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STANDARDIZED CATCH RATES FOR BLUE AND MAKO SHARKS FROM THE US PELAGIC LONGLINE LOGBOOK AND OBSERVER PROGRAMS

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SUMMARY

*Updated indices of abundance were developed for blue shark (*Prionace glauca*) and mako sharks (*Isurus *spp.) from two commercial sources, the US pelagic longline logbook program (1986-2007) and the US pelagic longline observer program (1992-2007). 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 blue sharks, the logbook time series showed a marked decreasing trend with signs of a potential recent recovery, but the observer time series showed no clear trend. For makos, both the logbook and observer time series showed a concave shape, with essentially no decline since 1992 and an upward trend since the late 1990s.*

KEYWORDS

Catch/effort, Commercial fishing, Long lining, Pelagic fisheries, Shark fisheries, By catch, Logbooks, Observer programs, Blue shark, Mako sharks

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1. INTRODUCTION

Relative abundance indices from several commercial and recreational sources in the US were produced and used in the 2004 ICCAT assessment of blue and shortfin mako sharks (ICCAT 2005). In this document, commercial series are updated to examine recent trends in relative abundance of blue and mako sharks and in preparation for the re-assessment of blue and shortfin mako sharks. Relative abundance series for these two species and data sources were analyzed by Brooks et al. (2005), Cortés (2007a,b), and Cortés et al. (2007).

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).

Data from the US pelagic longline logbooks were available for 1986-2007, and those from the US pelagic longline observer program, for 1992-2007. Mako sharks included both shortfin makos (mostly) and longfin makos (*Isurus paucus*) in the logbook analysis, and shortfin (mostly), longfin, and unidentified makos in the observer analysis. In the analysis of blue shark, the observer dataset was restricted to areas 5, 6, and 7, and for makos, the dataset was restricted to areas 2, 4, 5, 6, and 7 owing to insufficient and unbalanced observations by year in the remaining areas.

Based on the methodology used in Brooks et al. (2005), Cortés (2007a,b), and Cortés et al. (2007), the following factors were considered in the analyses for both blue and mako 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, 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 blue and mako shark catch rates associated with changes of fishing operations when the fleets switch between targeted species. We 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*Sqr and area*Tqr). Nominal catch rates were defined in all cases as catch 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. 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

Blue sharks—In the analysis of the logbook data, factors retained for the blue shark proportion of positive sets were area, Sqr and year; and for the positive catches, the factors area, year, quarter, year*area, Tqr*area, and year*quarter were retained (Table 1). The estimated annual mean CPUE and CV values are given in Table 2. As is to be expected the updated index is almost identical to that developed by Cortés (2007b), with the 2007 value being higher than the 2006 and 2005 values. In all, the entire time series showed an 85% decline since 1986, corresponding to a mean instantaneous rate of change in abundance per year (r) of –0.089 (95% confidence interval [CI]:-0.169 to -0.009; Fig. 2). This decline was largely driven by a 55% decline in the first three years of the series (1986-1988), with 1986 having the lowest number of positive observations (sets with catches) in any year (n=568; Fig. 2). From 1989 to 2007, the series slowly declined from a relative value of about 1.06 to 0.42, showing an upward trend from 2005 to 2007. In contrast, the nominal series showed a flatter trend, especially from 1998 to 2007. When removing 1986 from the standardized time series, the relative decline since 1987 was still 78%. Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 3).

In the analysis of the observer data, factors retained for the blue shark proportion of positive sets were Sqr, year, Tqr, experiment, area, and quarter; and for the positive catches, the factors area, quarter, year, Tqr, year*quarter, year*area, and Sqr*area were retained (Table 3). The estimated annual mean CPUE and CV values are given in Table 4. The observer index showed an increase when comparing the 2007 value to that for 1992 (r=0.02; 95% CI:-0.320 to +0.359) and larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years (Fig. 4). The nominal observer series showed only a 4% decline. The sharper interannual fluctuations in the observer index may be due to the smaller sample size (observer coverage on pelagic longline vessels averages 4%). Note also that some of the lowest index values (2001-2003), when the proportion of positive sets drastically decreased with respect to other years, correspond to the years of experimental fishing (2000-2003; Fig. 4). Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 5).

Mako sharks— In the analysis of the logbook data, factors retained for the mako shark proportion of positive sets were area, Sqr and year; and for the positive catches, the factors Tqr, year, area, Sqr, quarter, year*area, Tqr*area, and Sqr*area were retained (Table 5). The estimated annual mean CPUE and CV values are given in Table 6. As for blue shark, the updated index is almost identical to that developed by Cortés (2007b), with 2007 having the highest value since 1992. In all, the entire time series showed a 33% decline since 1986 (r=-0.019, 95% CI:-0.082 to +0.044; Fig. 6). This decline was largely driven by a 35% decline in the first six years of the series (1986-1991), which was followed by an increase in 1992 and a progressive decline from that year to 1999. The series progressively started increasing from 1999 to 2005, followed by a dip in 2006, and a peak in the last year of data, 2007 (Fig. 6). As with the blue shark, 1986 had the lowest number of positive observations for any year (n=354). The nominal series had a somewhat flatter trend, with essentially the same relative decline from beginning to end (32%) as the standardized series. When removing 1986 from the standardized time series, the relative decline from beginning to end was the same as when including 1986 (33%). Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 7).

In the analysis of the observer data, factors retained for the mako shark proportion of positive sets were area, Sqr, experiment, year, quarter, and year*quarter; and for the positive catches, the factors area, quarter, year, Sqr, Tqr, year*area, Tqr*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 only a 4% decline since 1992 (r=-0.003, 95% CI: -0.217 to 0.212), but larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years (Fig. 8). The trends of both indices are similar, however, as was the trend for the nominal observer series. As for blue shark, the sharper interannual fluctuations in the observer index may be due to the smaller sample size. In this case, however, despite having a low proportion of positive sets, the years of experimental fishing (2000-2003) did not have the lowest index values (Fig. 8). Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 9).

4. DISCUSSION

Declines in relative abundance were much more accentuated in the analyses of the logbook dataset compared with those from the observer dataset, especially for blue sharks. For blue sharks, the logbook series declined, whereas the observer series increased from beginning to end; for mako sharks, both series had a concave shape showing a recovery since the late 1990s. The trends of the logbook and observer series were in agreement for mako sharks, and less so for blue sharks, although both showed an increasing trend since 2005 for this species.

The observer dataset had smaller sample sizes leading to more uncertain trends and larger interannual variation than the logbook dataset. In contrast, the logbook dataset had much larger sample sizes, but species identification and reporting is much less reliable than for the observer dataset (see Cortés et al. [2007] and references therein for a more extensive discussion).

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

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	286510	315507	-157754
Final model AREA SQR YEAR	286479	205259	-102629

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	68643	126907	-118493
Final model AREA YEAR QUARTER YEAR*AREA TQR*AREA YEAR*QUARTER	68379	72609	-99329

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

Year	Mean CPUE	CV
1986	18.998	0.233
1987	13.398	0.167
1988	8.606	0.167
1989	7.409	0.163
1990	6.946	0.162
1991	8.849	0.161
1992	8.219	0.162
1993	9.021	0.162
1994	8.043	0.160
1995	7.842	0.159
1996	8.278	0.157
1997	7.581	0.160
1998	6.130	0.164
1999	4.815	0.166
2000	4.317	0.171
2001	3.462	0.173
2002	3.151	0.175
2003	2.821	0.182
2004	3.608	0.177
2005	2.277	0.189
2006	2.687	0.187
2007	2.935	0.19

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

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	3956	5475	-2738
Final model SQR YEAR TQR EXPERIMENT AREA QUARTER	3929	2085	-1042

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	2078	3339	-3442
Final model AREA QUARTER YEAR TQR YEAR*QUARTER YEAR*AREA SQR*AREA	1980	1618	-2690

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

Year	Mean CPUE	CV
1992	8.382	0.316
1993	11.878	0.284
1994	10.487	0.279
1995	10.781	0.284
1996	9.888	0.496
1997	16.616	0.329
1998	18.072	0.333
1999	7.839	0.353
2000	10.472	0.323
2001	2.875	0.403
2002	2.893	0.407
2003	2.394	0.370
2004	10.784	0.286
2005	3.419	0.348
2006	5.782	0.307
2007	11.252	0.317

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

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	286510	245214	-122607
Final model AREA SQR YEAR	286479	209004	-104502

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	43844	26109	-50849
Final model TQR YEAR AREA SQR QUARTER YEAR*AREA TQR*AREA SQR*AREA	43619	19876	-44869

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

Year	Mean CPUE	CV
1986	1.137	0.171
1987	1.137	0.090
1988	0.897	0.091
1989	1.037	0.084
1990	0.827	0.091
1991	0.738	0.095
1992	0.870	0.091
1993	0.755	0.094
1994	0.716	0.093
1995	0.648	0.093
1996	0.578	0.100
1997	0.529	0.105
1998	0.505	0.110
1999	0.496	0.114
2000	0.522	0.112
2001	0.485	0.117
2002	0.506	0.118
2003	0.553	0.118
2004	0.650	0.111
2005	0.658	0.112
2006	0.513	0.123
2007	0.765	0.106

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

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	84113	8363	-4181
Final model AREA SQR EXPERIMENT YEAR QUARTER YEAR*QUARTER	8343	6059	-3029

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	1661	1077	-1997
Final model AREA QUARTER YEAR SQR TQR YEAR*AREA TQR*AREA YEAR*QUARTER	1523	686	-1623

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

Year	Mean CPUE	CV
1992	1.261	0.232
1993	1.036	0.202
1994	0.610	0.238
1995	0.942	0.207
1996	0.526	0.438
1997	0.663	0.271
1998	0.415	0.389
1999	0.534	0.307
2000	0.925	0.228
2001	0.583	0.286
2002	0.738	0.285
2003	0.608	0.265
2004	1.341	0.191
2005	0.774	0.229
2006	1.139	0.21
2007	1.214	0.193

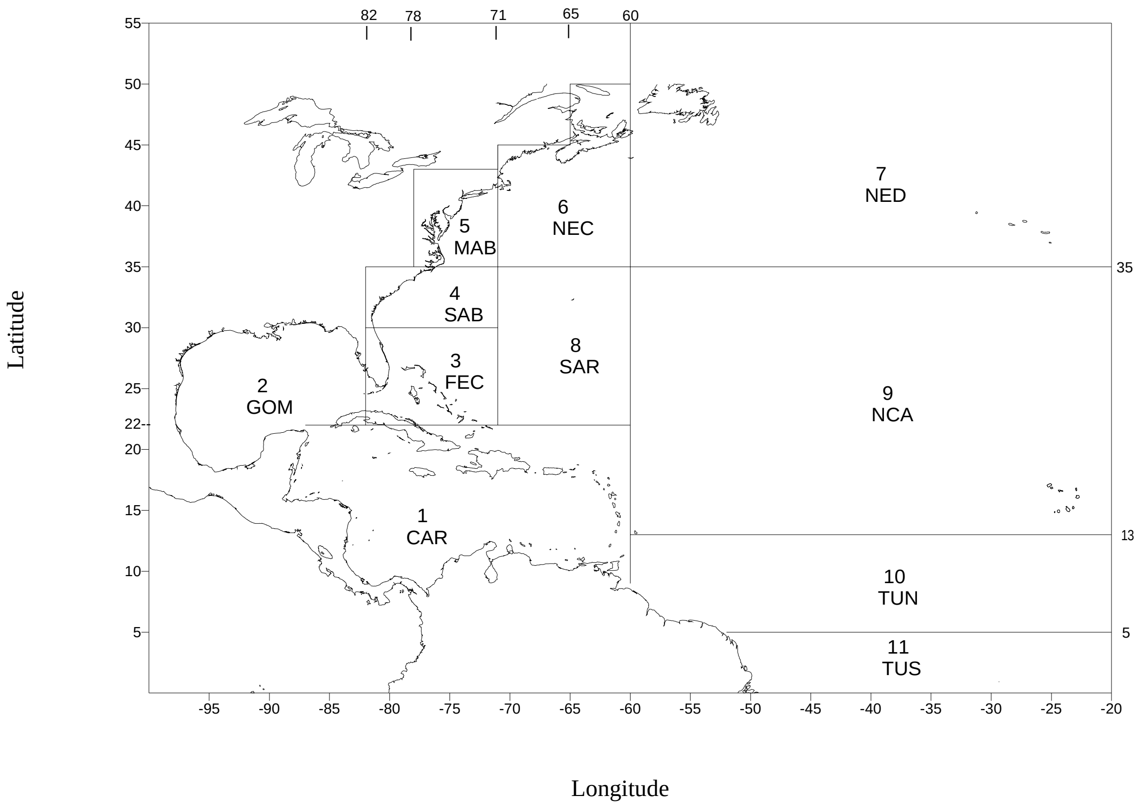
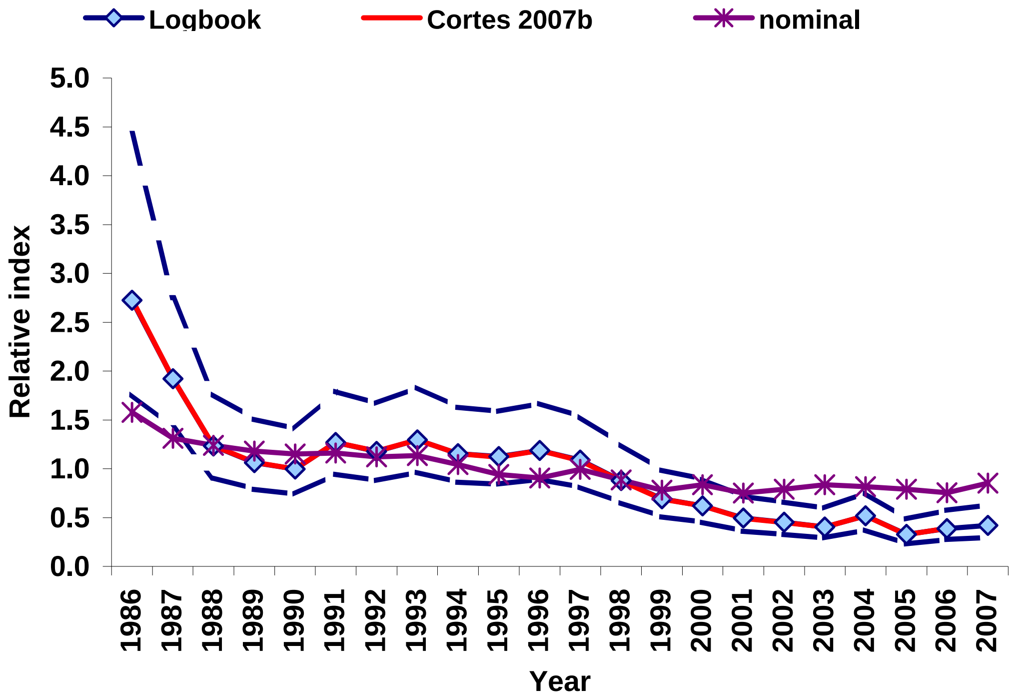


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean; 2) Gulf of Mexico; 3) Florida East Coast; 4) South Atlantic Bight; 5) Mid Atlantic Bight; 6) Northeast Coastal; 7) Northeast Distant; 8) Sargasso; 9) North Central Atlantic; 10) Tuna North; 11) Tuna South.



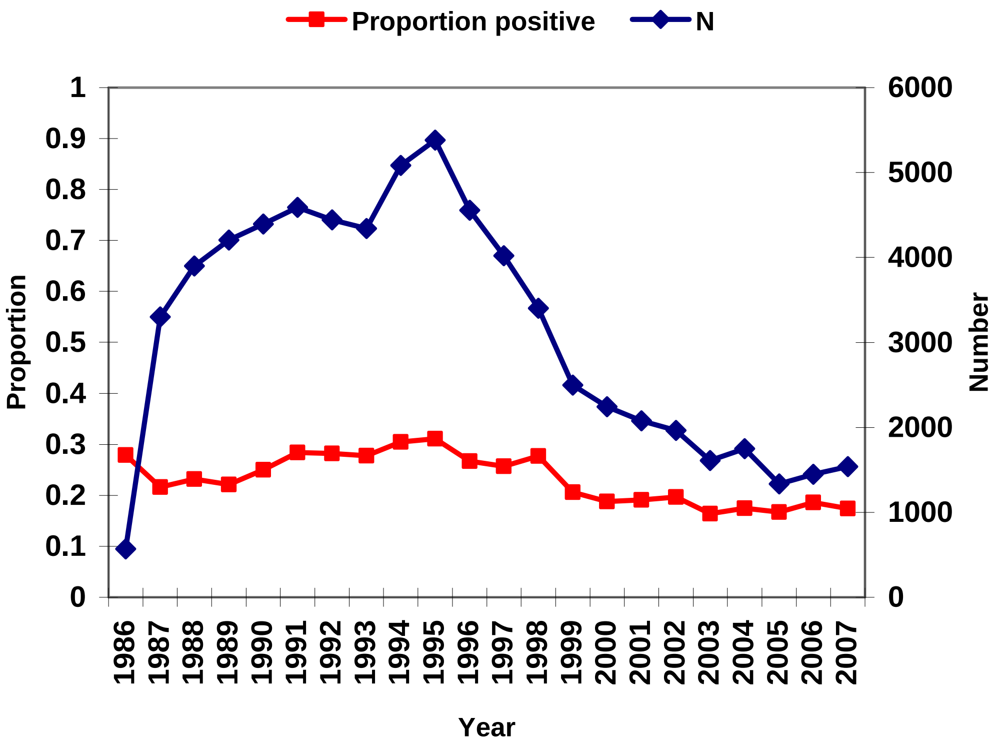


Figure 2. Standardized CPUE (in number) and 95% confidence intervals for blue shark from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample size by year.

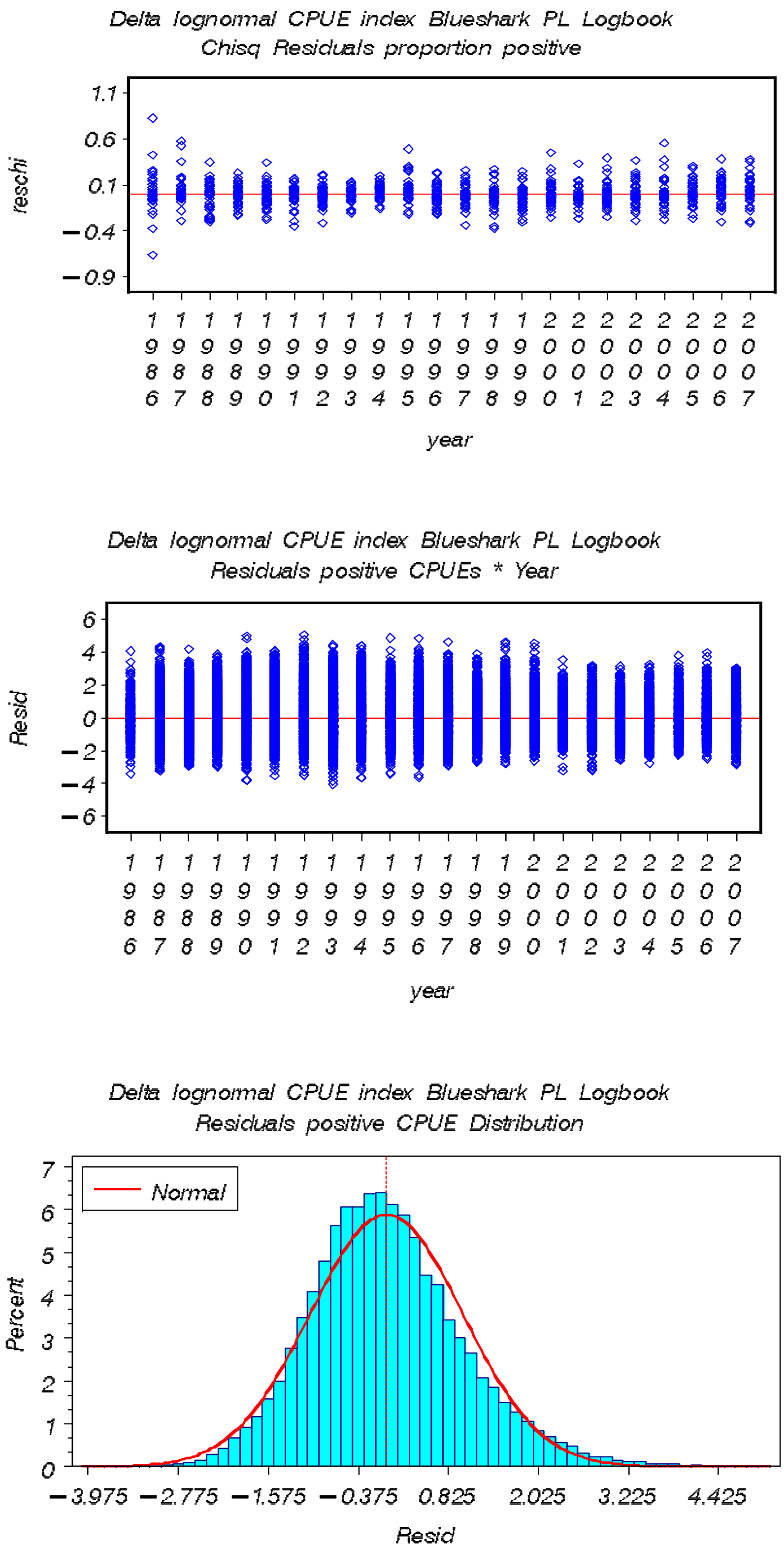


Figure 3. Diagnostic plots of CPUE model from logbook data for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

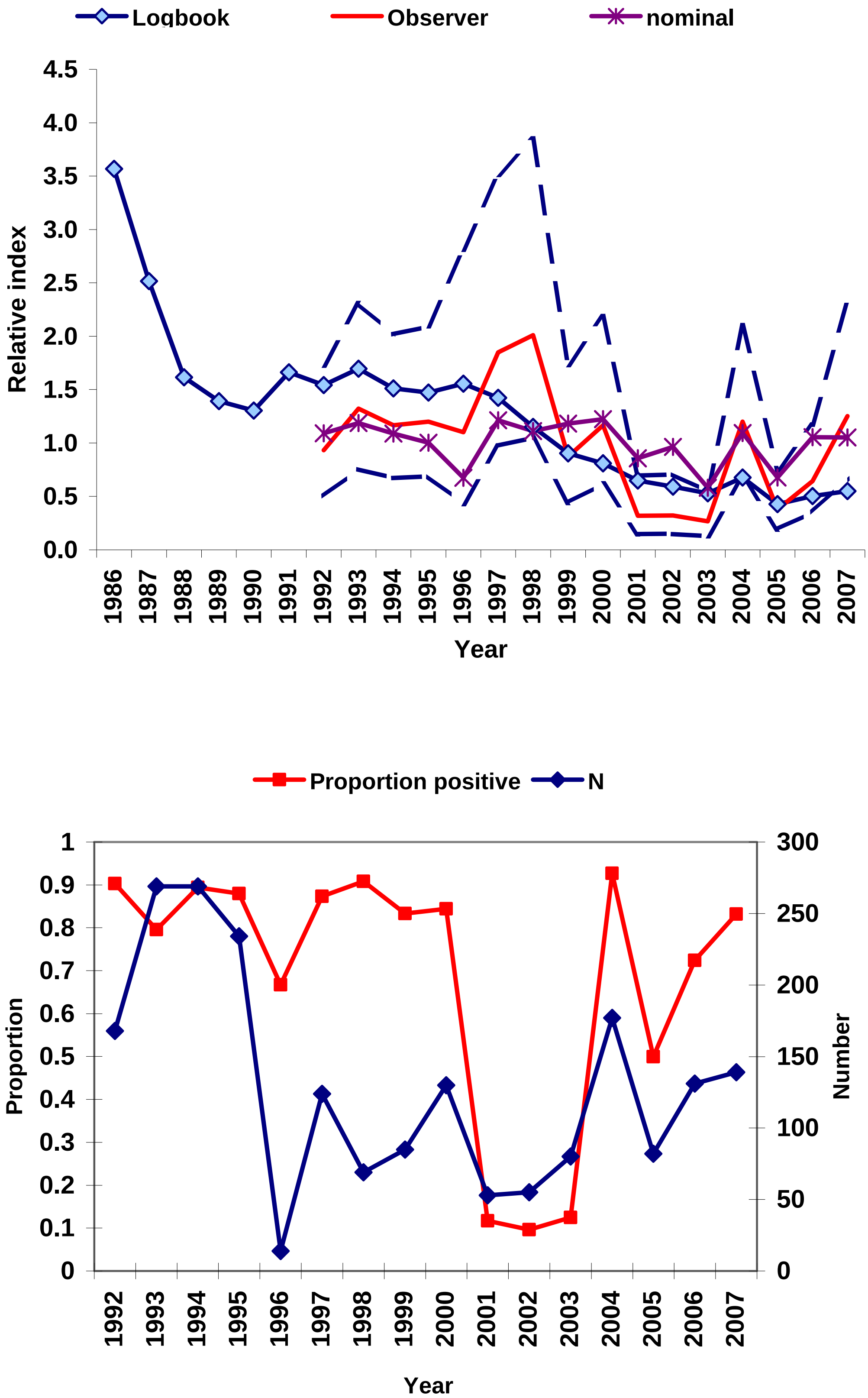


Figure 4. Standardized CPUE (in number) and 95% confidence intervals for blue shark from the pelagic longline observer program compared to the pelagic longline logbook. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample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

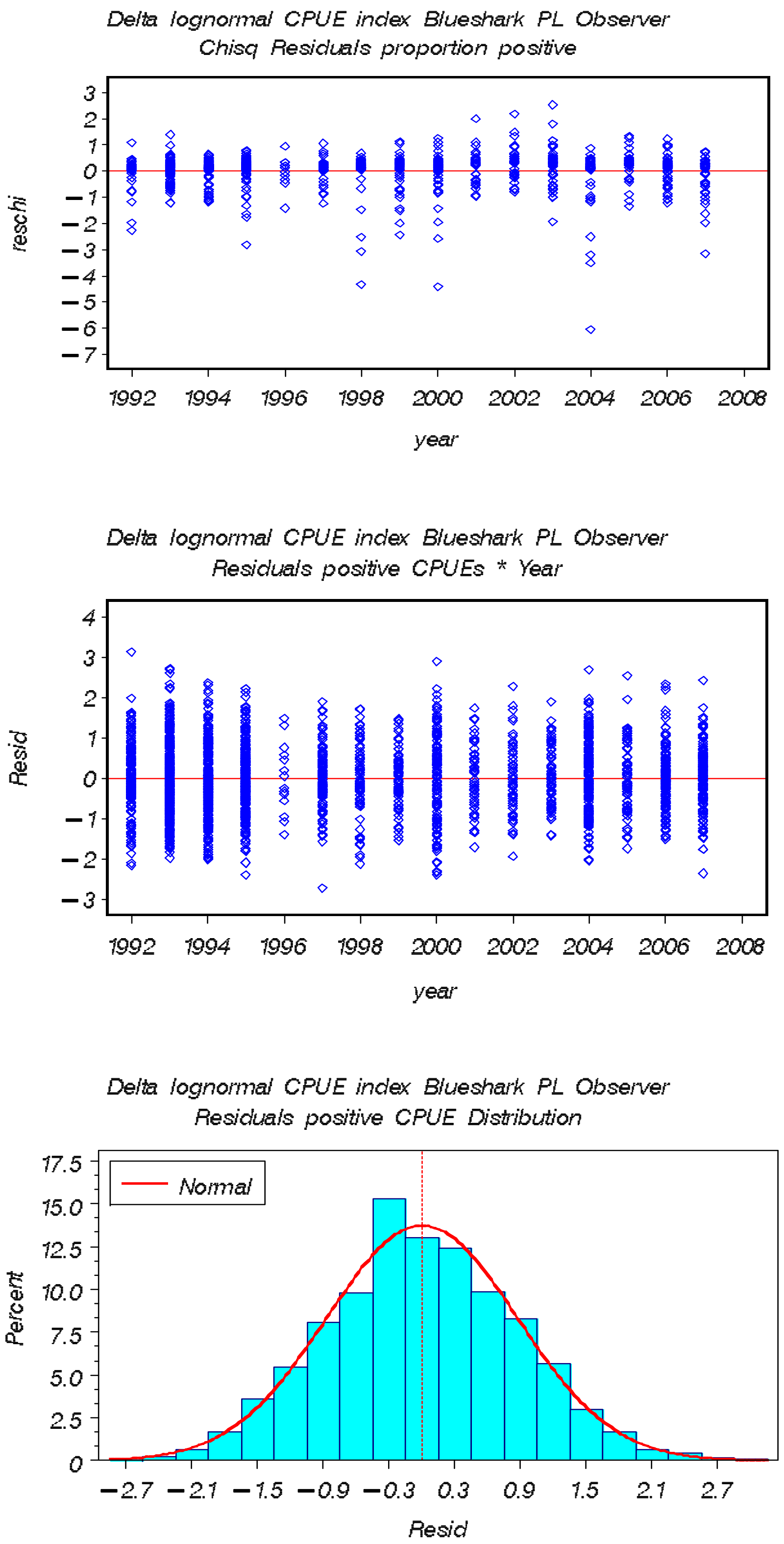
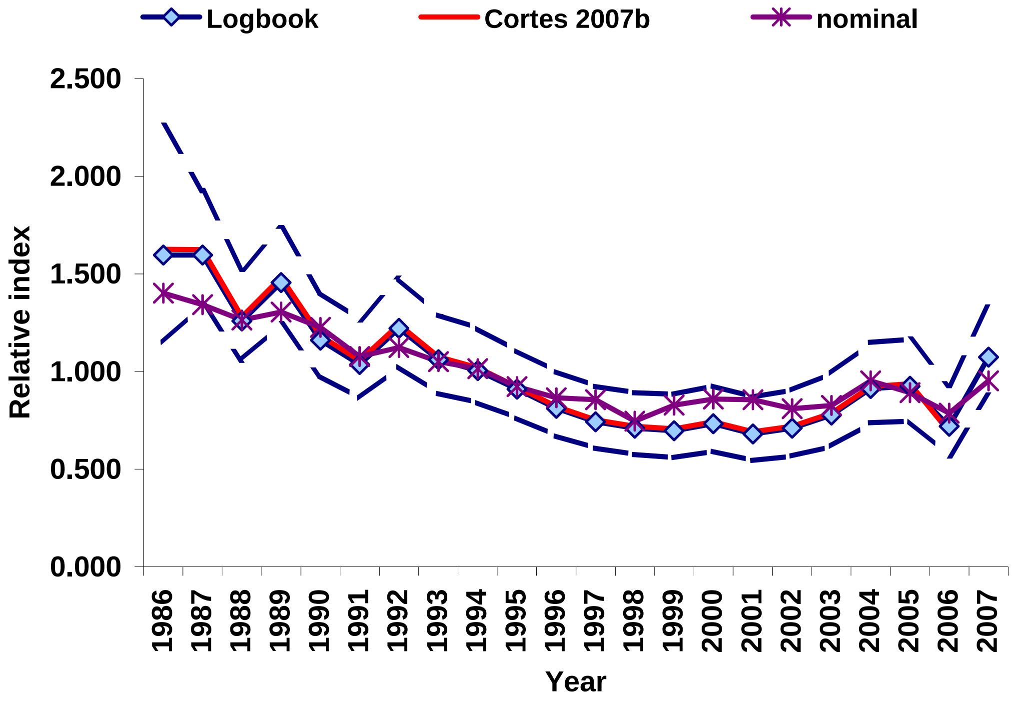


Figure 5. Diagnostic plots of CPUE model from observer data for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.



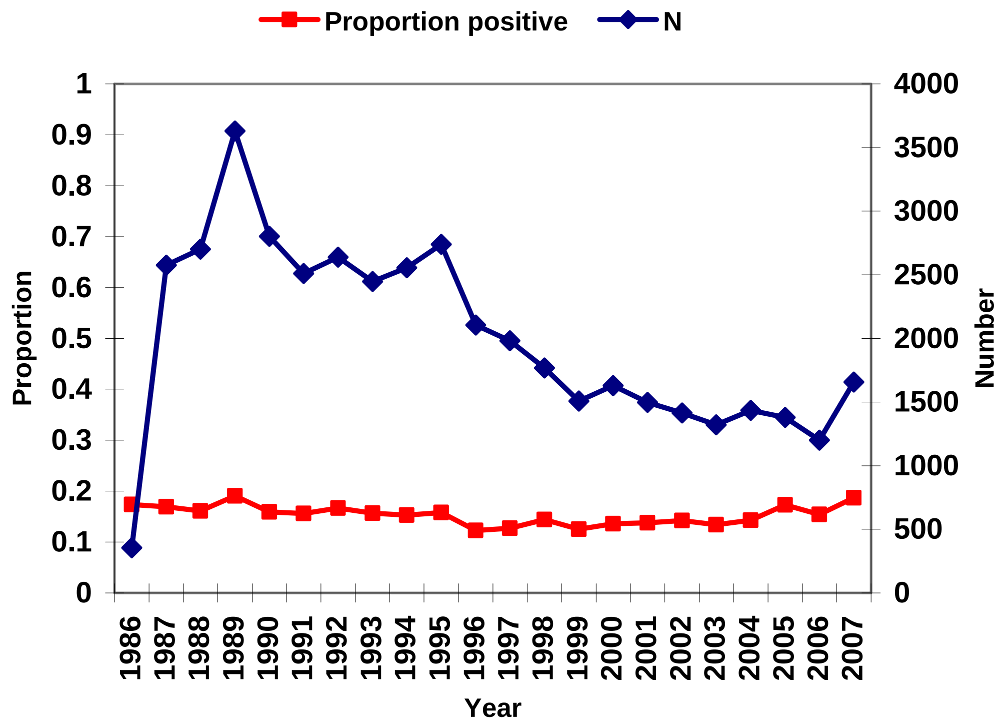


Figure 6. Standardized CPUE (in number) and 95% confidence intervals for mako sharks from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample size by year.

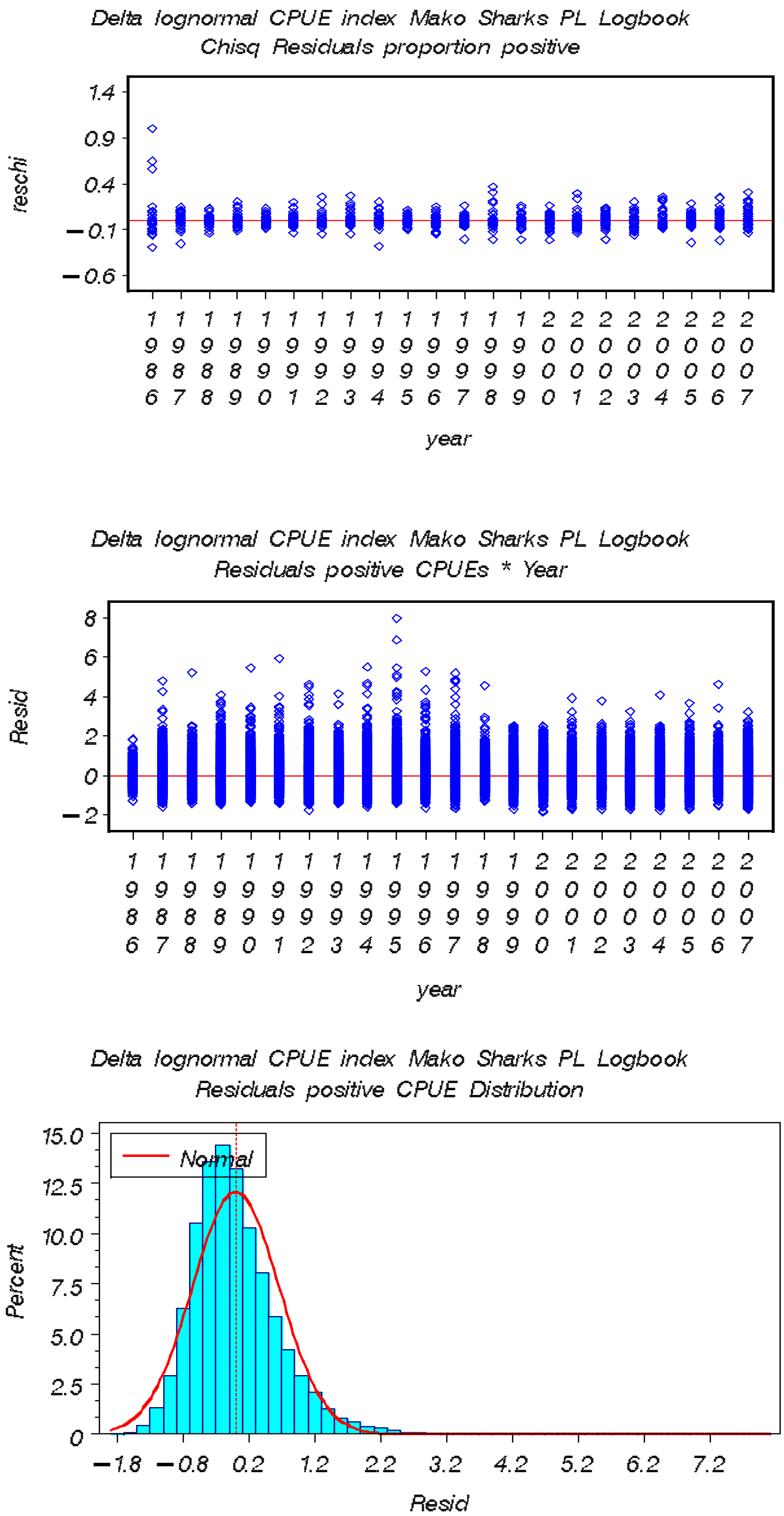


Figure 7. Diagnostic plots of CPUE model from logbook data for mako sharks.
Top: residuals of proportion positive sets; middle: residuals of positive catch;
bottom: residual positive catch distribution.

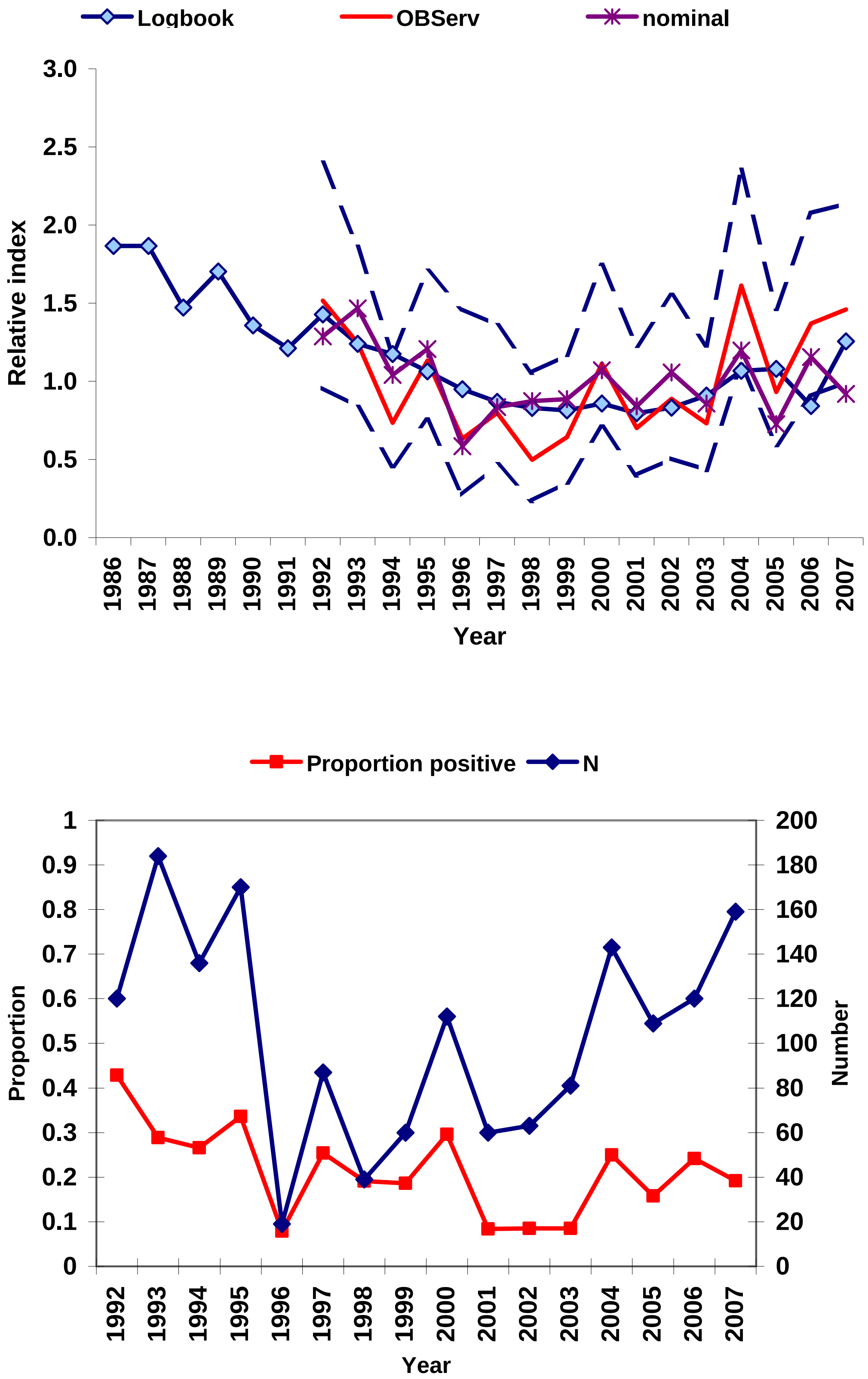


Figure 8. Standardized CPUE (in number) and 95% confidence intervals for mako sharks from the pelagic longline observer program compared to the pelagic longline logbook. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample size by year.

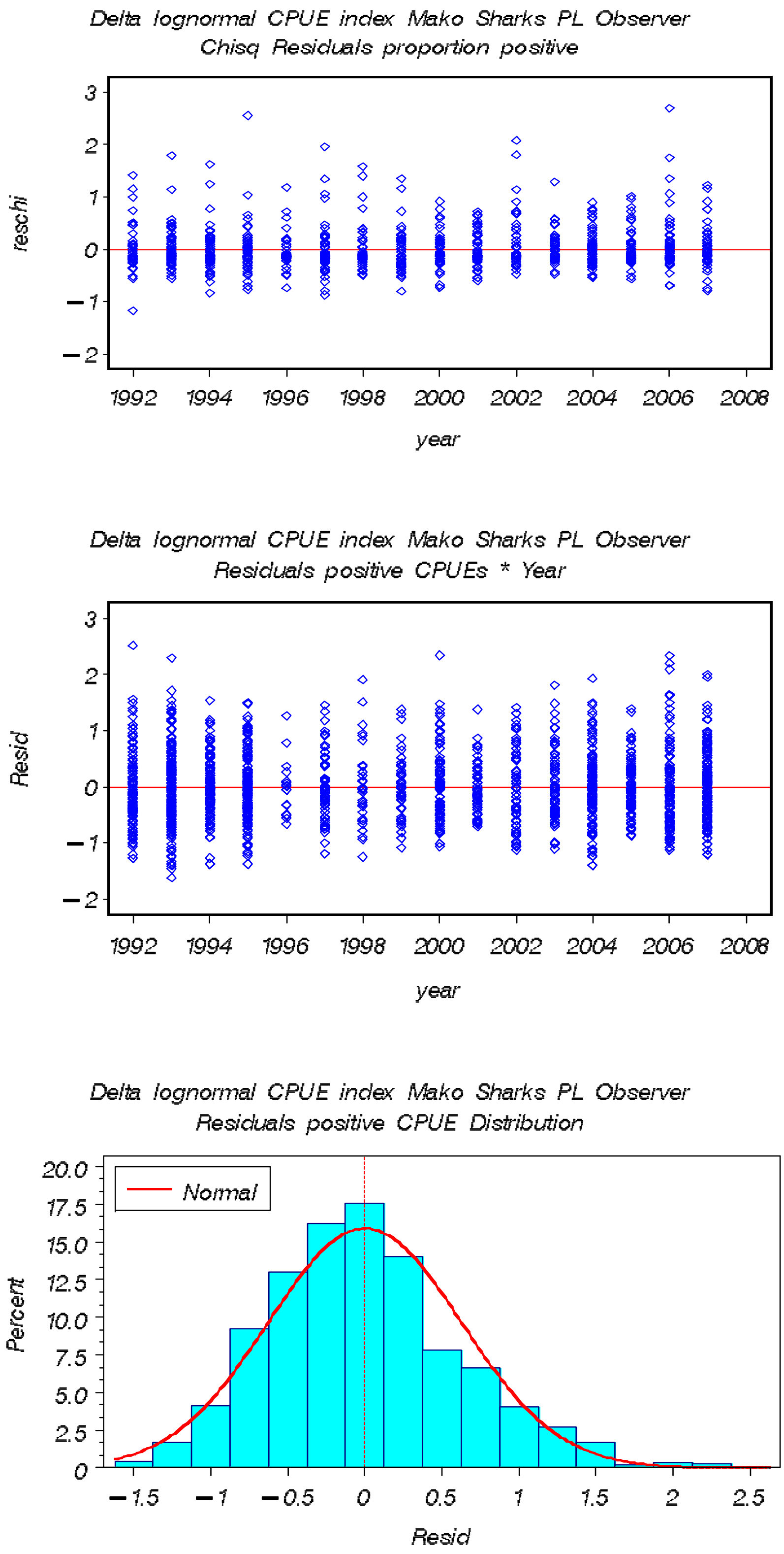


Figure 9. Diagnostic plots of CPUE model from observer data for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.