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STANDARDIZED CATCH RATES FOR BLUE AND MAKO SHARKS FROM THE U.S. PELAGIC LONGLINE LOGBOOK AND OBSERVER PROGRAMS

Enric Cortés[1]

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 (1986-2006) and the US pelagic longline observer program (1992-2006). 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, but the observer time series decline was much more attenuated. For makos, the logbook time series declined by over 50% from 1986 to 2006, but the observer time series showed a concave shape with almost no decline.*

RÉSUMÉ

*Des indices d'abondance actualisés ont été mis au point pour le requin peau bleue (*Prionace glauca*) et les requins taupes (*Isurus spp.*) à partir de deux sources commerciales, le programme de carnets de pêche palangrière pélagique des Etats-Unis (1986-2006) et le programme d'observateurs palangriers pélagiques des Etats-Unis (1992-2006). Les indices ont été calculés à l'aide d'une approche delta-lognormale en deux étapes qui traite séparément la proportion des opérations positives et la CPUE des prises positives. Les indices standardisés avec des intervalles de confiance de 95% sont déclarés. Pour le requin peau bleue, les séries temporelles des carnets de pêche ont dégagé une tendance marquée à la baisse, mais la diminution des séries temporelles des observateurs était bien plus atténuée. Pour les requins taupes, les séries temporelles des carnets de pêche ont chuté de plus de 50 % de 1986 à 2006, mais les séries temporelles des observateurs ont donné lieu à une forme concave sans presque aucune chute.*

RESUMEN

*Se desarrollaron índices actualizados de abundancia para la tintorera (*Prionace glauca*) y los marrajos (*Isurus spp.*) a partir de dos fuentes comerciales, el programa de cuadernos de pesca del palangre pelágico de Estados Unidos (1986-2006) y el programa de observadores de palangre pelágico de Estados Unidos (1992-2006). Los índices se calcularon utilizando un enfoque delta-lognormal en dos fases, que trata la proporción de lances positivos y la CPUE de las capturas positivas por separado. Se informa sobre índices estandarizados con un 95% de intervalos de confianza. Para la tintorera, la serie temporal de los cuadernos de pesca mostraba una tendencia marcadamente descendente, pero el descenso de la serie temporal de los observadores era mucho más atenuado. Para los marrajos, la serie temporal de los cuadernos de pesca descendía en más del 50% desde 1986 hasta 2006, pero la serie temporal de los observadores mostraba una forma cóncava casi sin descenso.*

KEYWORDS

Catch/effort, commercial fishing, long lining, pelagic fisheries, shark fisheries, by-catch, logbooks, observer programs, blue shark, mako sharks

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 an upcoming 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 (2006), and more recently by Cortés *et al.* (2007).

[1] National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City Laboratory, 3500 Delwood Beach Road, Panama City, Florida 32408, U.S.A. E-mail: Enric.Cortes@noaa.gov

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 **(Figure 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 U.S. pelagic longline logbooks were available for 1986-2006, and those from the U.S. pelagic longline observer program, for 1992-2006. 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 (2006), 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 et al. (2006), with the 2006 value being higher than the 2005 value. In all, the entire time series showed an 86% decline since 1986, corresponding to a mean instantaneous rate of change in abundance per year (r) of –0.098 (95% confidence interval [CI]:-0.182 to -0.013; **Figure 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; **Figure 2**). From 1989 to 2006, the series slowly declined from a relative value of about 1.03 to 0.38. In contrast, the nominal series showed a flatter trend, with a relative decline of 53% from beginning to end. When removing 1986 from the standardized time series, the relative decline since 1987 was still 80%. Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals **(Figure 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, Sqr, 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 a 24% decline since 1992 (r=-0.020, 95% CI: -0.387 to 0.347), but larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years **(Figure 4)**. The nominal observer series showed only a 3% 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; **Figure 4**). Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals **(Figure 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 *et al*. (2006), with the 2006 value being lower than the 2005 value. In all, the entire time series showed a 57% decline since 1986 (r=-0.043, 95% CI:-0.099 to +0.013; **Figure 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 until 2005, followed by a dip in the last year of data, 2006 **(Figure 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 a lower initial and a higher final value, and a relative decline of 44% from beginning to end. When removing 1986 from the standardized time series, the relative decline from beginning to end was essentially the same as when including 1986 (57%). Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals **(Figure 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, Tqr, year, Sqr, quarter, 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 7% decline since 1992 (r=-0.005, 95% CI: -0.252 to 0.241), but larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years **(Figure 8)**. The trends of both indices are similar, however. The nominal observer series showed a 10% decline. As for blue shark, the sharper interannual fluctuations in the observer index may be due to the smaller sample size (observer coverage on pelagic longline vessels averages 4%). 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 **(Figure 8)**. Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals **(Figure 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. For blue sharks, declines were 86% vs. 24% in the logbook and observer datasets, respectively, and 57% vs. 7% for mako sharks. Restricting the comparison to the overlapping years between the two datasets (1992-2006) resulted in somewhat smaller differences between datasets (76% vs. 24% for blue sharks and 44% vs. 7% for mako sharks).

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	276397	305948	-152974
Final model AREA SQR YEAR	276387	201110	-100555
Positive catches	*Degrees of freedom*	*Deviance*	*Log-likelihood*
Null model	66907	123331	-115397
Final model AREA YEAR QUARTER YEAR*AREA TQR*AREA YEAR*QUARTER	66654	71094	-96968

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	18.930	0.235
1987	13.307	0.169
1988	8.572	0.168
1989	7.375	0.164
1990	6.896	0.163
1991	8.787	0.163
1992	8.172	0.163
1993	8.977	0.163
1994	7.998	0.161
1995	7.744	0.161
1996	8.223	0.159
1997	7.501	0.161
1998	6.057	0.165
1999	4.772	0.168
2000	4.286	0.172
2001	3.415	0.174
2002	3.120	0.176
2003	2.801	0.183
2004	3.579	0.178
2005	2.259	0.190
2006	2.692	0.191

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	3790	5253	-2627
Final model SQR YEAR TQR EXPERIMENT AREA QUARTER	3764	1956	-978

Positive catches	*Degrees of freedom*	*Deviance*	*Log-likelihood*
Null model	1939	3062	-3195
Final model AREA QUARTER YEAR TQR SQR YEAR*QUARTER YEAR*AREA SQR*AREA	1847	1529	-2522

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	8.095	0.312
1993	11.857	0.278
1994	10.500	0.272
1995	10.667	0.277
1996	9.659	0.493
1997	16.517	0.322
1998	18.354	0.325
1999	7.674	0.350
2000	10.347	0.317
2001	2.925	0.397
2002	3.152	0.399
2003	2.545	0.361
2004	11.334	0.278
2005	3.507	0.340
2006	6.135	0.298

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	276397	235480	-117740
Final model AREA SQR YEAR	276387	201912	-100956

Positive catches	*Degrees of freedom*	*Deviance*	*Log-likelihood*
Null model	41982	24870	-48580
Final model TQR YEAR AREA SQR QUARTER YEAR*AREA TQR*AREA SQR*AREA	41765	18842	-42753

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	1.131	0.169
1987	1.130	0.088
1988	0.891	0.090
1989	1.031	0.082
1990	0.823	0.089
1991	0.734	0.094
1992	0.863	0.090
1993	0.748	0.093
1994	0.709	0.092
1995	0.641	0.092
1996	0.571	0.099
1997	0.523	0.104
1998	0.501	0.109
1999	0.491	0.114
2000	0.517	0.112
2001	0.481	0.117
2002	0.501	0.117
2003	0.547	0.117
2004	0.642	0.110
2005	0.652	0.111
2006	0.481	0.131

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	7587	7553	-3777
Final model AREA SQR EXPERIMENT YEAR QUARTER YEAR*QUARTER	7521	5397	-2698

Positive catches	*Degrees of freedom*	*Deviance*	*Log-likelihood*
Null model	1502	974	-1806
Final model AREA TQR YEAR SQR QUARTER YEAR*AREA TQR*AREA YEAR*QUARTER	1372	621	-1468

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	1.329	0.230
1993	1.096	0.202
1994	0.660	0.238
1995	1.011	0.206
1996	0.536	0.448
1997	0.722	0.269
1998	0.453	0.393
1999	0.576	0.309
2000	0.979	0.227
2001	0.645	0.287
2002	0.845	0.282
2003	0.688	0.264
2004	1.446	0.189
2005	0.818	0.231
2006	1.231	0.209

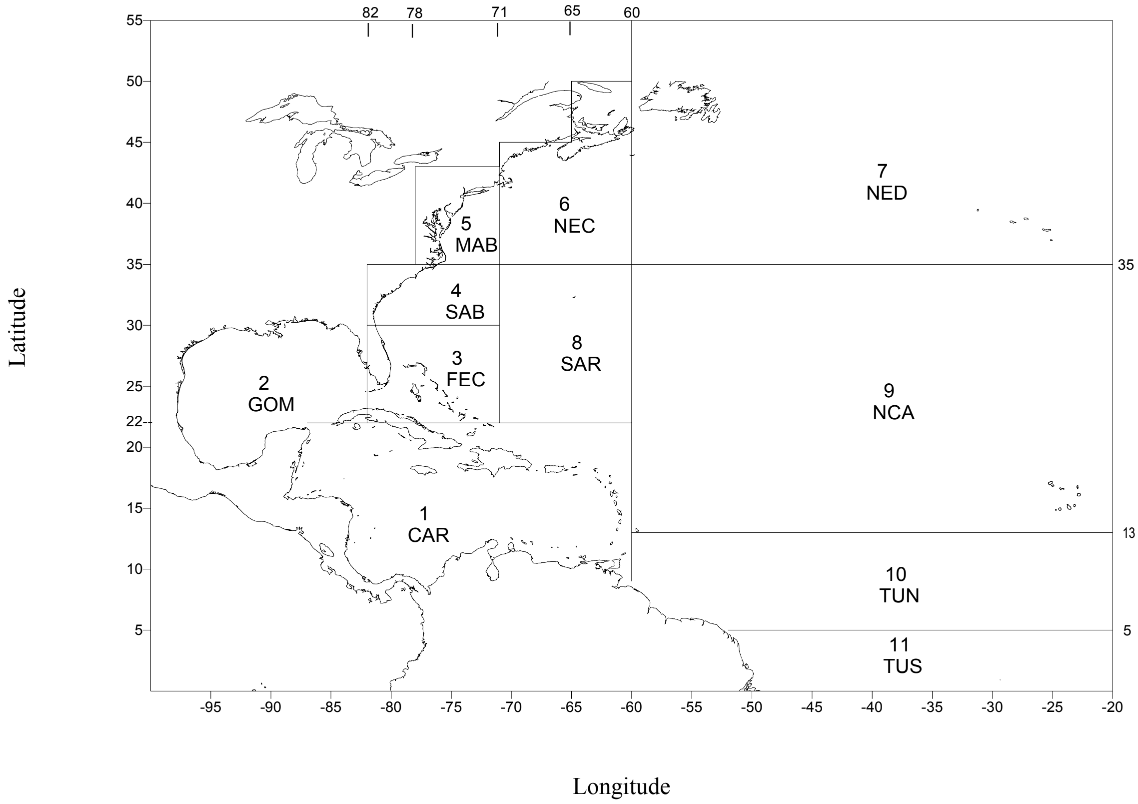


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean; 2) Gulf of Mexico; 3) Florida East Coast; 4) South Atlantic Bight; 5) Mid Atlantic Bight; 6) Northeast Coastal; 7) Northeast Distant; 8) Sargasso; 9) North Central Atlantic; 10) Tuna North; 11) Tuna South.

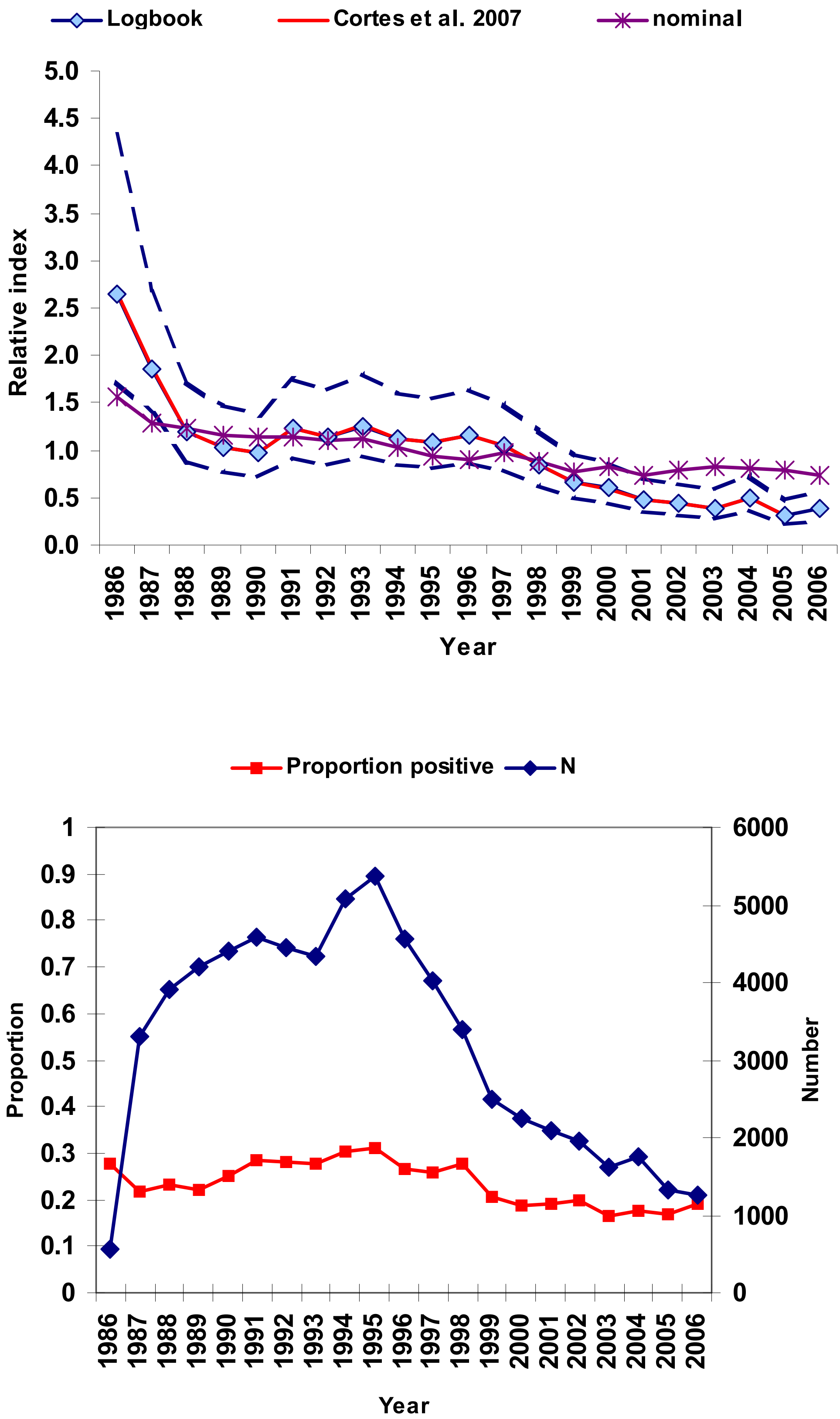


Figure 2. Standardized CPUE (in number) and 95% confidence intervals for blue shark from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample size by year.

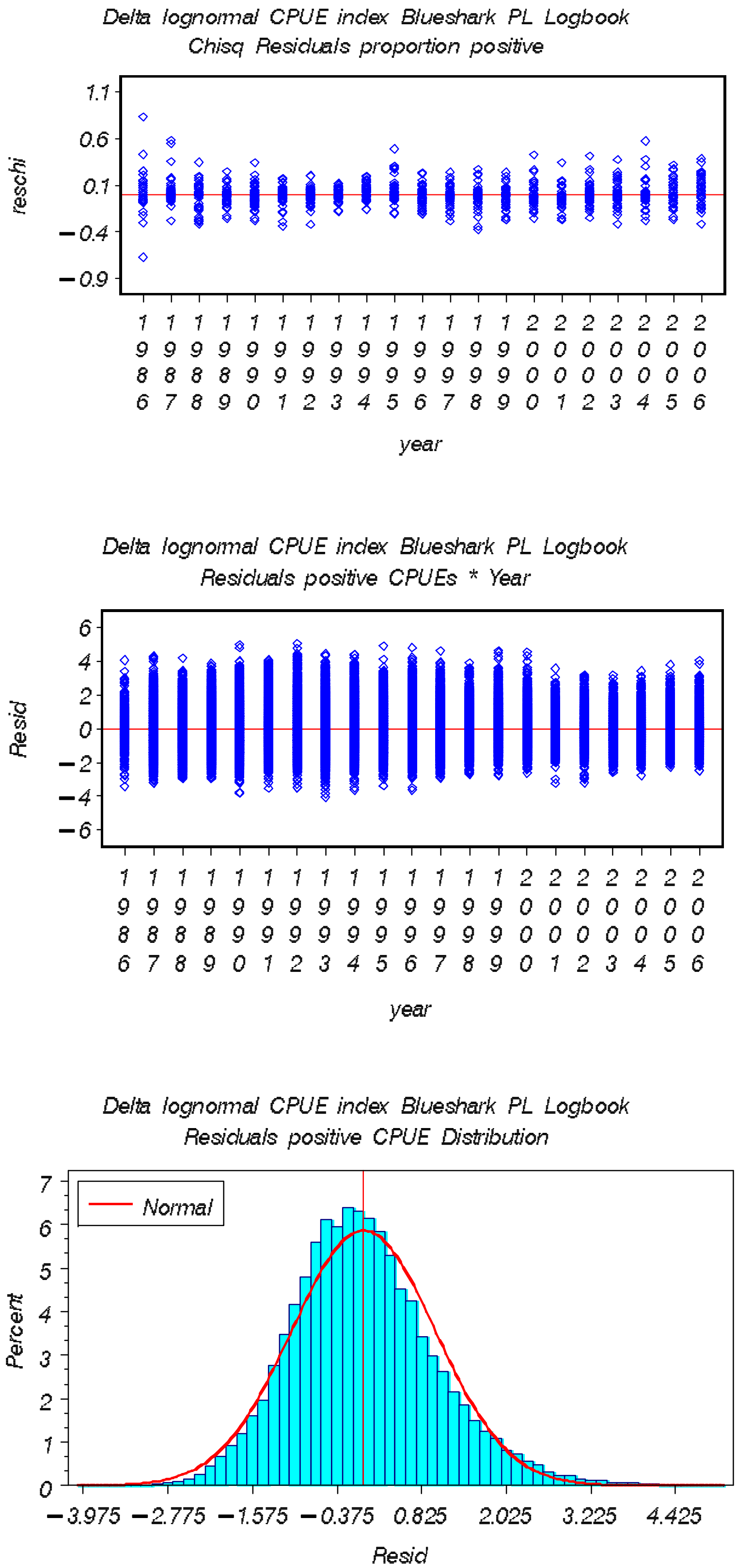


Figure 3. Diagnostic plots of CPUE model from logbook data for blue shark.
Top: residuals of proportion positive sets; middle: residuals of positive catch;
Bottom: residual positive catch distribution

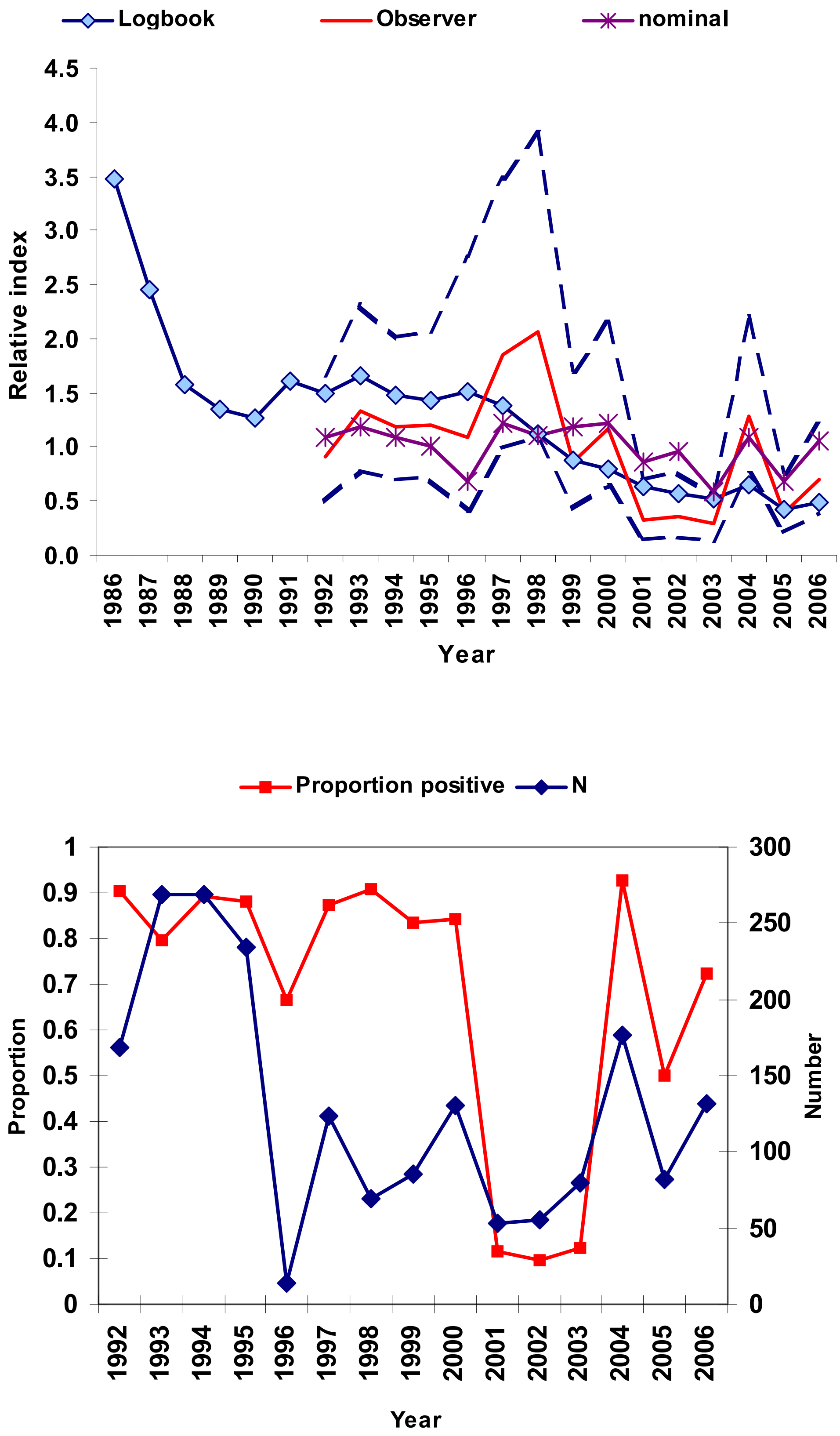


Figure 4. Standardized CPUE (in number) and 95% confidence intervals for blue shark from the pelagic longline observer program compared to the pelagic longline logbook. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample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

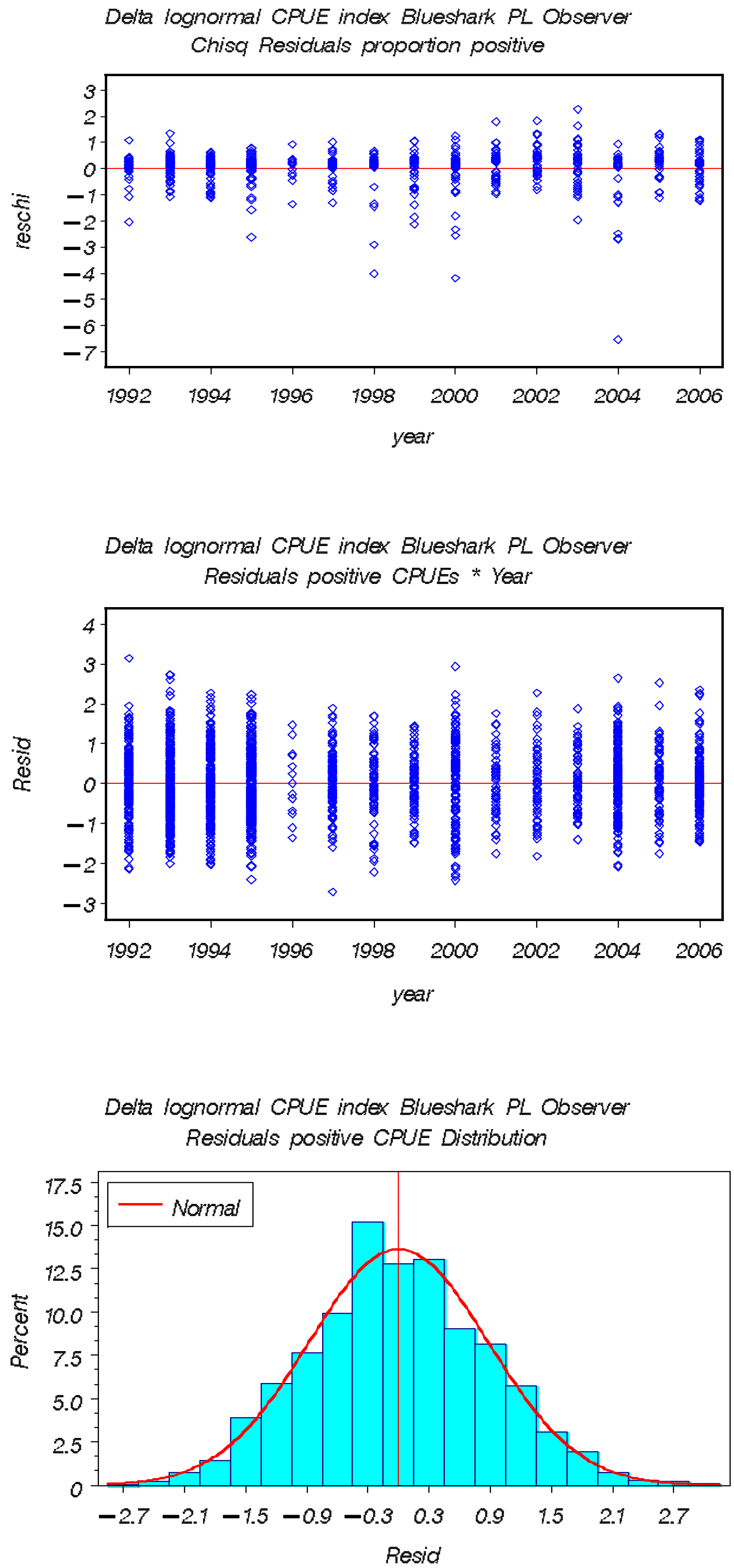


Figure 5. Diagnostic plots of CPUE model from observer data for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; Bottom: residual positive catch distribution

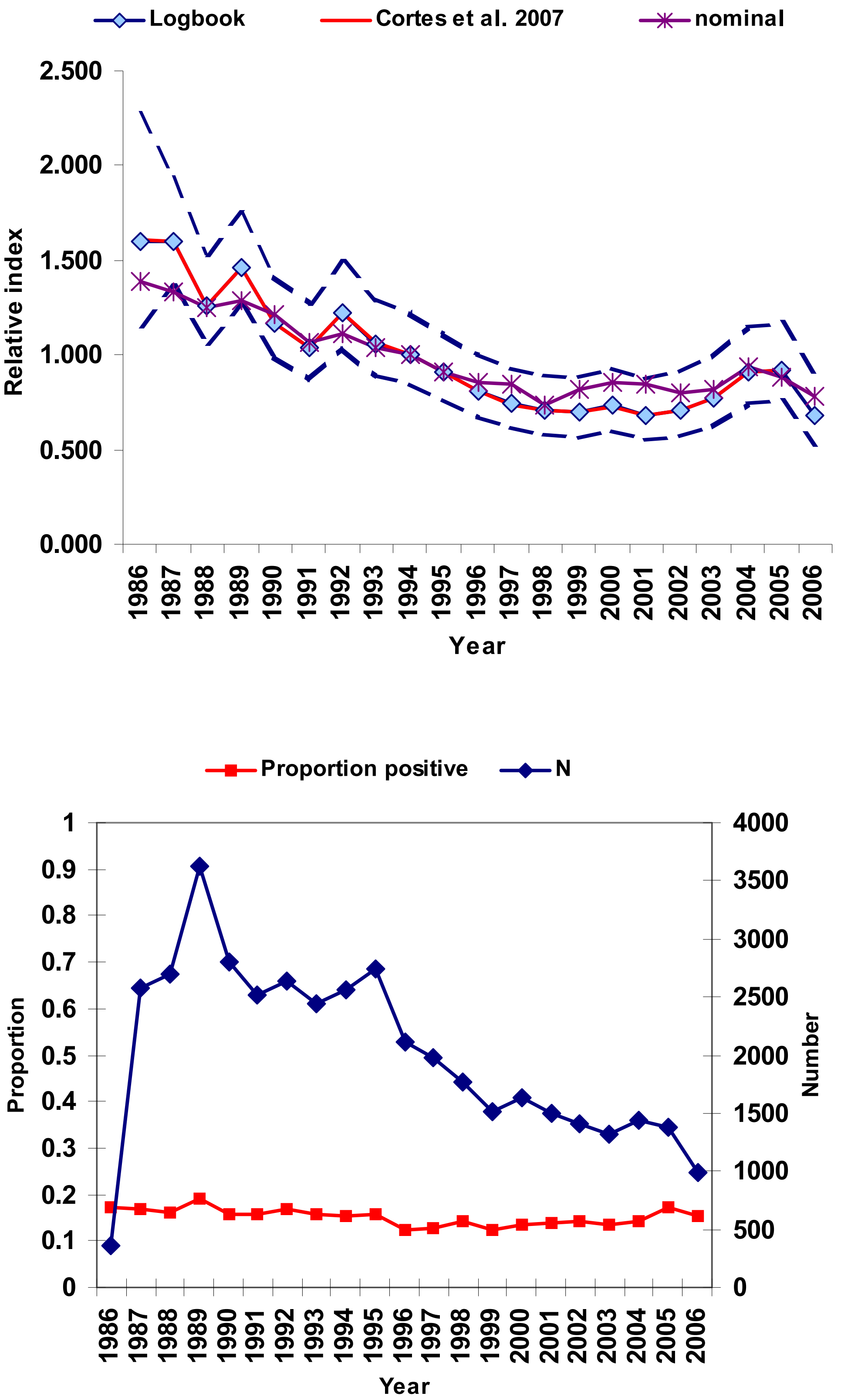


Figure 6. Standardized CPUE (in number) and 95% confidence intervals for mako sharks from the pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample size by year.

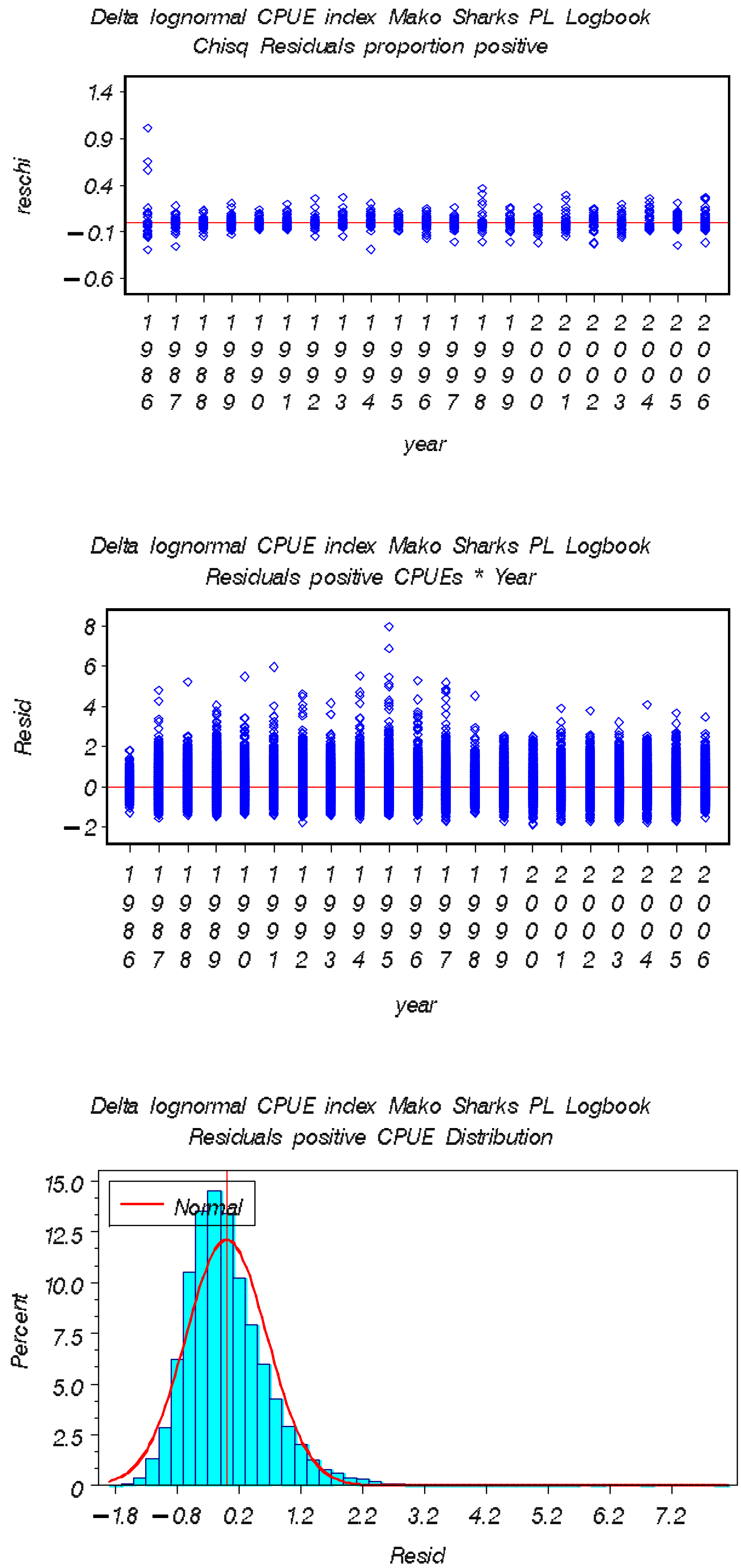
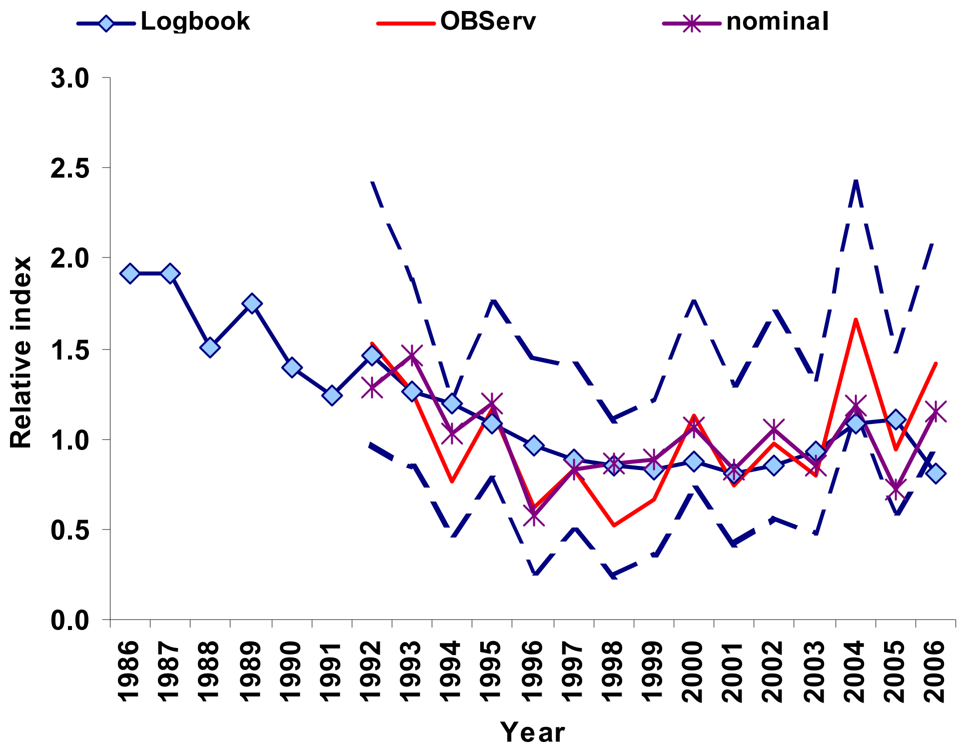


Figure 7. Diagnostic plots of CPUE model from logbook data for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; Bottom: residual positive catch distribution.



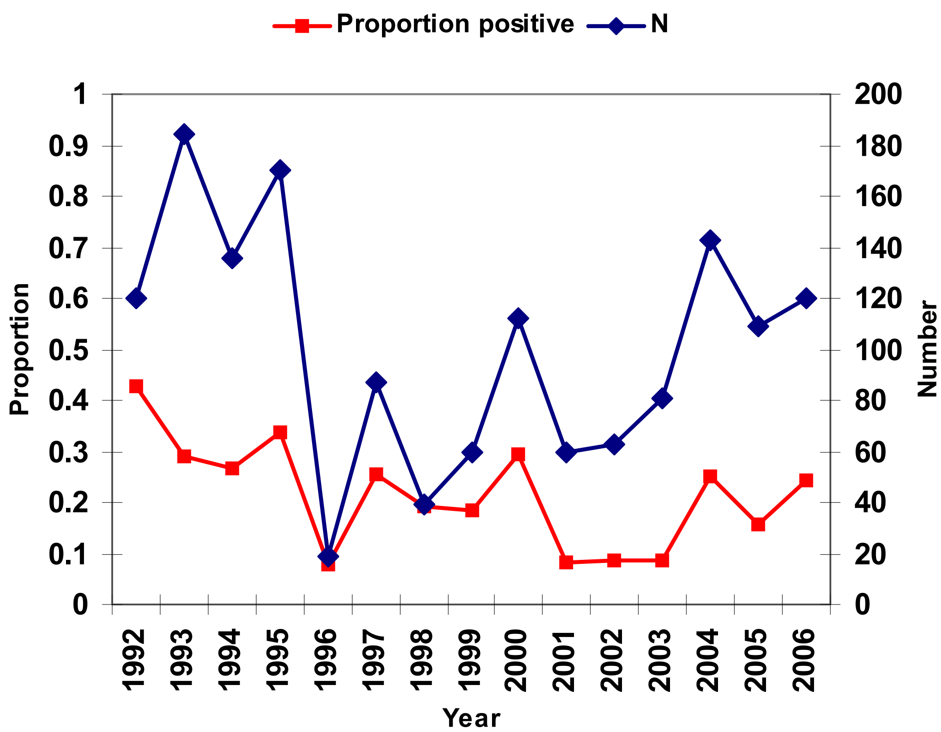


Figure 8. Standardized CPUE (in number) and 95% confidence intervals for mako sharks from the pelagic longline observer program compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion of positive sets and sample size by year.

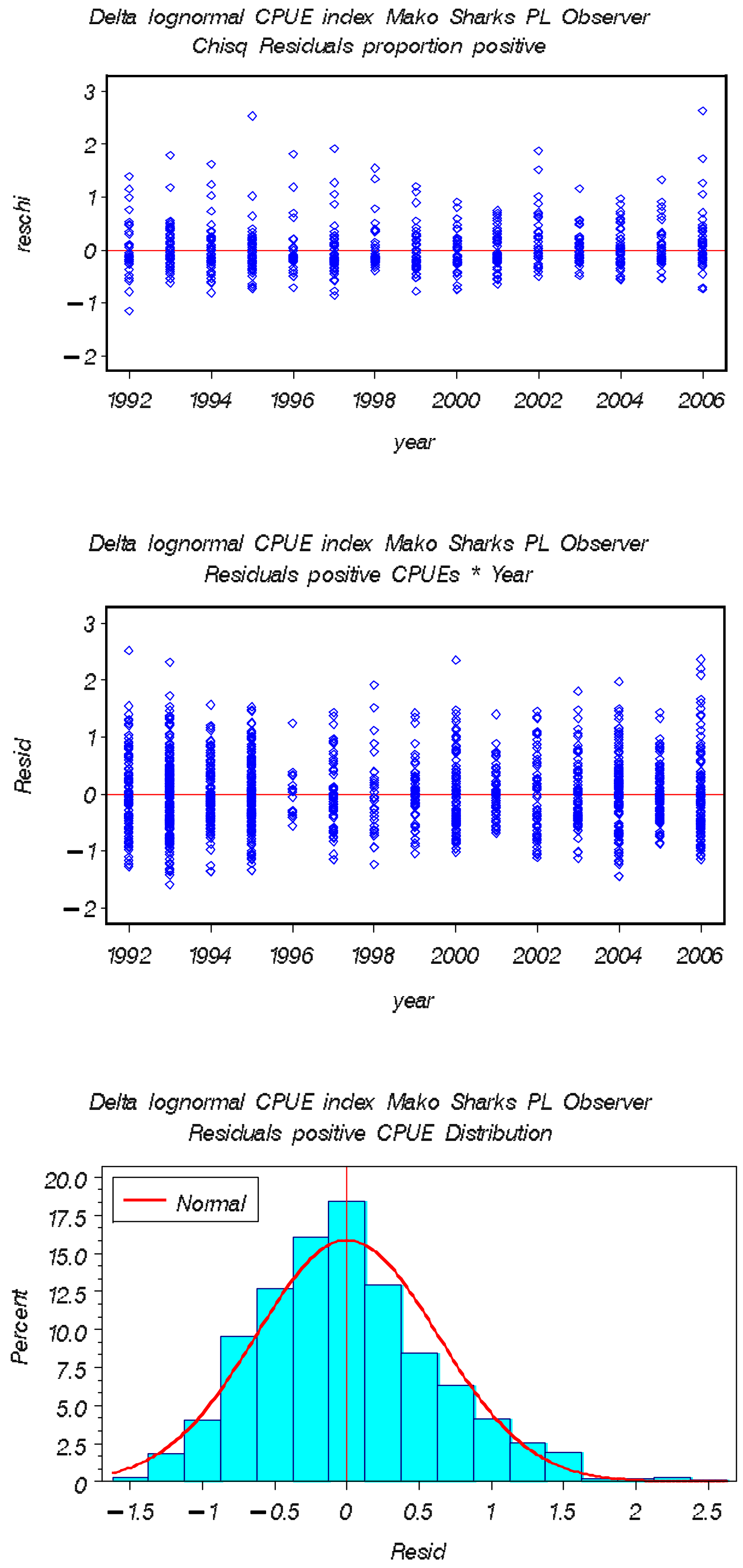


Figure 9. Diagnostic plots of CPUE model from observer data for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; Bottom: residual positive catch distribution.