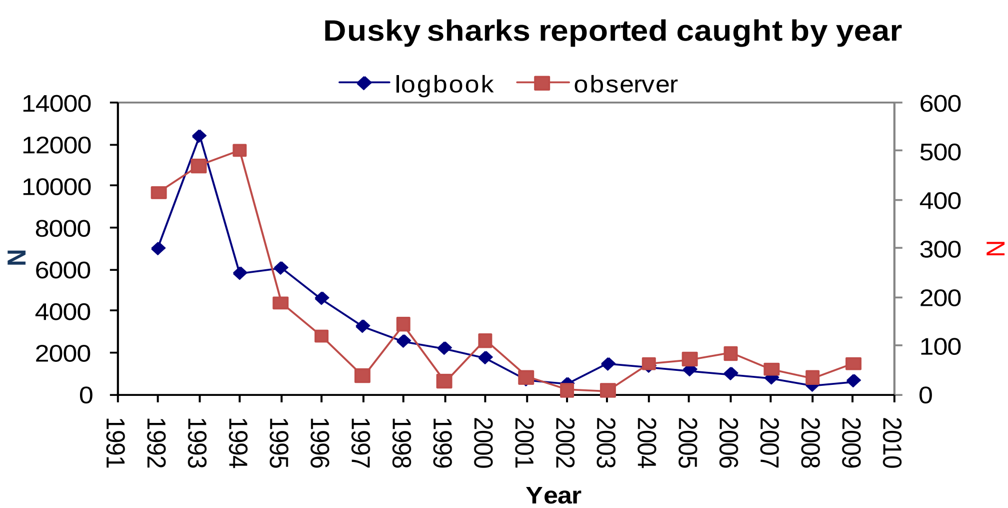
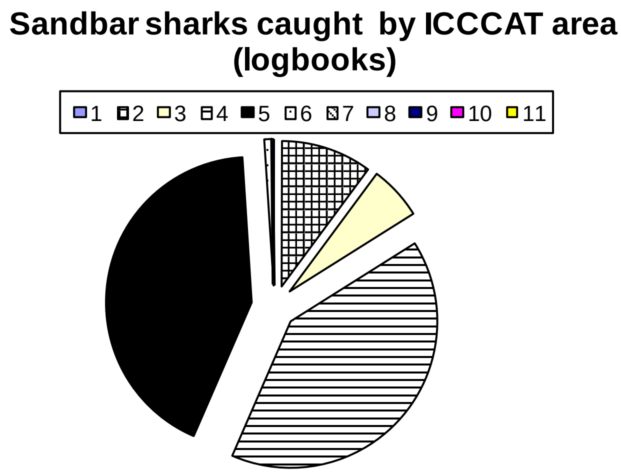
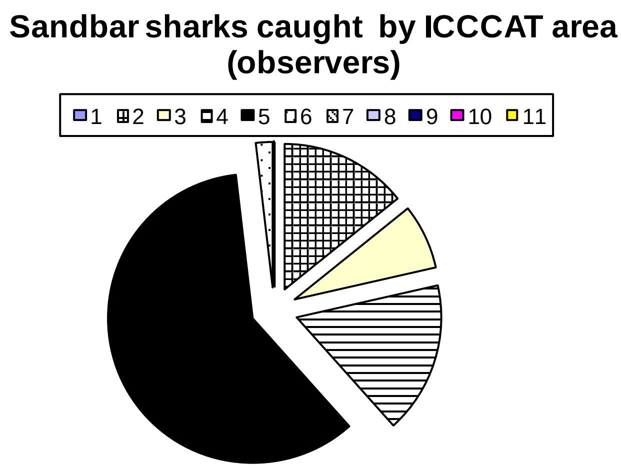


Figure 2. Dusky sharks caught by area as reported in the pelagic longline logbook and observer programs.





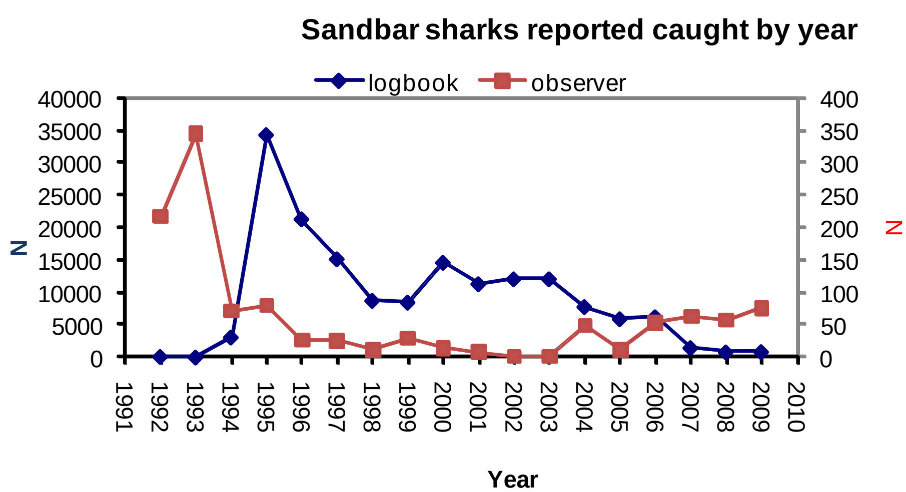
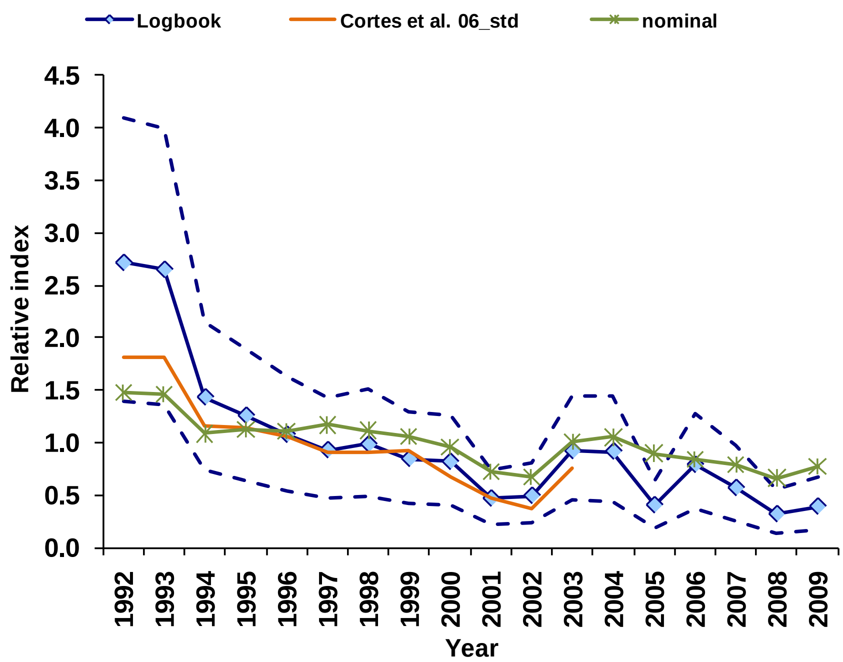


Figure 3. Sandbar sharks caught by area as reported in the pelagic longline logbook and observer programs.



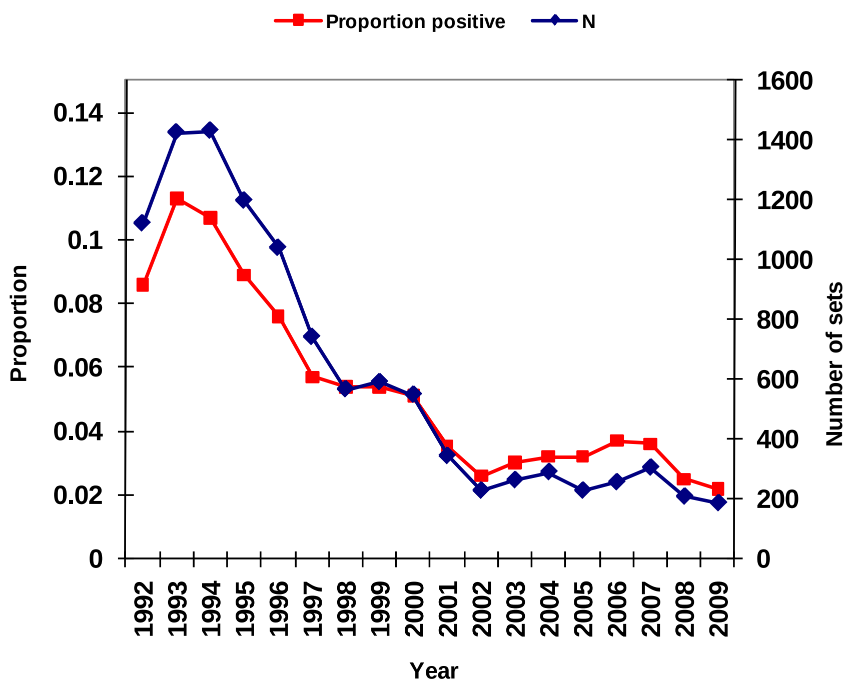


Figure 4. Standardized CPUE (in number) and 95% confidence intervals for dusky shark from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

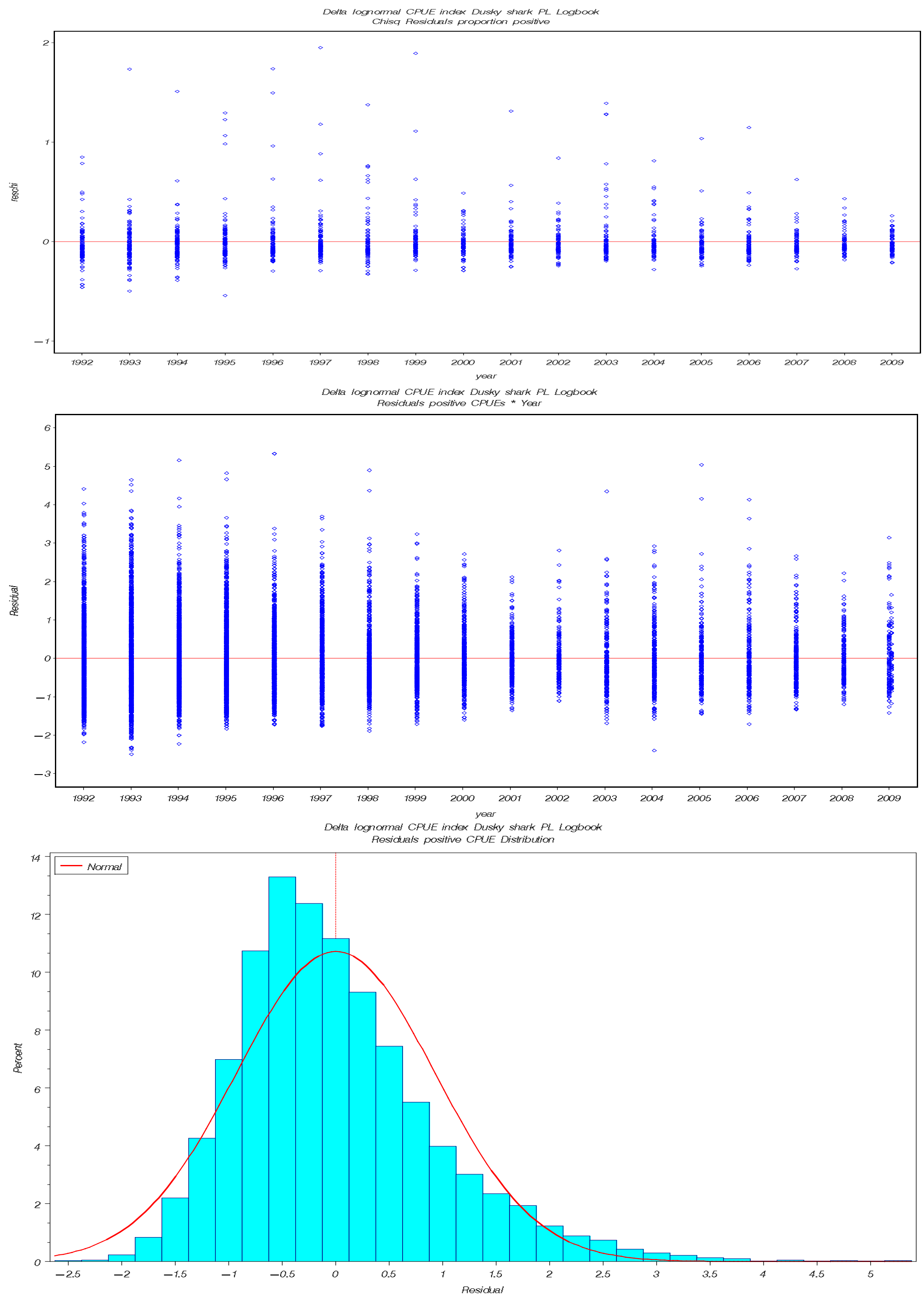
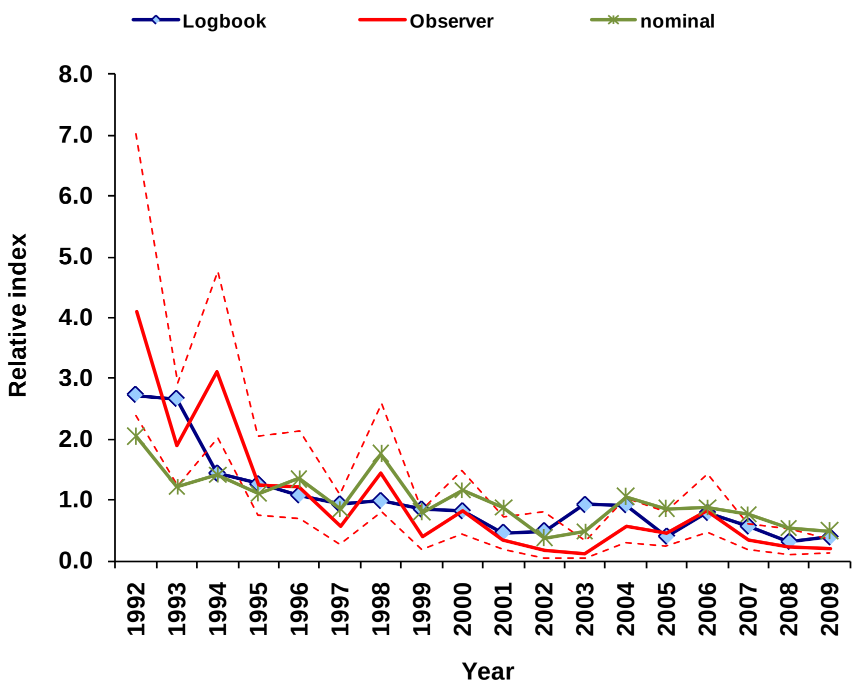


Figure 5. Diagnostic plots of CPUE model from pelagic longline logbook data for dusky shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch frequency distribution.



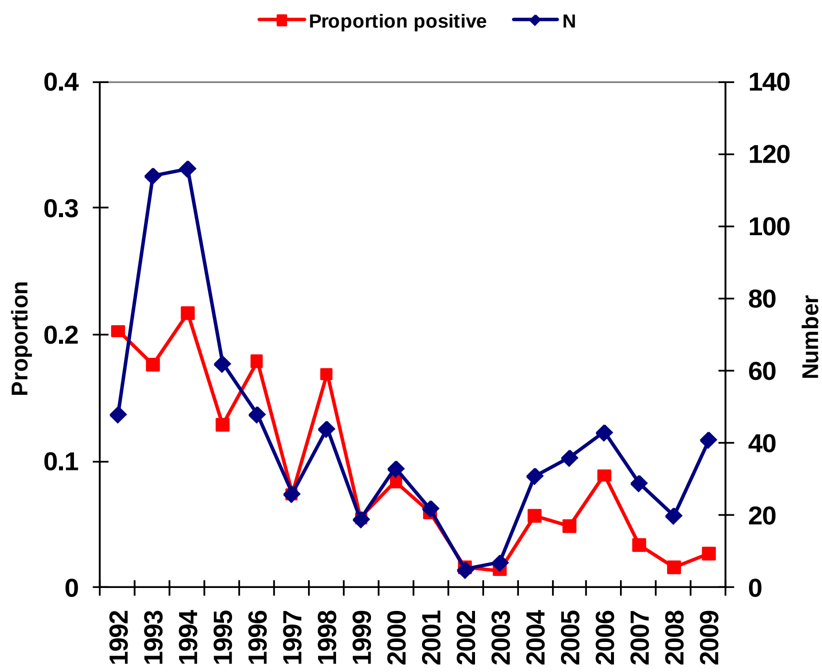


Figure 6. Standardized CPUE (in number) and 95% confidence intervals for dusky shark from the pelagic longline observer program compared to the pelagic longline logbook. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

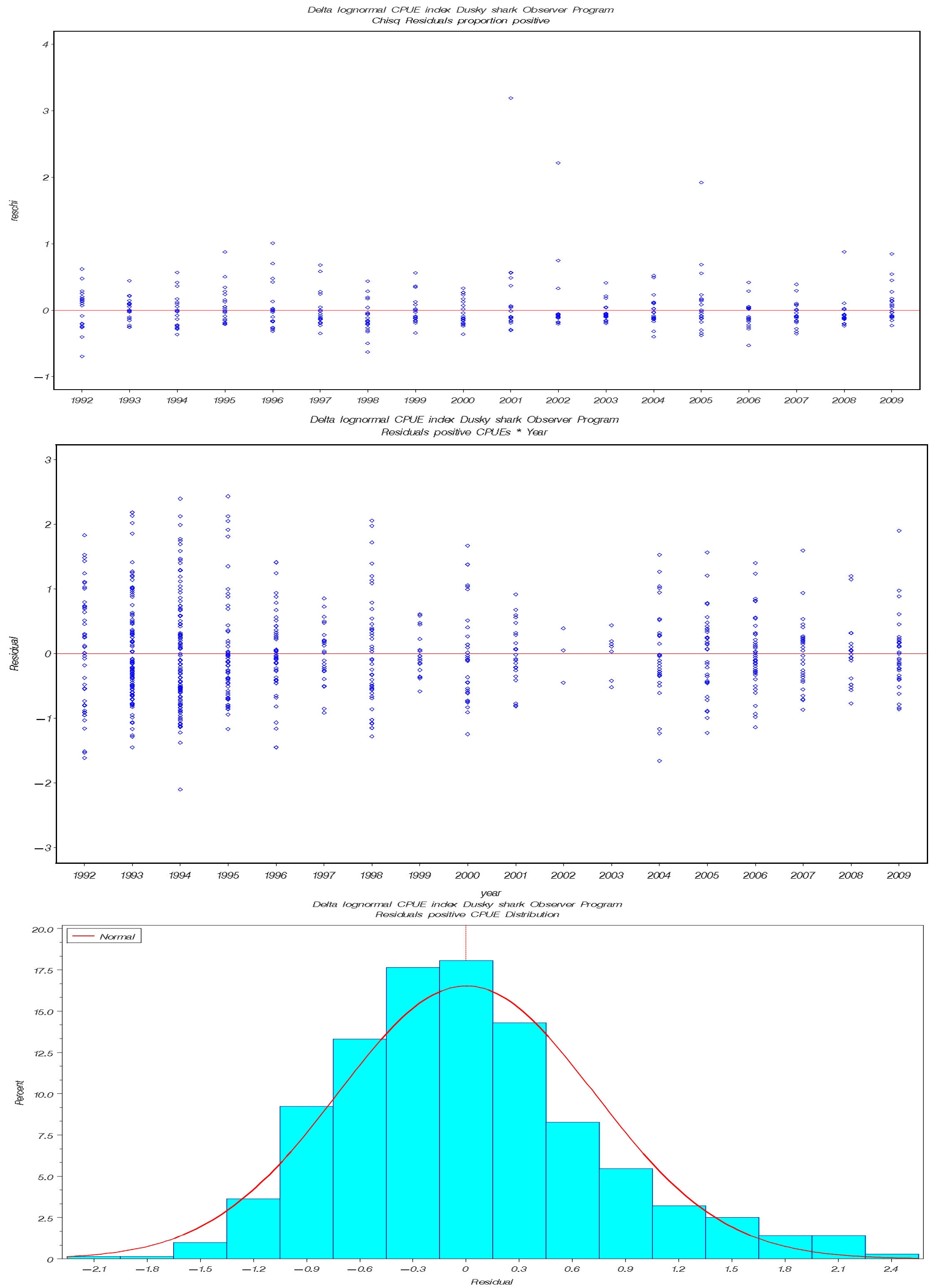
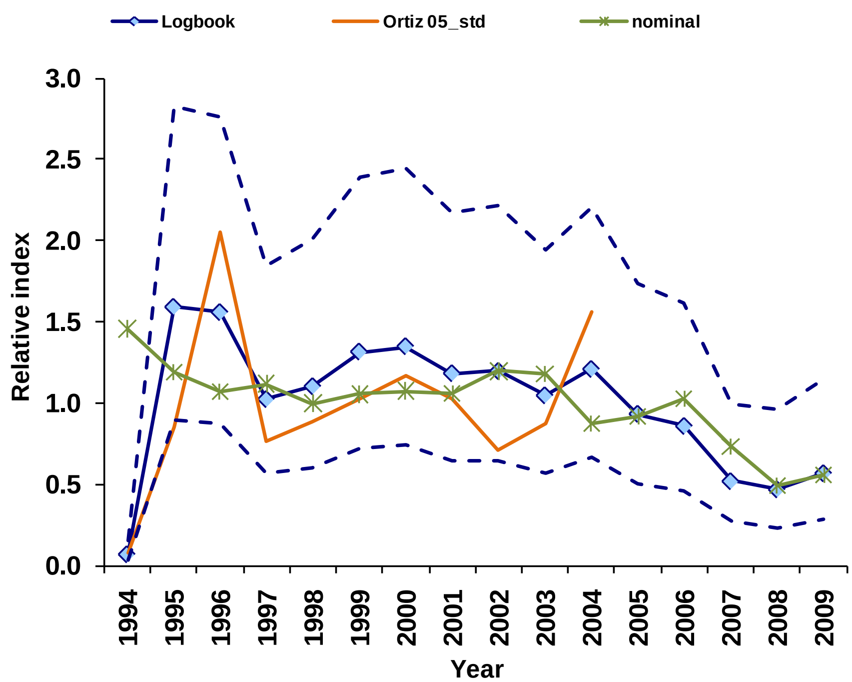


Figure 7. Diagnostic plots of CPUE model from pelagic longline observer data for dusky shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch frequency distribution.



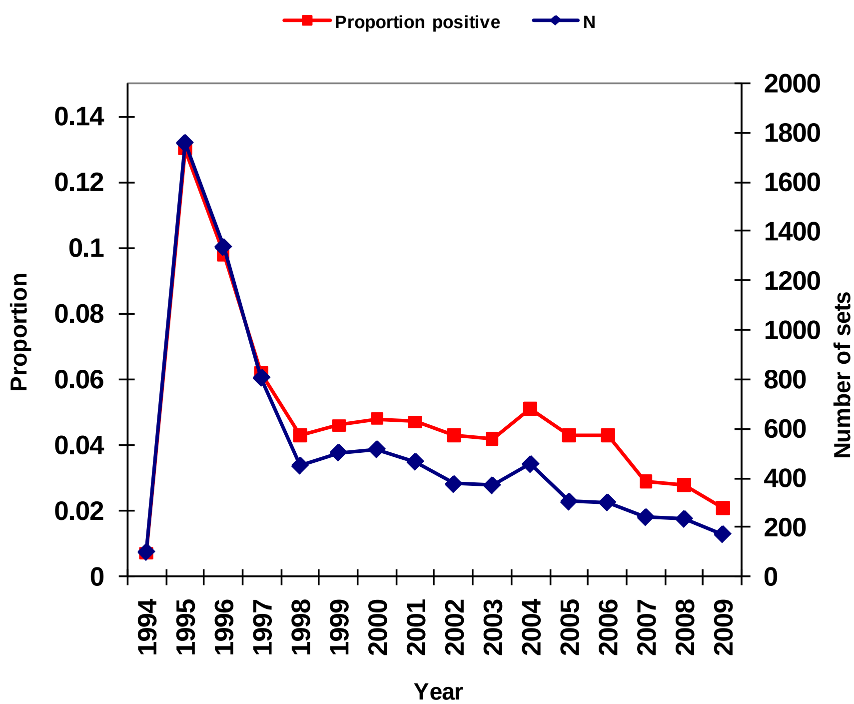


Figure 8. Standardized CPUE (in number) and 95% confidence intervals for sandbar shark from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

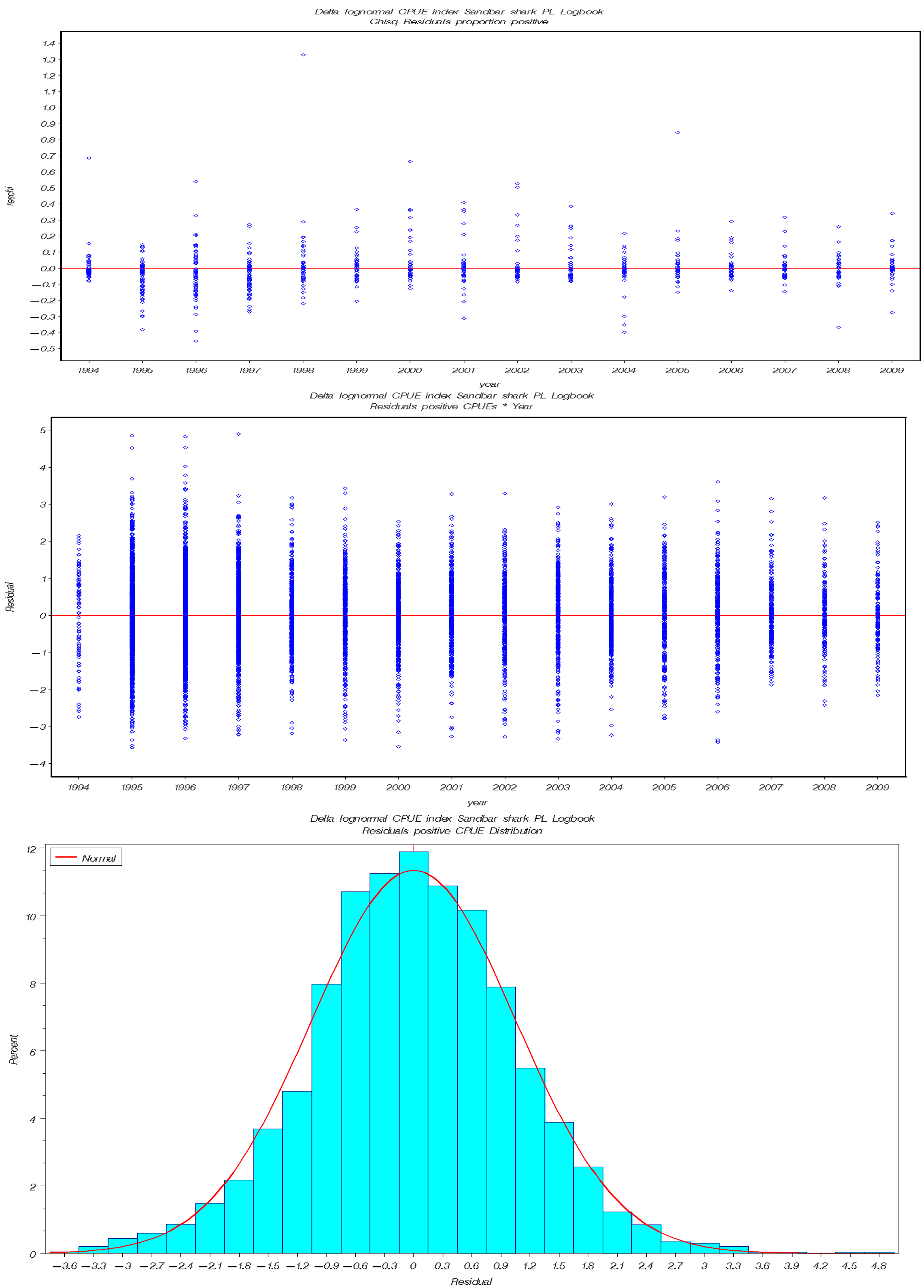
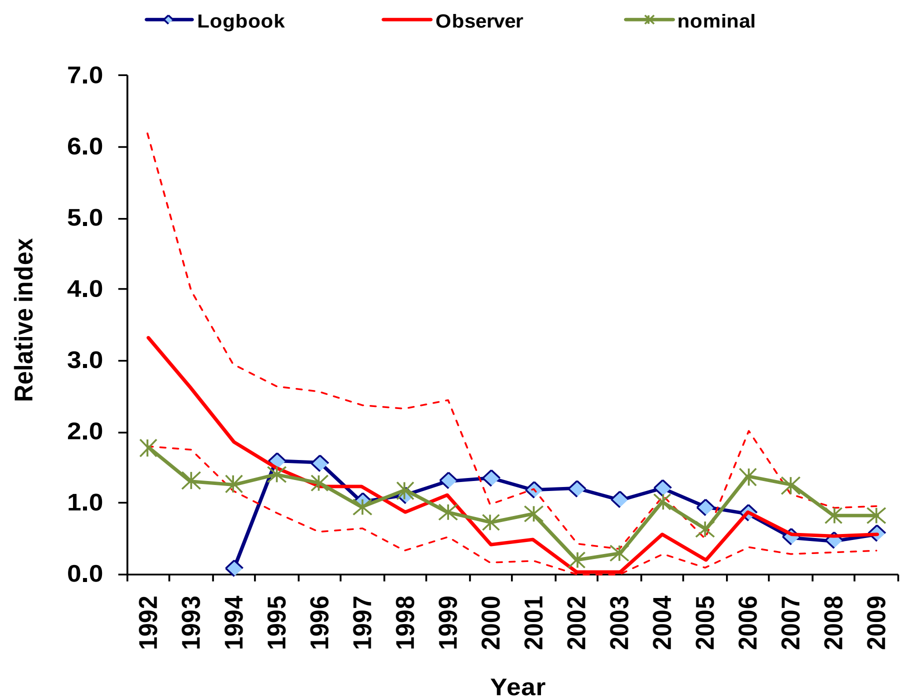


Figure 9. Diagnostic plots of CPUE model from pelagic longline logbook data for sandbar shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch frequency distribution.



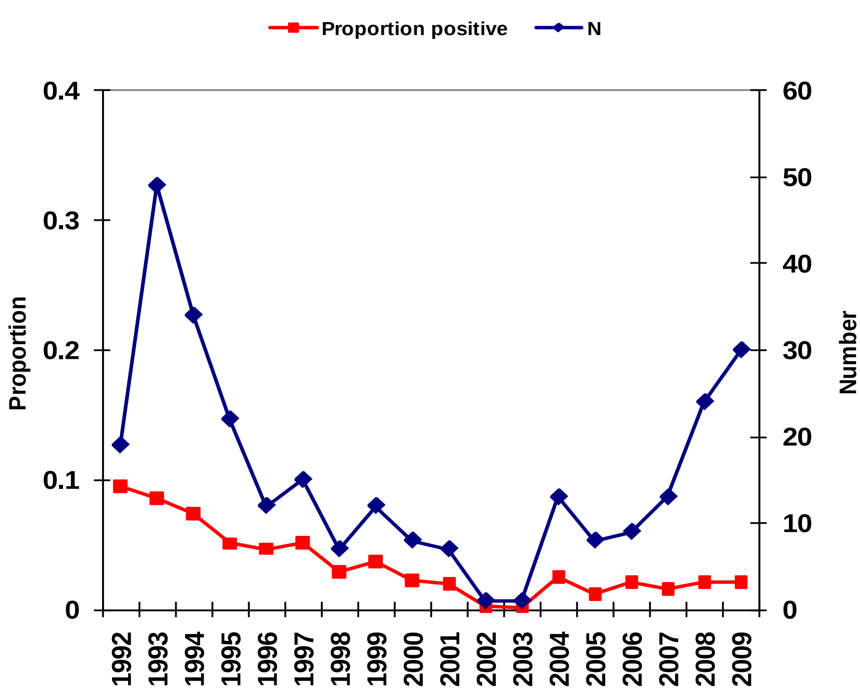


Figure 10. Standardized CPUE (in number) and 95% confidence intervals for sandbar shark from the pelagic longline observer program compared to the pelagic longline logbook. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

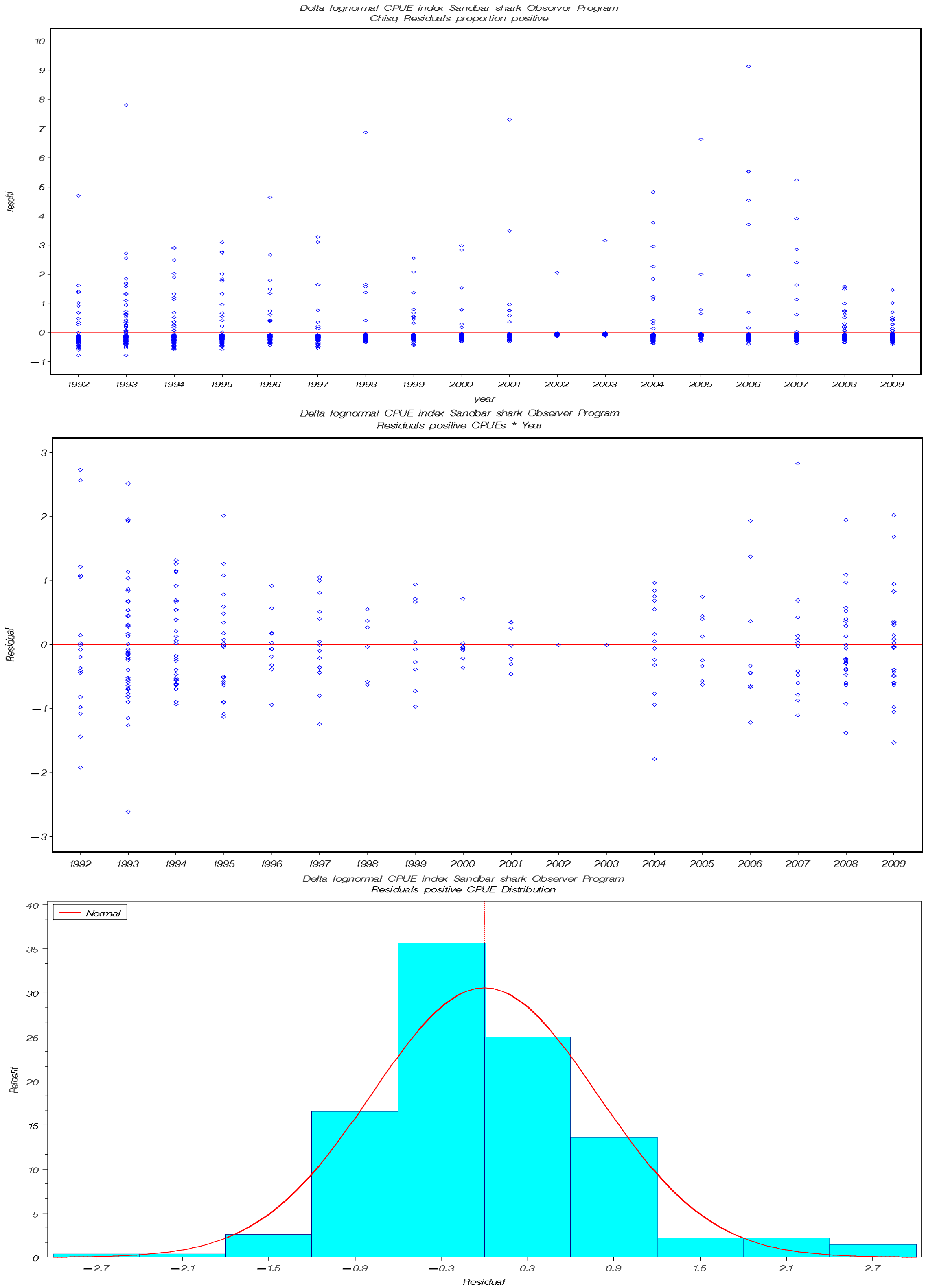
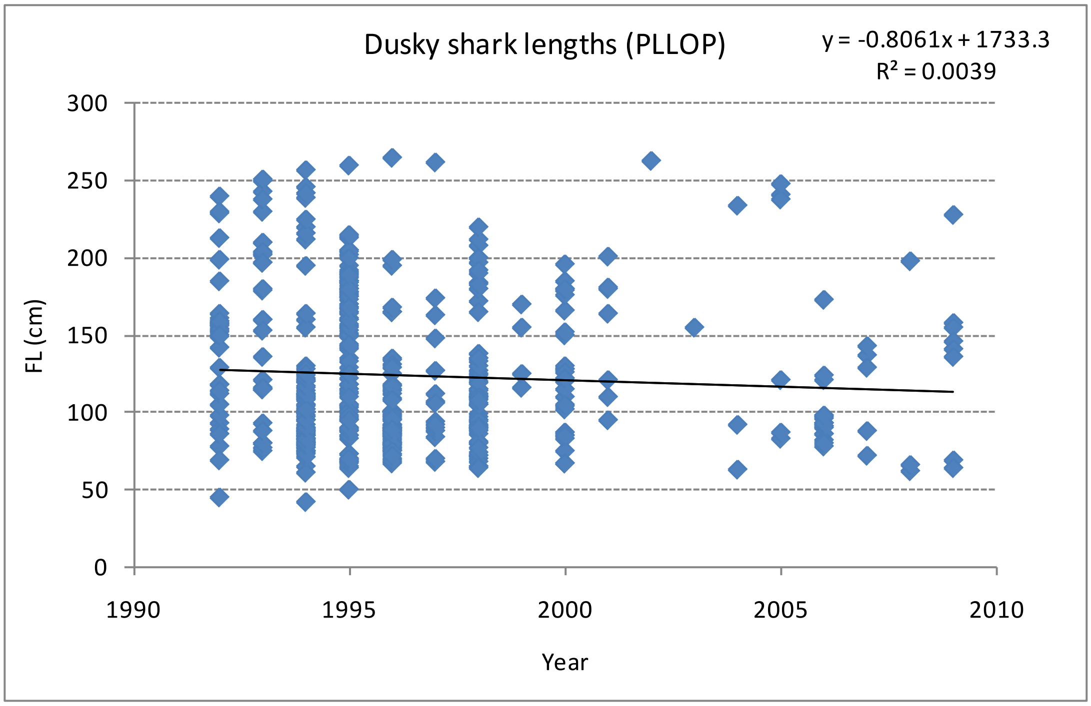


Figure 11. Diagnostic plots of CPUE model from pelagic longline observer data for sandbar shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch frequency distribution.



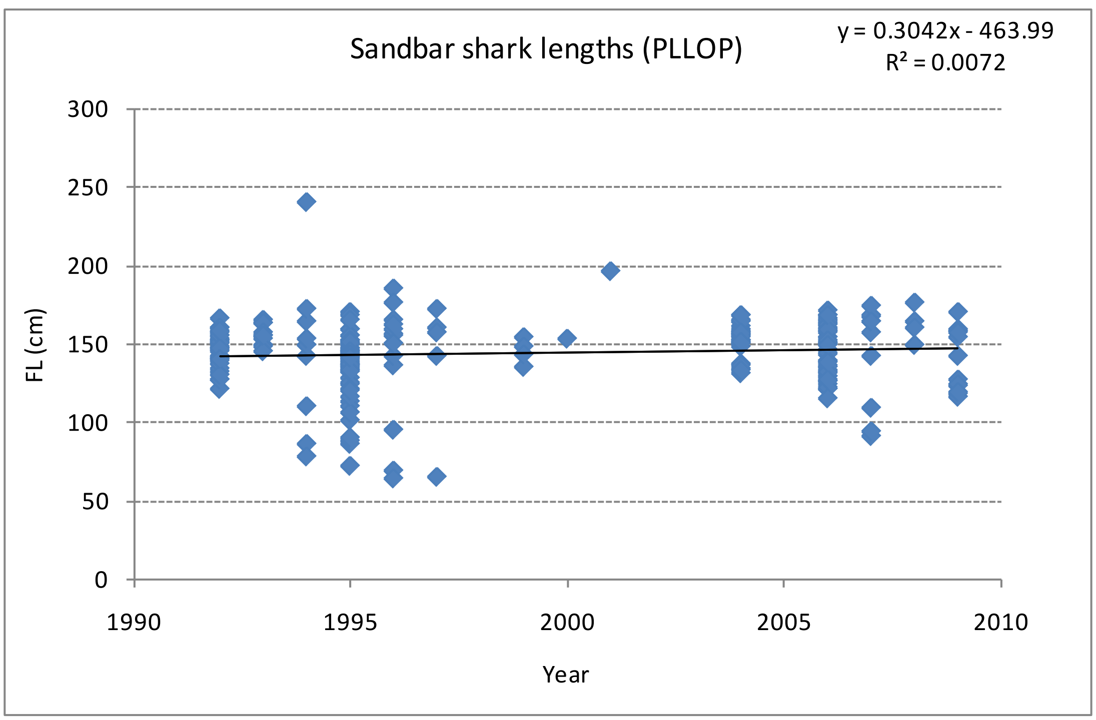


Figure 12. Observed fork lengths (FL) of dusky and sandbar sharks from the pelagic longline observer program.