STANDARDIZED CATCH RATES OF BLUE SHARKS IN THE WESTERN NORTH ATLANTIC OCEAN 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*) from two commercial sources, the US pelagic longline logbook program (1986-2013) and the US pelagic longline observer program (1992-2013). 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 a decreasing trend, dominated by a steep decline in the first few years of data, until the mid-2000s, followed by an increasing trend thereafter. The observer time series also showed a decreasing trend from 1992 to 2003, followed by an increasing tendency thereafter.*

RÉSUMÉ

*Des indices mis à jour d'abondance ont été élaborés pour le requin peau bleue (*Prionace glauca*) à partir de deux sources commerciales, le programme de carnets de pêche des palangriers pélagiques des États-Unis (1986-2013) et le programme d'observateurs à bord de palangriers pélagiques des États-Unis (1992-2013). Les indices ont été calculés en utilisant une approche delta log normale en deux étapes qui traite séparément la proportion d'opérations positives et la CPUE de captures positives. Les indices standardisés avec des intervalles de confiance de 95 % sont déclarés. La série temporelle des carnets de pêche affichait une tendance décroissante, marquée par une forte baisse au cours des toutes premières années de données jusqu'à la moitié de la première décennie 2000, avant de connaître une tendance à la hausse par la suite. La série temporelle des observateurs présentait également une tendance décroissante de 1992 à 2003, suivie d'une tendance à la hausse par la suite.*

RESUMEN

*Se desarrollaron índices de abundancia actualizados para la tintorera (*Prionace glauca*) a partir de dos fuentes comerciales, el programa de cuadernos de pesca del palangre pelágico estadounidense (1986-2013) y el programa de observadores de palangre pelágico estadounidense (1992-2013). Los índices se calcularon utilizando un enfoque delta-lognormal de dos fases que trata la proporción de lances positivos y la CPUE de las capturas positivas por separado. Se comunican los índices estandarizados con intervalos de confianza del 95%. La serie temporal de cuadernos de pesca presenta una tendencia descendente, dominada por un brusco descenso en los primeros años de datos, hasta mediados de 2000, seguida de una tendencia creciente desde entonces. La serie temporal de observadores presentaba también una tendencia descendente desde 1992 a 2003, seguida de una tendencia creciente desde entonces.*

KEYWORDS

Catch/effort, commercial fishing, longlining, pelagic fisheries, shark fisheries, by-catch, logbooks, observer programs, blue shark

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1. Introduction

Relative abundance indices from the US commercial pelagic longline fishery were generated and used in the 2004 and 2008 ICCAT assessments of blue and shortfin mako sharks (Anon. 2005, 2009). In this document, commercial series are updated to examine recent trends in abundance of blue sharks and for use in the 2015 stock assessment of the North Atlantic stock. Indices of abundance for blue sharks from these sources were previously developed by Brooks *et al*. (2005), Cortés (2007; 2009), 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 (**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 US pelagic longline logbooks were available for 1986-2013, and those from the US pelagic longline observer program, for 1992-2013. The observer dataset was restricted to areas 5, 6, and 7 (north of 35º North latitude) owing to insufficient and unbalanced observations by year in the remaining areas (**Figure 2**).

Based on the methodology used in Brooks *et al*. (2005), Cortés (2007, 2009), and Cortés *et al*. (2007), the following factors were considered in the analysis: 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 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).

Additionally, we examined trends in length and length-frequency distributions of blue sharks recorded in the US pelagic longline observer program.

3. Results

Logbook data—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, quarter, year, year*area, and year*quarter were retained (**Table 1**). The factor area explained 95% and 82% of the deviance for the proportion positive and positive catches, respectively (Appendix **Table 1**). The estimated annual mean CPUE and CV values are given in **Table 2**. As expected, the updated index tracks very closely that developed by Cortés (2009), and shows an increasing trend from 2007 to 2013. In all, the entire time series showed a 76% decline since 1986, corresponding to a mean instantaneous rate of change in abundance per year (r) of –0.053 (95% confidence interval [CI]:-0.142 to +0.036; **Figure 3**). 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 3**). From 1989 to 1993, the series increased then slowly declined until 2005, after which it showed an upward trend until the most recent year of data, 2013. The nominal series showed a flatter trend, especially since the late 1990s. Diagnostic plots showed good agreement with model assumptions and there were no apparent, systematic patterns in the residuals (**Figure 4**).

Observer data—In the analysis of the observer data, factors retained for the blue shark proportion of positive sets were Sqr, year, Tqr, area, quarter, and experiment; and for the positive catches, the factors area, quarter, year, Tqr, Sqr, year*area, year*quarter, and Sqr*area were retained (**Table 3**). The factor Sqr and the factor area explained 73% and 62% of the deviance for the proportion positive and positive catches, respectively (Appendix **Table 2**). The estimated annual mean CPUE and CV values are given in **Table 4**. The observer index showed essentially no change when comparing the 2013 value to that for 1992 (r=-0.001; 95% CI:-0.335 to +0.334) and much larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years (**Figure 5**). The sharper interannual fluctuations in the observer index may be due to the smaller sample size (observer coverage on pelagic longline vessels averages 7% annually; **Figure 2**). 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 5**). Diagnostic plots showed some patterns in the residuals of the proportion positive sets (**Figure 6**).

Trends in size—A scatter plot of individual lengths of blue sharks measured in the pelagic longline observer program revealed no trend over the time period considered (**Figure 7**). Time series of average lengths for males, females, or sexes combined also failed to reveal any marked pattern (**Figure 8**). Based on reported lengths at maturity of 230-249 cm TL for males and 221 cm TL for females, corresponding to fork lengths of 193-208 cm and 185 cm, respectively (Anon. 2015), length-frequency distributions revealed that most animals encountered were immature (**Figure 9**).

4. Discussion

Trends in relative abundance predicted from analysis of the logbook dataset and the observer dataset were similar, with both series showing a concave shape, consisting of an initial decline to about the mid-2000s, followed by an increasing trend thereafter. 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 and tighter CIs. Sharp interannual changes in abundance, such as those displayed by the observer series 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 blue sharks because pelagic longline fisheries have not traditionally targeted them, and catch rates used here are based on total catch (the sum of animals kept, discarded dead and released alive).

Several issues that may affect the U.S. 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). Identification is not an issue in this case because this species can easily be distinguished from other pelagic sharks. 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 have affected the index, but the increase in catch rates shown by both indices in the past decade seems to argue against that. 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 blue 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.

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

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	341537	374024	-187012
Final model			
AREA SQR YEAR	341527	249548	-124774

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	80932	152171	-140389
Final model			
AREA QUARTER YEAR YEAR*AREA YEAR*QUARTER	80626	78896	-113807

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

Year	Standardized CPUE	CV	Nominal CPUE
1986	19.622	0.221	3.579
1987	13.362	0.169	2.979
1988	9.011	0.168	2.817
1989	7.273	0.168	2.683
1990	7.586	0.167	2.616
1991	9.098	0.167	2.638
1992	8.842	0.167	2.544
1993	9.519	0.167	2.575
1994	7.98	0.166	2.365
1995	7.167	0.166	2.135
1996	7.7	0.166	2.057
1997	7.662	0.167	2.260
1998	6.076	0.168	2.013
1999	4.259	0.170	1.773
2000	3.903	0.172	1.897
2001	3.202	0.172	1.705
2002	3.044	0.174	1.798
2003	2.802	0.177	1.899
2004	3.364	0.175	1.858
2005	2.298	0.179	1.797
2006	2.540	0.181	1.712
2007	2.992	0.182	1.915
2008	3.383	0.174	1.757
2009	4.445	0.174	1.886
2010	5.829	0.175	1.957
2011	5.628	0.175	1.994
2012	3.691	0.176	1.824
2013	4.700	0.174	1.799

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

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	5763	7768	-3884
Final model SQR YEAR TQR AREA QUARTER EXPERIMENT	5729	3629	-1814

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	3446	6000	-5846
Final model AREA QUARTER YEAR TQR SQR YEAR*AREA YEAR*QUARTER SQR*AREA	3303	2787	-4525

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

Year	Mean CPUE	CV	Nominal CPUE
1992	7.455	0.314	0.827
1993	11.076	0.291	0.921
1994	9.717	0.289	0.844
1995	10.170	0.292	0.778
1996	8.208	0.503	0.525
1997	14.439	0.330	0.941
1998	18.408	0.346	0.862
1999	6.663	0.342	0.918
2000	9.541	0.319	0.949
2001	2.306	0.393	0.665
2002	2.277	0.394	0.748
2003	1.876	0.366	0.452
2004	9.503	0.297	0.849
2005	3.193	0.345	0.525
2006	4.674	0.310	0.819
2007	9.645	0.324	0.816
2008	8.512	0.321	0.727
2009	8.322	0.312	0.795
2010	13.545	0.308	0.830
2011	21.806	0.294	1.000
2012	8.128	0.336	0.615
2013	7.374	0.305	0.753

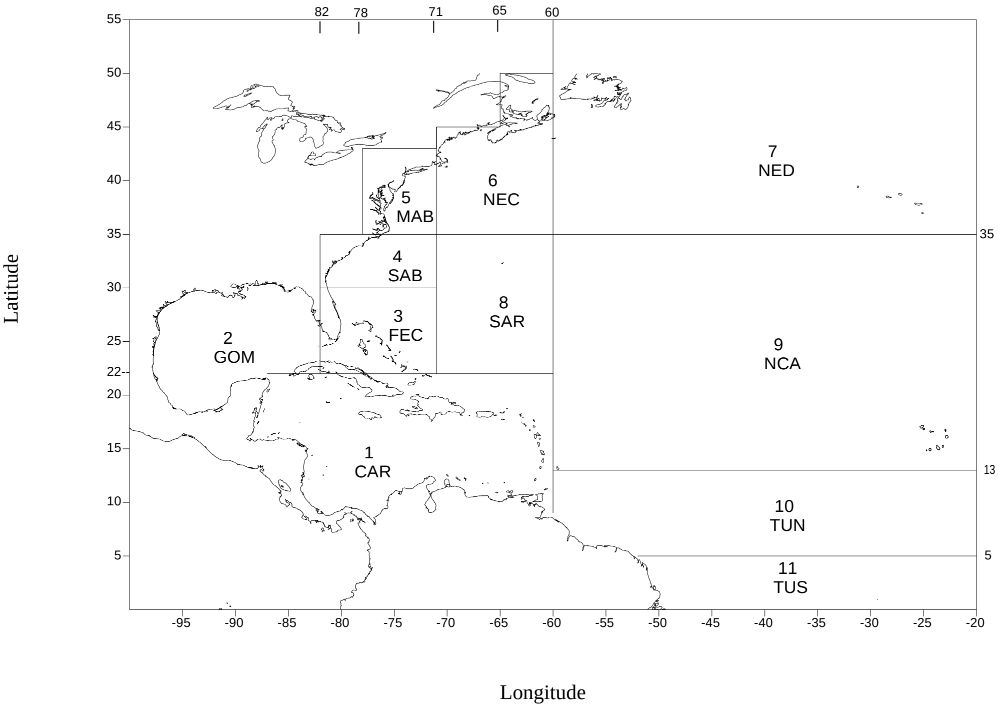


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean; 2) Gulf of Mexico;3) Florida East Coast; 4) South Atlantic Bight; 5) Mid Atlantic Bight; 6) Northeast Coastal; 7) Northeast Distant; 8) Sargasso; 9) North Central Atlantic; 10) Tuna North; 11) Tuna South.

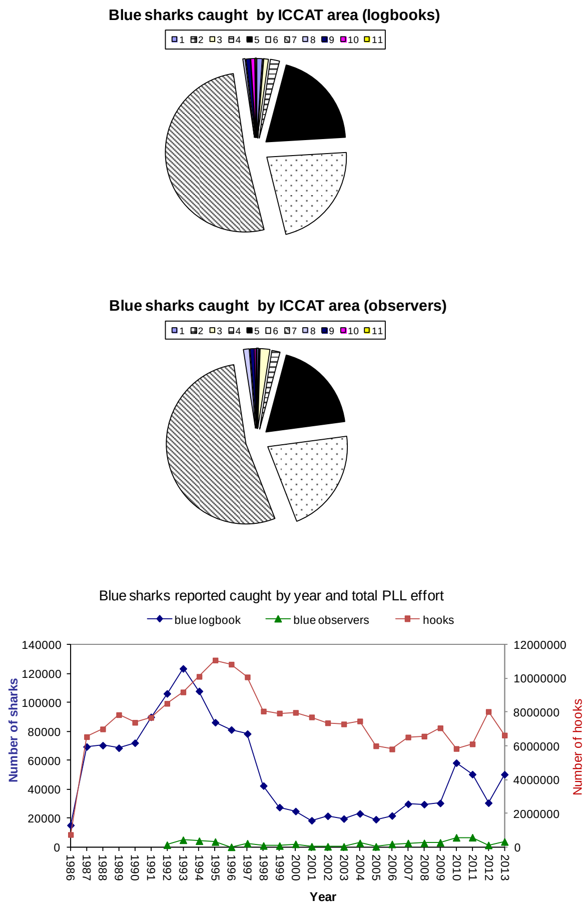
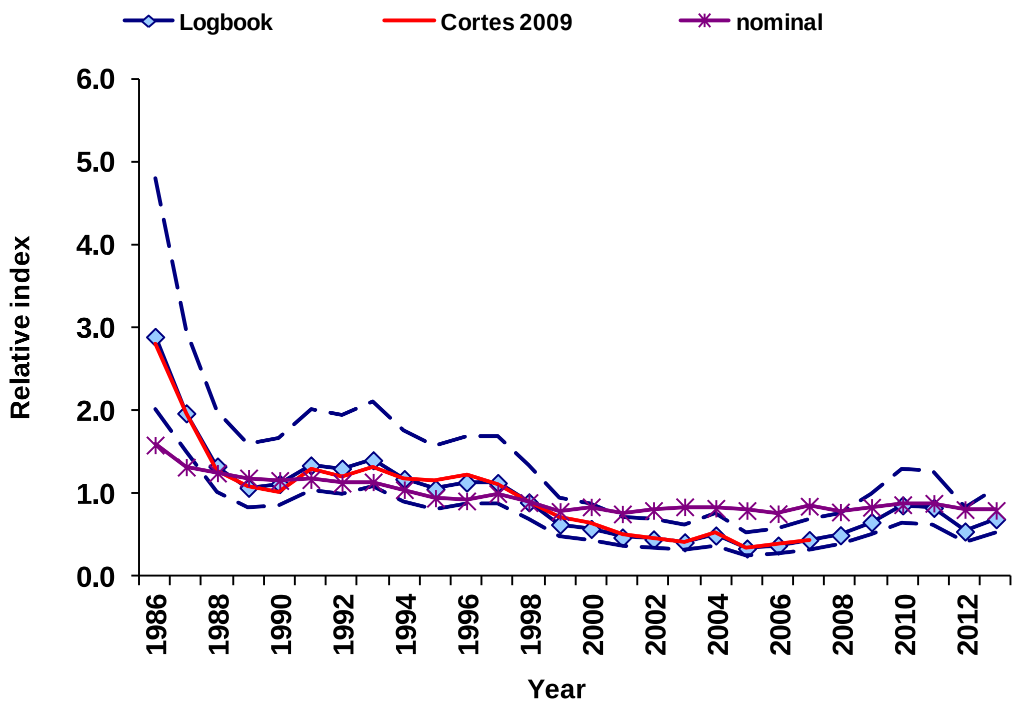


Figure 2. Blue sharks caught by ICCAT area as reported in the pelagic longline logbook (top) and observer (middle) programs. Blue sharks caught by year in all areas from both programs relative to total effort are shown in the bottom panel.



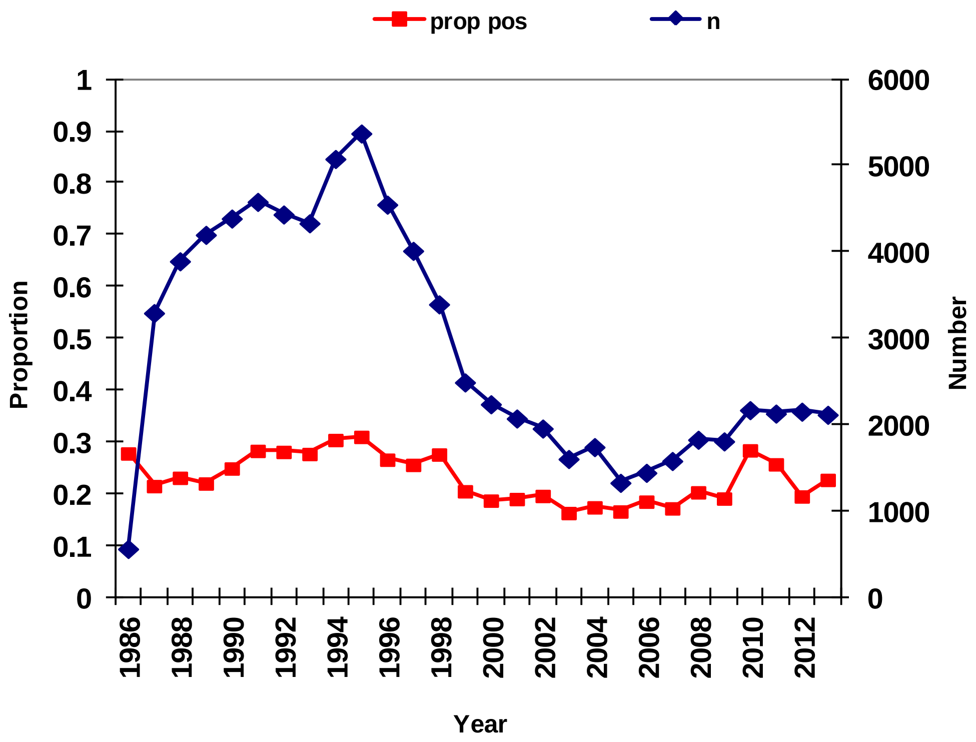


Figure 3. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for blue shark from the US pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

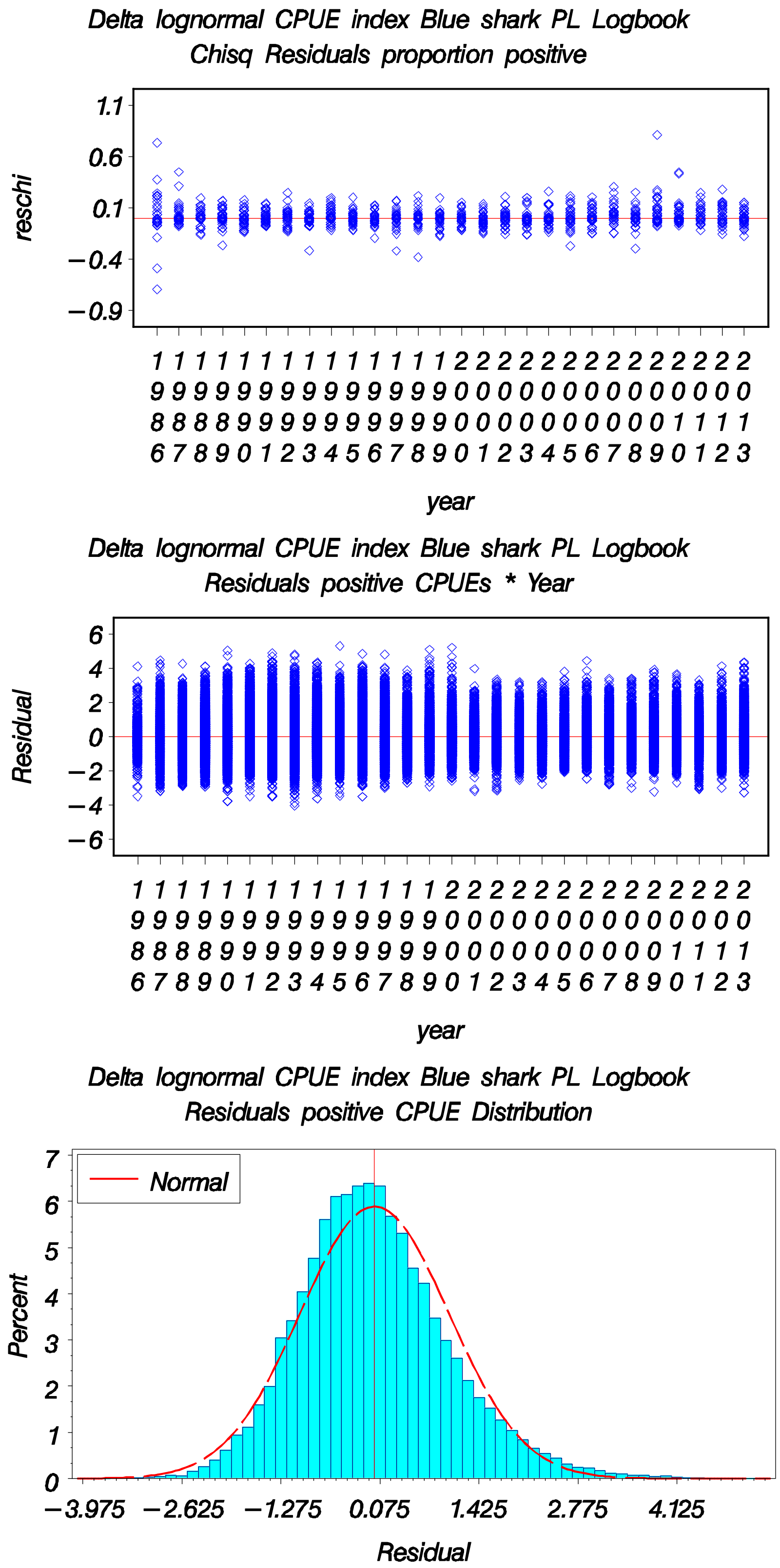
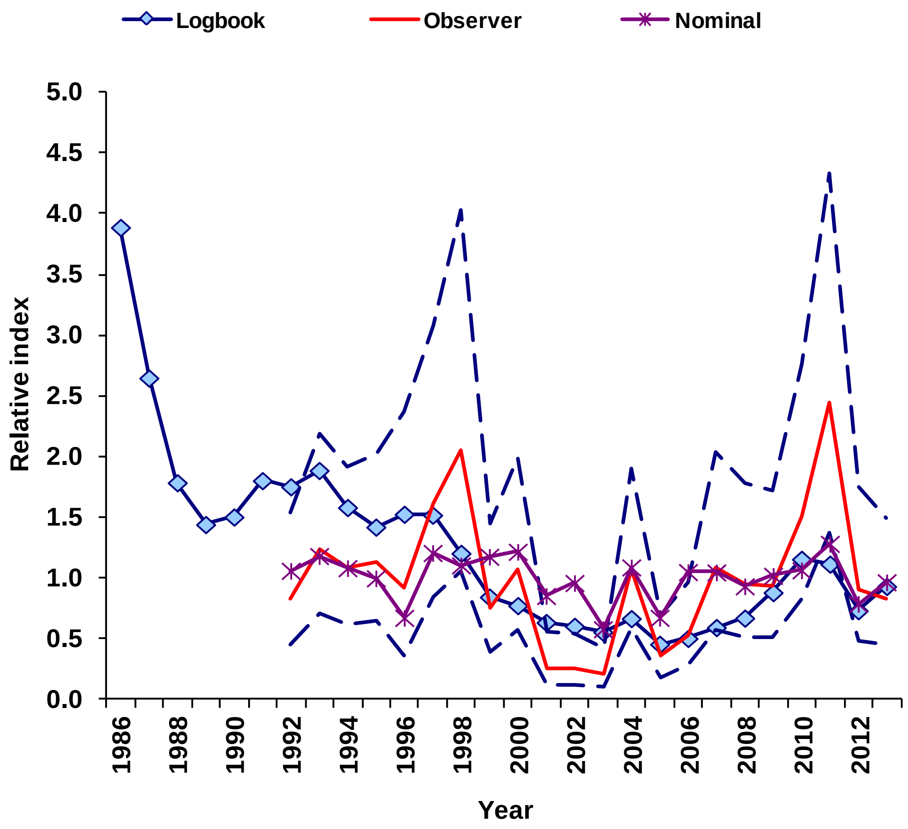


Figure 4. Diagnostic plots of CPUE model from US pelagic longline logbook data for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.



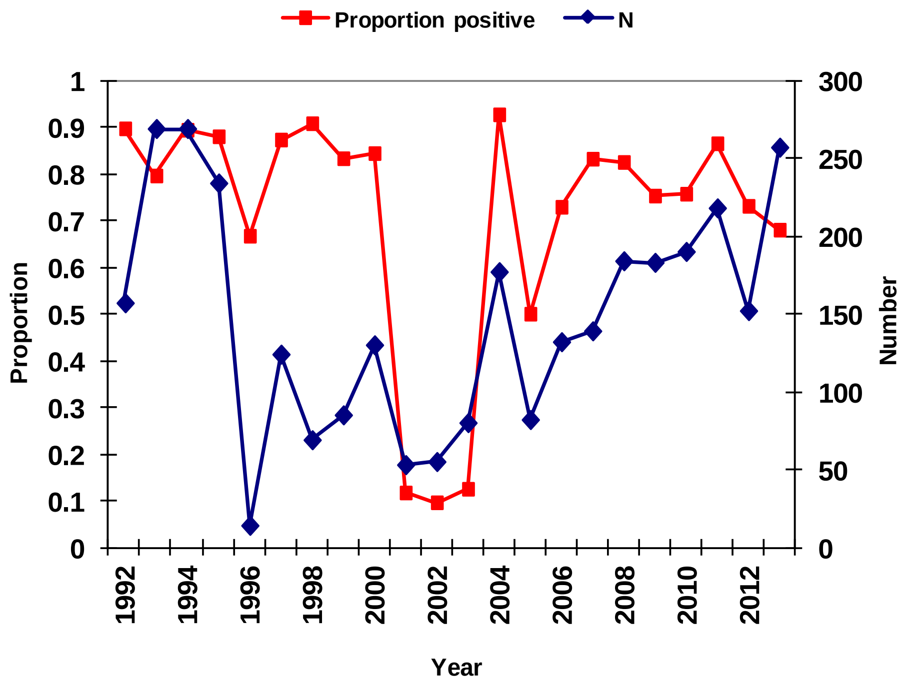


Figure 5. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for blue shark from the US pelagic longline observer program compared to the logbook program. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

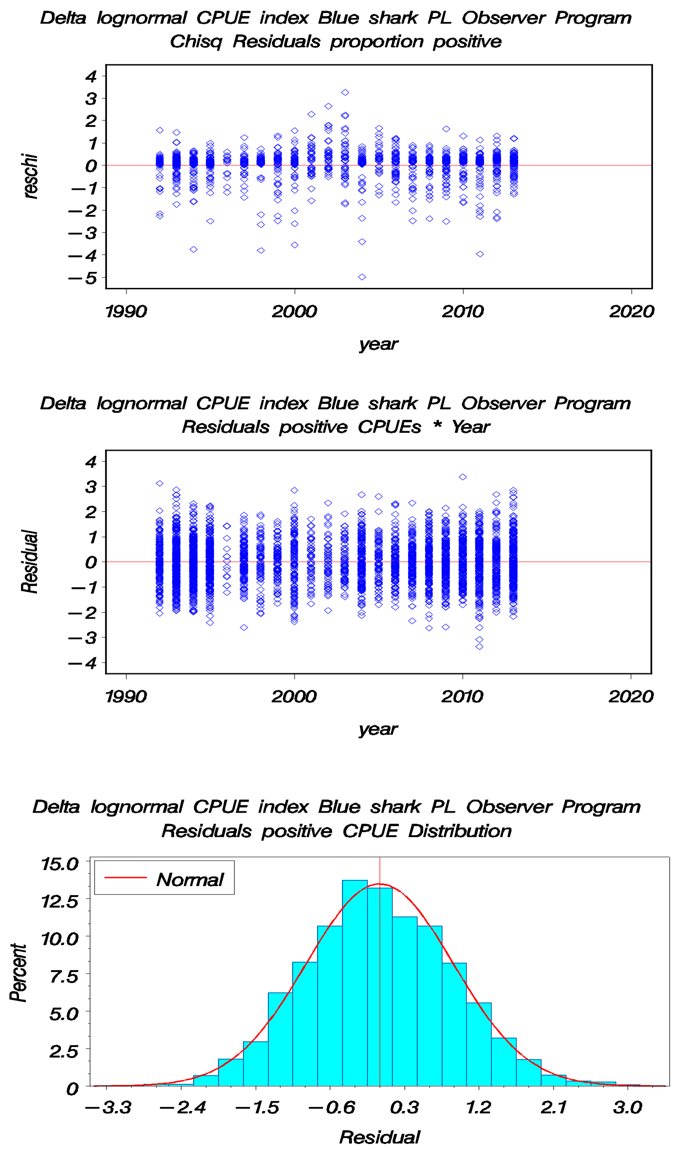


Figure 6. Diagnostic plots of CPUE model from US pelagic longline observer data for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

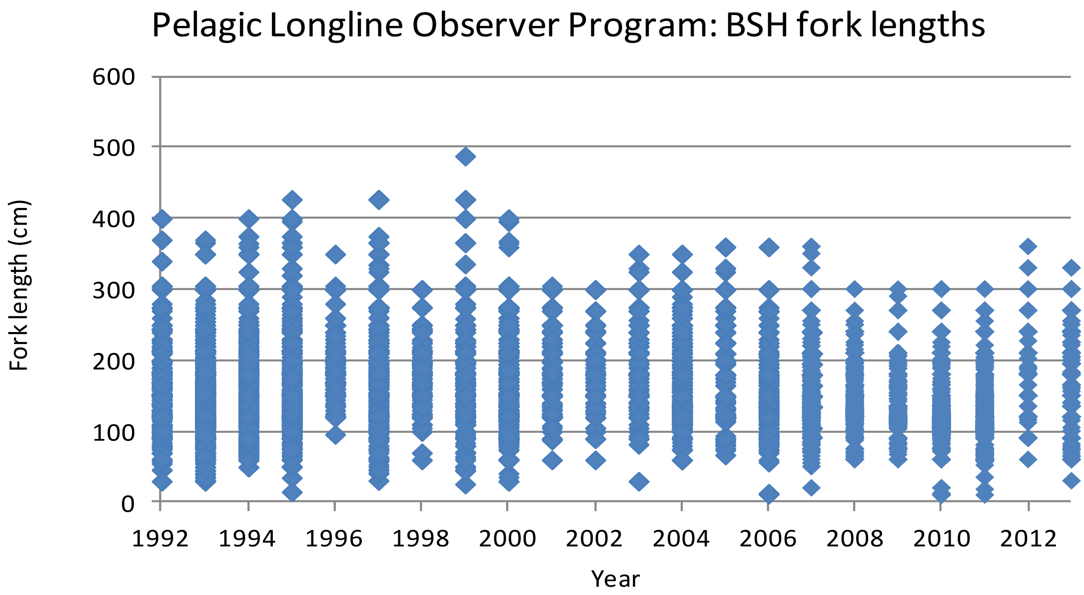
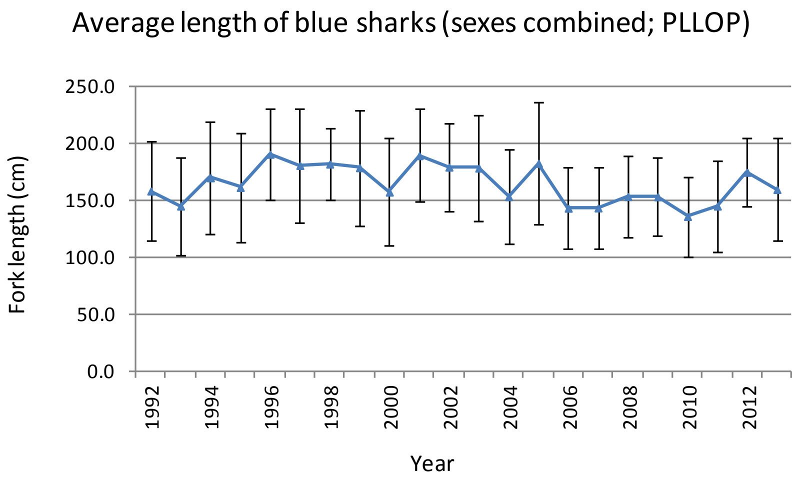
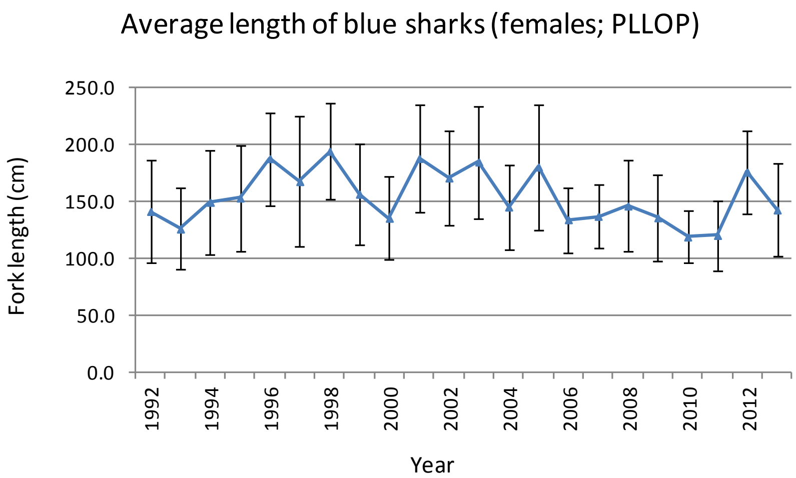


Figure 7. Scatter plot of blue shark lengths from the Pelagic Longline Observer Program, 1992-2013.





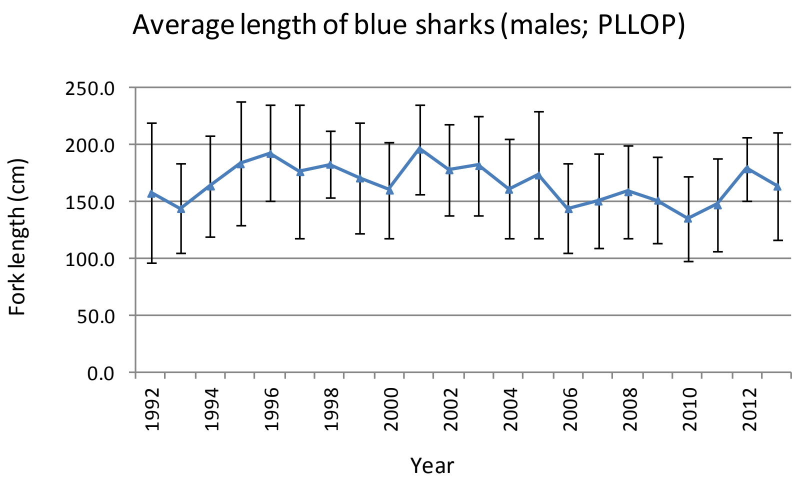


Figure 8. Average lengths of blue sharks from the Pelagic Longline Observer Program, 1992-2013. Error bars are ±1 SD.

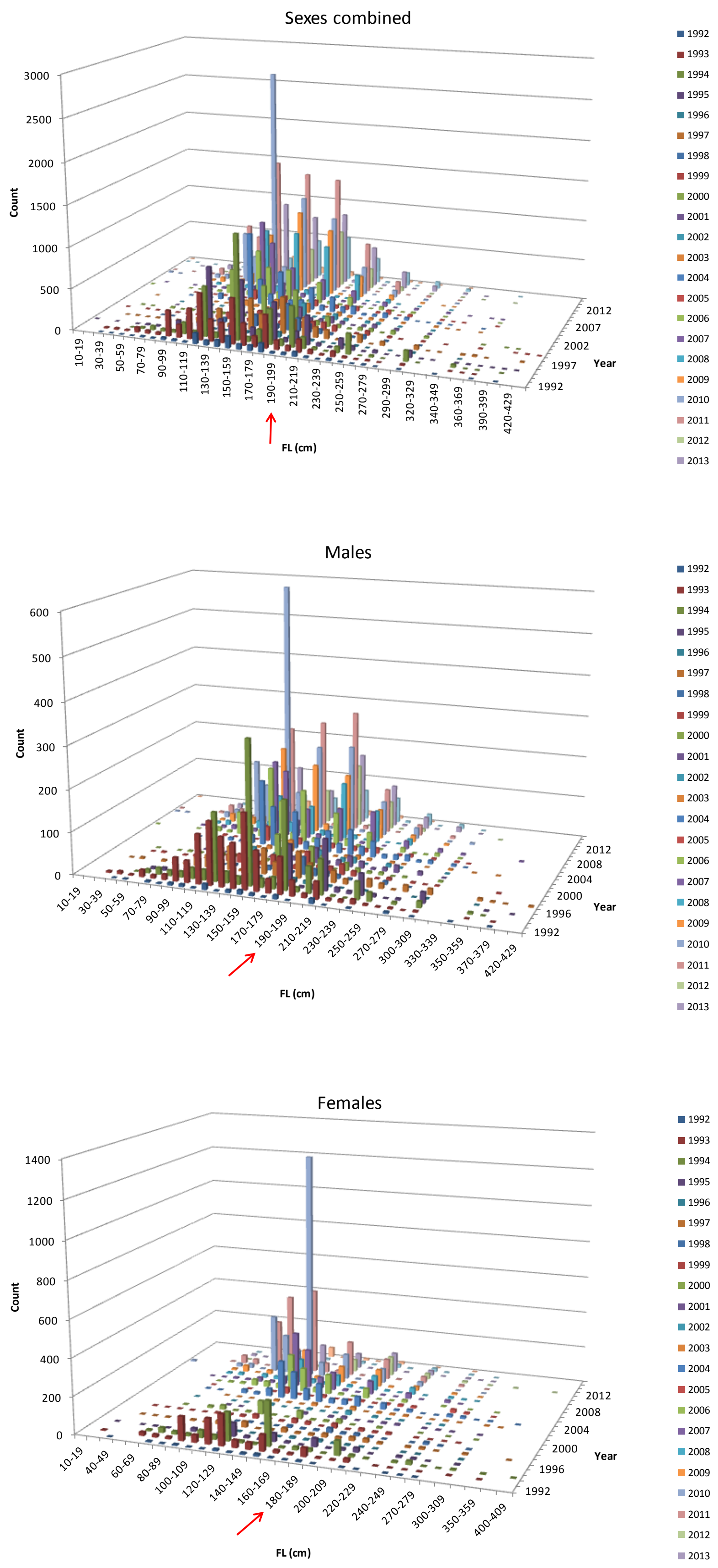


Figure 9. Length frequencies of blue sharks from Pelagic Longline Observer Program, 1992-2013. The arrows indicate approximate size at maturity.

Appendix table 1. Deviance analysis table of explanatory variables in the delta lognormal model for blue 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	% reduction	% of total deviance	*p*
Null		374024				
Area	7	254064	119960	32.10%	94.9%	< 0.0001
Area Sqr	3	249548	4516	1.78%	3.6%	< 0.0001
Area Sqr Year	27	247615	1933	0.77%	1.5%	< 0.0001

Model factors positive catch rates	d.f.	Residual deviance	Change in deviance		% of total deviance	*p*
Null		152170				
Area	7	92427	59743	39.26%	81.5%	< 0.0001
Area Quarter	3	88017	4410	4.77%	6.0%	< 0.0001
Area Quarter Year	27	85269	2748	3.09%	3.8%	< 0.0001
Area Quarter Year Year*Area	189	79894	5375	6.08%	7.3%	< 0.0001
Area Quarter Year Year*Area Year*Quarter	80	78896	998	1.15%	1.4%	< 0.0001

GLM Mixed Model	deviance	AIC	BIC
Proportion Positives			
Area Sqr Year	2258	2260	2264
Positive catch rates			
Area Quarter Year Year*Area Year*Quarter	230169	230175	230185

Appendix table 2. Deviance analysis table of explanatory variables in the delta lognormal model for blue shark catch rates (number of fish per 1000 hooks) from the US pelagic longline fishery observer program. 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		7768				
Sqr	3	4750	3018	38.81%	72.9%	< 0.0001
Sqr Year	22	3953	797	16.47%	19.3%	< 0.0001
Sqr Year Tqr	3	3790	163	4.08%	3.9%	< 0.0001
Sqr Year Tqr Area	2	3730	60	1.54%	1.4%	< 0.0001
Sqr Year Tqr Area Quarter	3	3678	52	1.33%	1.3%	< 0.0001
Sqr Year Tqr Area Quarter Experiment	1	3629	49	1.32%	1.2%	< 0.0001

Model factors positive catch rates	d.f.	Residual deviance	Change in deviance		% of total deviance	*p*
Null		6000				
Area	2	4023	1977	32.91%	61.9%	< 0.0001
Area Quarter	3	3667	356	8.77%	11.2%	< 0.0001
Area Quarter Year	22	3402	265	6.64%	8.3%	< 0.0001
Area Quarter Year Tqr	3	3349	53	1.46%	1.7%	< 0.0001
Area Quarter Year Tqr Sqr	3	3298	51	1.45%	1.6%	< 0.0001
Area Quarter Year Tqr Sqr Year*Area	38	3043	255	6.67%	8.0%	< 0.0001
Area Quarter Year Tqr Sqr Year*Area Year*Quarter	60	2864	179	4.18%	5.6%	< 0.0001
Area Quarter Year Tqr Sqr Year*Area Year*Quarter Sqr*Area	6	2808	56	1.78%	1.8%	< 0.0001

GLM Mixed Model	deviance	AIC	BIC
Proportion Positives			
Sqr Year Tqr Area Quarter Experiment	5917	5919	5925
Positive catch rates			
Area Quarter Year Tqr Sqr Year*Area Year*Quarter Sqr*Area	8592	8598	8604