

## STOCK STATUS INDICATORS OF MAKO SHARKS IN THE WESTERN NORTH ATLANTIC OCEAN BASED ON THE US PELAGIC LONGLINE LOGBOOK AND OBSERVER PROGRAMS

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### SUMMARY

*Two stock status indicators were examined for mako sharks (Isurus spp.) encountered by the US pelagic longline fleet. First, standardized indices of relative abundance were developed from data in the US pelagic longline logbook (1986-2015) and observer (1992-2015) programs. Indices were calculated using a two-step delta-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately. Observations affected by fishing regulations (time-area closures or bait restrictions) were subsequently excluded in a restricted analysis. The logbook time series showed a concave shape from the beginning of the series in the mid-1980s to 2009-2010, followed by a downward trend thereafter. The observer time series also showed a concave shape from the beginning of the series in the early 1990s to 2011, followed by a declining trend thereafter. Overall, the logbook index did not show a substantial change in relative abundance since the late 1990s and the observer index showed a generally increasing tendency since the mid-1990s. No discernible trends in size were detected, suggesting that no specific segment of the population is being disproportionately affected.*

### RÉSUMÉ

*Le présent document examine deux indicateurs de l'état du stock des requins-taupes (Isurus spp.) rencontrés par la flottille palangrière pélagique des États-Unis. Tout d'abord, des indices standardisés d'abondance relative ont été développés à partir des données des programmes américains de carnet de pêche à la palangre pélagique (1986-2015) et d'observateurs palangriers pélagiques (1992-2015). Les indices ont été calculés en utilisant une approche delta log normal de deux étapes qui traite séparément la proportion d'opérations positives et la CPUE de captures positives. Les observations affectées par les réglementations en matière de pêche (fermetures spatiotemporelles ou restrictions concernant les appâts) ont ensuite été exclues dans une analyse restreinte. Les séries temporelles des carnets de pêche ont fait apparaître une forme concave depuis le début de la série au milieu des années 80 à 2009-2010, suivie d'une tendance à la baisse par la suite. Les séries temporelles des observateurs ont également fait apparaître une forme concave depuis le début de la série au début des années 90 à 2011, suivie d'une tendance à la baisse par la suite. Dans l'ensemble, l'indice des carnets de pêche n'a pas montré de changement substantiel dans l'abondance relative depuis la fin des années 90, et l'indice des observateurs a montré une tendance généralement croissante depuis le milieu des années 90. Aucune tendance perceptible dans la taille n'a été détectée, ce qui suggère qu'aucun segment spécifique de la population n'est affecté de manière disproportionnée.*

### RESUMEN

*Se examinaron dos indicadores del estado del stock para los marrajos (Isurus spp.) que encuentra la flota de palangre pelágico de Estados Unidos. En primer lugar, los índices de abundancia relativa estandarizados se desarrollaron a partir de los datos de los programas de cuadernos de pesca (1986-2015) y de observadores (1992-2015) del palangre pelágico de Estados Unidos. Los índices se calcularon utilizando un enfoque delta-lognormal de dos etapas que trata la proporción de lances positivos y la CPUE de las capturas positivas por separado. Las observaciones que se vieron afectadas por las reglamentaciones pesqueras (vedas espaciotemporales o restricciones al cebo) fueron posteriormente excluidas en un análisis restringido.*

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*La serie temporal de los cuadernos de pesca presentaba una forma cóncava desde el inicio de la serie temporal a mediados de los ochenta hasta 2009-2010, seguida de una tendencia descendente desde entonces. La serie temporal de los observadores presentaba también una forma cóncava desde el inicio de la serie temporal a principios de los noventa hasta 2011, seguida de una tendencia descendente desde entonces. En general, el índice de los cuadernos de pesca no presentaba un cambio sustancial en la abundancia relativa desde finales de los noventa, y el índice de observadores presentaba una tendencia generalmente creciente desde mediados de los noventa. No se detectaron tendencias discernibles en la talla, lo que sugiere que ningún segmento específico de la población se está viendo afectado de forma desproporcionada.*

## KEYWORDS

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

## 1. Introduction

Relative abundance indices from the US commercial pelagic longline fishery were produced and used in the 2004, 2008, and 2012 ICCAT assessments of shortfin makos (ICCAT 2005, 2009, 2013). In this document, commercial series are updated to examine recent trends in relative abundance of mako sharks as indicators of stock status and for input into the 2017 stock assessment. Indices of abundance for mako sharks from these sources were previously developed by Brooks et al. (2005), Cortés (2007; 2009; 2013; 2016), and Cortés et al. (2007). Trends in average length from the pelagic longline observer program are also examined.

## 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 1986-2015, and those from the US pelagic longline observer program, for 1992-2015. Both shortfin (mostly) and longfin makos (*Isurus paucus*) were included in the logbook analysis owing to mis-identification problems in the early years of the time series. Shortfin (n=7,087) and some unidentified makos (n=768) were included in the observer analysis as the latter are likely to be shortfin makos (only 492 longfin makos were positively identified as such). The observer dataset was restricted to areas 2 (GOM), 5 (MAB), 6 (NEC), and 7 (NED) owing to insufficient and unbalanced observations by year in the remaining areas. Areas 2, 5, 6, and 7 accounted for almost 90% of all observations in both the logbook and observer datasets (Fig. 2).

Several data restrictions were implemented in the present analysis to account for time-area closures or bait restrictions following Walter and Laretta (2015). Due to the different effects of spatio-temporal closures in different areas, a single “closure” effect could not be considered because it would likely differ among areas and thus the most parsimonious approach was to exclude data from the entire time series before and after the closure for each area. More specifically, the following data restrictions were applied: (1) the DeSoto Canyon Closed Area in the Gulf of Mexico, closed year-round; (2) the East Florida Coast Closed Area, closed year-round; (3) the Charleston Bump Closed Area, closed February-April; (4) the Northeastern United States Closed Area, closed in June; (5) the Northeast Distant Gear Restricted Area, closed year-round except for specific bait-gear configurations; and (6) the Spring Gulf of Mexico Gear Restricted Areas, closed April-May (Fig.1). The analysis incorporating the data restrictions to account for management regulations is referred to as “restricted analysis”; the analysis with the whole dataset is referred to as “continuity analysis”.

Based on the methodology used in Brooks et al. (2005), Cortés (2007, 2009, 2013, 2016), 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  $-2 \times$  the residual log likelihood ( $-2\text{Res L}$ ). 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. LSMean 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).

Trends in length and the length-frequency distribution were also examined by using records of animals that were brought onboard and measured (fork length, measured in a straight line) by scientific observers from the pelagic longline observer program (observation code=1). No estimated lengths, sometimes recorded by observers, were used.

## 3. Results

**Logbook data**—In the continuity analysis of the logbook data, factors retained for the proportion of positive sets were area, Sqr and year; and for the positive catches, the factors area, Tqr, year, quarter, year\*area, and Tqr\*area were retained (Table 1). The factor area explained 88% and 58% of the deviance for the proportion positive and positive catches, respectively (Appendix Table 1). The estimated annual mean CPUE and CV values are listed in Table 2. The time series showed a 58% decline since 1986 (Fig. 3). The series declined from 1986 to 2001, increased from 2001 to 2009, and decreased again from 2009 to 2015. The earliest years, 1986-1992, and the period 2003-2012 showed the largest fluctuations in the index (Fig. 3). The year 1986 had the lowest number of positive observations of any year ( $n=354$ ), but the proportion of positive sets remained stable throughout the

series, oscillating between 12 and 21%. The nominal series had a somewhat flatter trend than the standardized series, with a lower relative decline from beginning to end (39%) because the data showed an increasing tendency since 2012 compared with the decreasing trend of 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 (58%). Diagnostic plots showed good agreement with model assumptions and there were no clear systematic patterns in the residuals (Fig. 4).

In the restricted analysis, which took into account time-area closures, factors retained for the proportion of positive sets were area, Sqr, quarter, and year; and for the positive catches, the factors area, Tqr, year, quarter, year\*area, Tqr\*area, and Sqr\*area were retained (Table 1). The factor area explained 80% and 41% of the deviance for the proportion positive and positive catches, respectively (Appendix Table 2). The estimated annual mean CPUE and CV values are listed in Table 2. The time series showed a 67% decline since 1986 (Fig. 3). The series declined from 1986 to 1998, increased from 1998 to 2010, and decreased again from 2010 to 2015. Like the continuity series, the earliest years, 1986-1992, and the period 2003-2012 showed the largest fluctuations in the index (Fig. 3). The year 1986 also had the lowest number of positive observations of any year ( $n=279$ ), but the proportion of positive sets remained stable throughout the series, oscillating between 11 and 21%. The nominal series had a somewhat flatter trend than the standardized series, with a lower relative decline from beginning to end (42%) because the data showed an increasing tendency since 2012 compared with the decreasing trend of the standardized series. When removing 1986 from the standardized time series, the relative decline from beginning to end was slightly smaller than when including 1986 (63%). Diagnostic plots showed good agreement with model assumptions and there were no clear systematic patterns in the residuals (Fig. 5).

**Observer data**—In the continuity analysis of the observer data, factors retained for the proportion of positive sets were area, Sqr, year, Sqr\*area, and year\*quarter; and for the positive catches, the factors area, year, Sqr, quarter, year\*area, year\*quarter, and Tqr\*area were retained (Table 3). The factor area explained 45% and 52% of the deviance for the proportion positive and positive catches, respectively (Appendix Table 3). The estimated annual mean CPUE and CV values are listed in Table 4. The observer index showed a 44% decline since 1992, but larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years (Fig. 6). The nominal series had a flatter trend than the standardized series, with a relative decline from beginning to end of only 11% and a generally increasing tendency since 2012 compared with the decreasing trend of the standardized series. Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 7).

In the restricted analysis, which took into account time-area closures, factors retained for the proportion of positive sets were area, Sqr, year, year\*area, and year\*quarter; and for the positive catches, the factors area, Sqr, year, quarter, year\*quarter, year\*area, and Tqr\*area were retained (Table 3). The factor area explained 60% and 30% of the deviance for the proportion positive and positive catches, respectively (Appendix Table 4). The estimated annual mean CPUE and CV values are listed in Table 4. The observer index showed a 63% decline since 1992 (Fig. 6). The nominal series had a flatter trend than the standardized series, with a relative decline from beginning to end of only 9% and a generally increasing tendency since 2012 compared with the decreasing trend of the standardized series. Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (Fig. 8).

**Trends in size**—A scatter plot of individual lengths of shortfin makos ( $n=4,064$ ) observed in the pelagic longline observer program revealed no trend over the time period considered (Fig. 9). Similarly, time series of average lengths for males ( $n=2,270$ ), females ( $n=1,771$ ), or sexes combined also failed to reveal any pattern (Fig. 10). Based on reported values for the western North Atlantic of length at maturity of 280-300 cm TL (258-277 cm FL) for females and 200 cm TL (184 cm FL) for males, the length-frequency distribution aggregated for all years available revealed that almost all females were immature, but a substantial proportion of males encountered were mature (Fig. 11).

#### 4. Discussion

Trends in relative abundance predicted from analyses of the logbook dataset compared with those from the observer dataset, and taking or not taking into account management regulations, were similar, with all series showing a concave shape up to ca.2010, consisting of an initial decline followed by a recovery since about the late 1990s, and then a declining 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 relative abundance, such as those

displayed by the observer series in some years seem inconsistent with the biology of most sharks, whose stock abundance would be expected to fluctuate relatively little from year to year. Management measures, i.e., time-area closures and gear restrictions did not appear to overly influence the predicted catch rates and it is also unlikely that other management actions, such as quota reductions, may have had any effect on the catch rates of mako sharks because the pelagic longline fishery in the USA has 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). We included all makos, identified as either shortfin or longfin, in the logbook analysis owing to potential mis-identification problems during the early years of the time series (1986-1991). When excluding these early years, only ca. 9% of all makos were identified as longfin makos in the logbooks compared to 6% identified by scientific observers. Given the low prevalence of longfin makos in the observer dataset, we assumed that unidentified makos that were not brought onboard (9% of the total) were shortfin makos to augment the sample size in the observer analysis. Since makos can easily be distinguished from other pelagic sharks, it is unlikely that further mis-identification may have taken place. Changes in reporting practices as a result of the implementation of several logbook programs historically, 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 logbook index to some extent. The decline in both the logbook and observer indices in recent years does not seem to be related to any changes in management measures since the only measure introduced recently was the Spring Gulf of Mexico Gear Restricted Area in 2015 (6), which was accounted for in the analyses.

Other factors, such as hook size and type, and bait type were not included in the analysis because they have not been reported consistently in the logbooks throughout the time series, but may have affected catch rates of mako 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.

Stock status indicators - The logbook indices showed a concave shape from the beginning of the series in the mid-1980s to 2009-2010, followed by a downward trend thereafter. The observer indices also showed a concave shape from the beginning of the series in the early 1990s to 2011, followed by a declining trend thereafter. Overall, the logbook indices did not show a substantial change in relative abundance since the late 1990s and the observer indices showed a generally increasing tendency since the mid-1990s. The lack of strong trends in all series suggests that the status of the stock is stable, yet the declining trend since 2009-2011 should continue to be closely monitored.

There were no discernible trends in size for all sharks combined or for females or males separately. Since the vast majority of females encountered by the gear were immature, there is no concern that the reproductive stock is being greatly affected and the removal of immature individuals would only be of concern if it were at a rate that substantially impaired production of reproductive females. In contrast, mature males were substantially more represented in the catches. Overall, the lack of trends in size suggests that no specific segment of the population is being disproportionately affected.

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<b>Table 1.</b> Factors retained in the model of proportion of positive sets and positive catch of mako sharks for U.S. pelagic longline logbook data. Top: continuity analysis; bottom: restricted analysis.			
<b>Proportion positive</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	360356	310954	-155477
Final model			
AREA SQR YEAR	360346	265223	-132612
<b>Positive catches</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	55890	26568	-58523
Final model			
AREA TQR YEAR QUARTER YEAR*AREA TQR*AREA	55626	20582	-51389
<b>Proportion positive</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	317349	259466	-129733
Final model			
AREA SQR QUARTER YEAR	317337	222890	-111445
<b>Positive catches</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	45102	17816	-43051
Final model			
AREA TQR YEAR QUARTER YEAR*AREA TQR*AREA SQR*AREA	44850	14308	-38106

**Table 2.** 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	Continuity analysis			Restricted analysis		
	Standardized		Nominal	Standardized		Nominal
	CPUE	CV	CPUE	CPUE	CV	CPUE
1986	1.157	0.137	1.366	1.284	0.129	1.390
1987	1.163	0.084	1.309	1.121	0.074	1.303
1988	0.917	0.083	1.233	0.825	0.074	1.197
1989	1.063	0.080	1.272	0.879	0.070	1.181
1990	0.833	0.082	1.195	0.686	0.073	1.114
1991	0.74	0.084	1.050	0.658	0.074	1.008
1992	0.876	0.082	1.095	0.761	0.073	0.985
1993	0.767	0.083	1.024	0.632	0.073	0.917
1994	0.721	0.082	0.989	0.574	0.073	0.888
1995	0.694	0.081	0.900	0.536	0.072	0.792
1996	0.618	0.084	0.844	0.493	0.074	0.747
1997	0.569	0.086	0.834	0.455	0.076	0.774
1998	0.538	0.088	0.727	0.447	0.078	0.683
1999	0.526	0.090	0.807	0.455	0.080	0.795
2000	0.557	0.090	0.838	0.533	0.079	0.842
2001	0.507	0.092	0.834	0.5	0.080	0.860
2002	0.532	0.093	0.790	0.505	0.081	0.811
2003	0.573	0.094	0.805	0.558	0.082	0.858
2004	0.676	0.091	0.928	0.567	0.080	0.868
2005	0.68	0.092	0.870	0.555	0.082	0.813
2006	0.529	0.097	0.770	0.48	0.084	0.746
2007	0.803	0.092	0.946	0.658	0.080	0.871
2008	0.675	0.090	0.820	0.525	0.079	0.717
2009	0.862	0.090	0.948	0.649	0.078	0.822
2010	0.754	0.091	0.810	0.680	0.078	0.806
2011	0.704	0.091	0.743	0.622	0.078	0.720
2012	0.513	0.092	0.682	0.450	0.080	0.663
2013	0.543	0.093	0.819	0.472	0.081	0.813
2014	0.489	0.095	0.909	0.416	0.083	0.915
2015	0.484	0.099	0.828	0.419	0.085	0.810

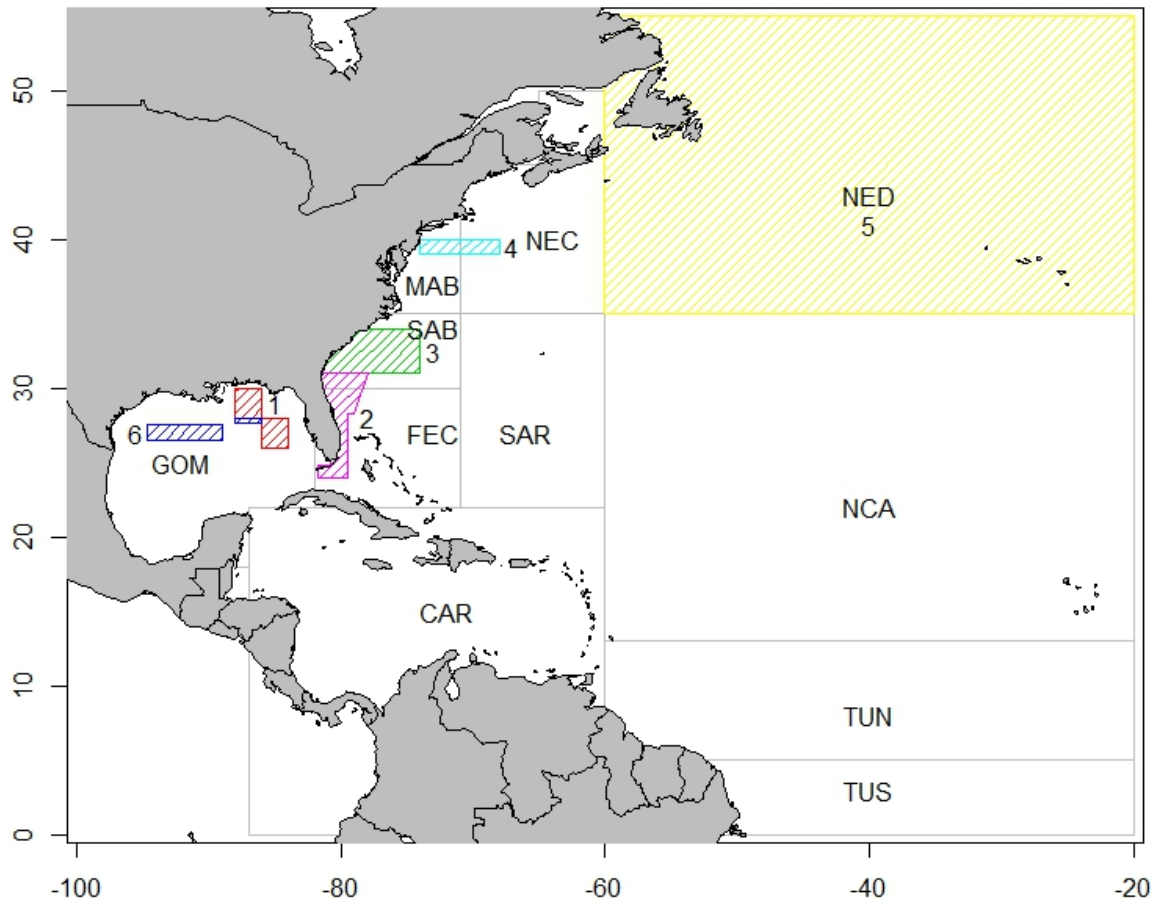


**Table 3.** Factors retained in the model of proportion of positive sets and positive catch of mako sharks for U.S. pelagic longline observer program data. Top: continuity analysis; bottom: restricted analysis.

<b>Proportion positive</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	14663	15130	-7565
Final model AREA SQR YEAR SQR*AREA YEAR*QUARTER	14554	11425	-5712
<b>Positive catches</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	3100	1594	-3369
Final model AREA YEAR SQR QUARTER YEAR*AREA YEAR*QUARTER TQR*AREA	2927	1087	-2775
<b>Proportion positive</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	11271	11884	-5942
Final model AREA SQR YEAR YEAR*AREA YEAR*QUARTER	11126	9210	-4605
<b>Positive catches</b>	Degrees of freedom	Deviance	Log-likelihood
Null model	2481	1021	-2420
Final model AREA SQR YEAR QUARTER YEAR*QUARTER YEAR*AREA TQR*AREA	2329	745	-2028

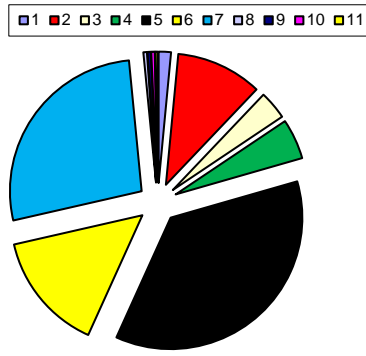
**Table 4.** Estimates of mean annual CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for mako sharks from the U.S. pelagic longline observer program data.

Year	Continuity analysis			Restricted analysis		
	Standardized		Nominal	Standardized		Nominal
	CPUE	CV	CPUE	CPUE	CV	CPUE
1992	1.121	0.199	1.028	1.334	0.235	0.980
1993	0.857	0.165	1.108	0.635	0.224	0.908
1994	0.576	0.182	0.818	0.378	0.250	0.561
1995	0.890	0.169	0.970	0.655	0.226	0.676
1996	0.511	0.460	0.395	0.331	0.465	0.414
1997	0.668	0.225	0.660	0.421	0.291	0.422
1998	0.493	0.300	0.755	0.405	0.300	0.755
1999	0.531	0.237	0.737	0.467	0.304	0.603
2000	0.807	0.191	0.908	0.927	0.228	0.945
2001	0.674	0.235	0.710	0.620	0.252	0.710
2002	0.815	0.231	0.853	0.737	0.248	0.865
2003	0.678	0.206	0.676	0.616	0.235	0.680
2004	0.996	0.171	0.962	1.097	0.201	0.882
2005	0.711	0.188	0.585	0.503	0.237	0.525
2006	0.770	0.184	0.889	0.952	0.208	0.862
2007	0.870	0.169	0.720	0.818	0.223	0.652
2008	0.638	0.157	0.649	0.700	0.203	0.666
2009	1.350	0.145	0.933	1.072	0.190	0.766
2010	0.883	0.166	0.810	0.972	0.199	0.856
2011	1.261	0.154	0.801	1.167	0.184	0.783
2012	1.105	0.165	0.701	0.822	0.209	0.711
2013	0.777	0.148	0.738	0.639	0.204	0.726
2014	0.811	0.162	0.697	0.611	0.219	0.702
2015	0.630	0.176	0.897	0.492	0.242	0.891

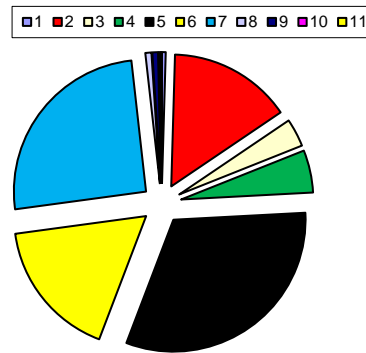


**Figure 1.** Map of the western North Atlantic Ocean. Areas are as follows: CAR=Caribbean (area 1); GOM=Gulf of Mexico (area 2); FEC=Florida East Coast (area 3); SAB=South Atlantic Bight (area 4); MAB=Mid-Atlantic Bight (area 5); NEC=Northeast Coastal (area 6); NED=Northeast Distant (area 7); SAR=Sargasso (area 8); NCA=North Central Atlantic (area 9); TUN=Tuna North (area 10); TUS=Tuna South (area 11). Time-area closures (designated by numbers in the map) are as follows: 1- DeSoto Canyon; 2- Florida East Coast; 3- Charleston Bump; 4- Bluefin tuna Northeast Atlantic; 5- Grand Banks; 6- Bluefin tuna spring Gulf of Mexico.

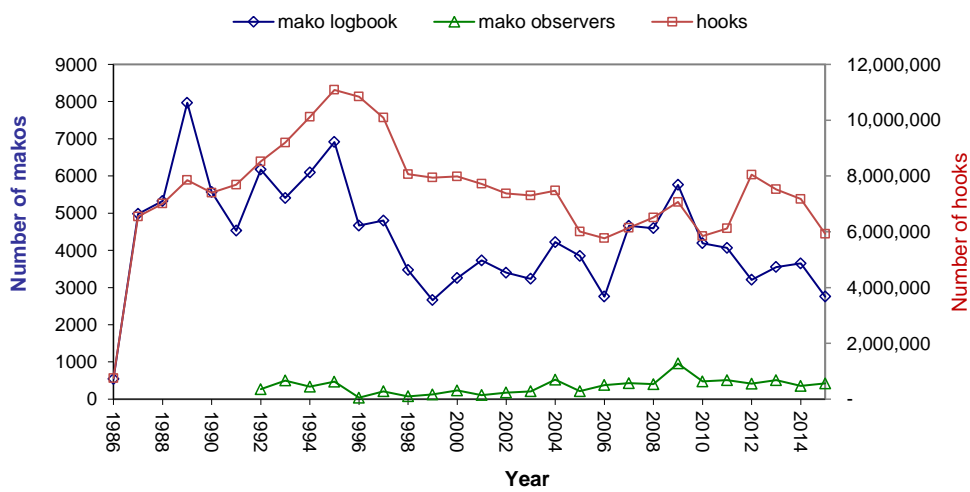
Mako sharks caught by ICCAT area (logbooks)



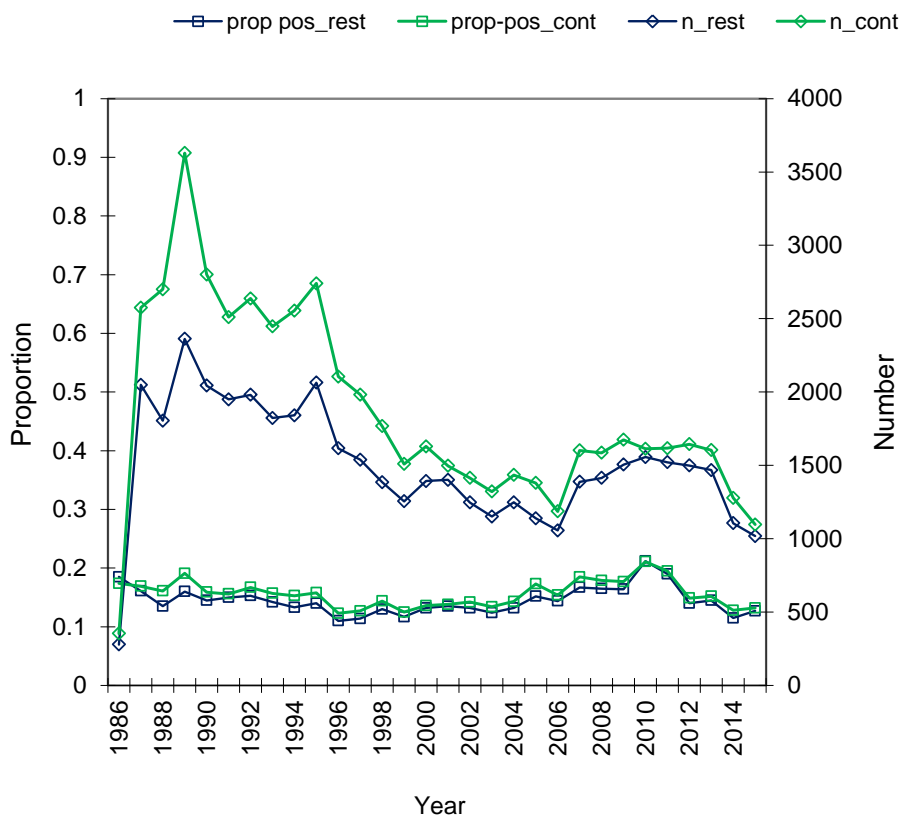
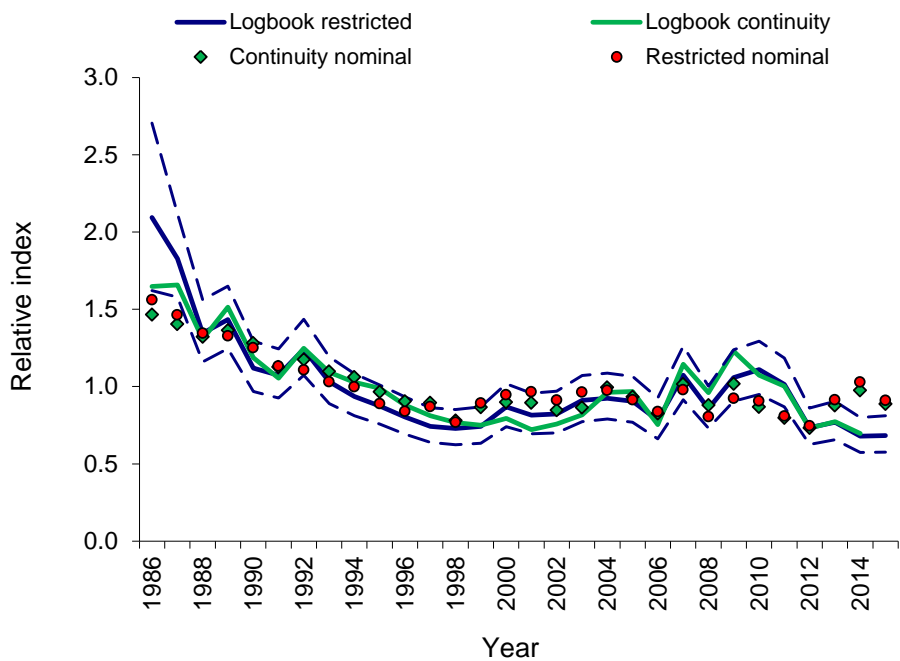
Mako sharks caught by ICCAT area (observers)



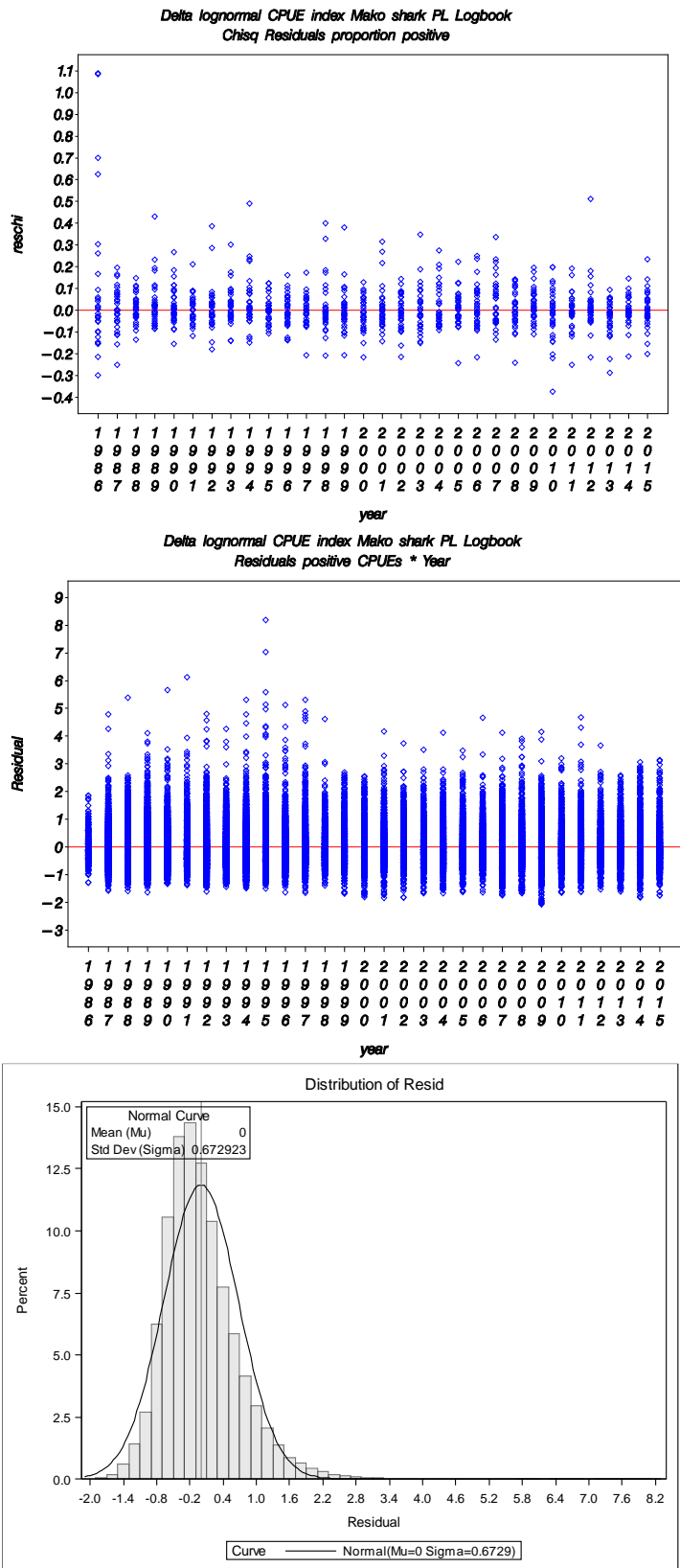
Mako sharks reported caught by year and total PLL effort



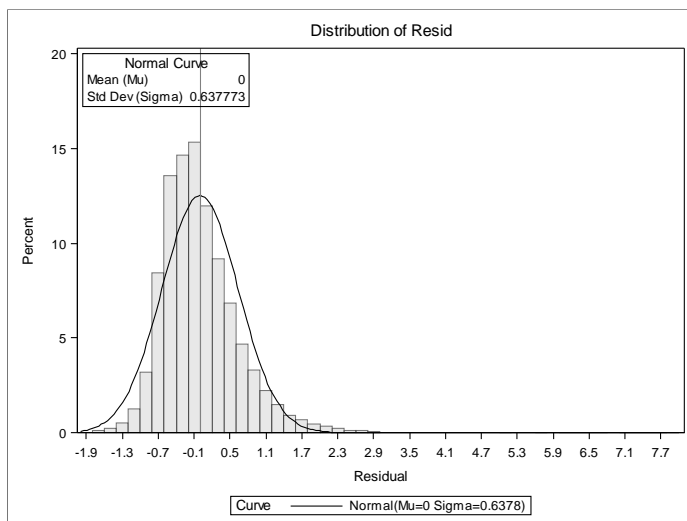
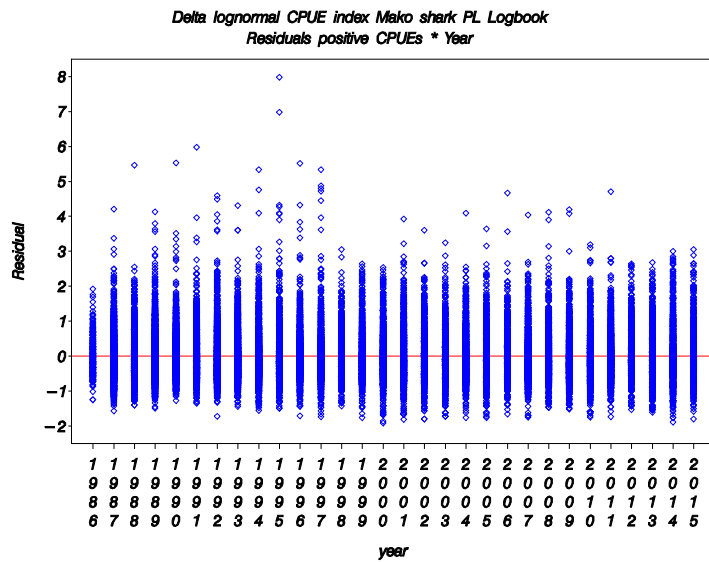
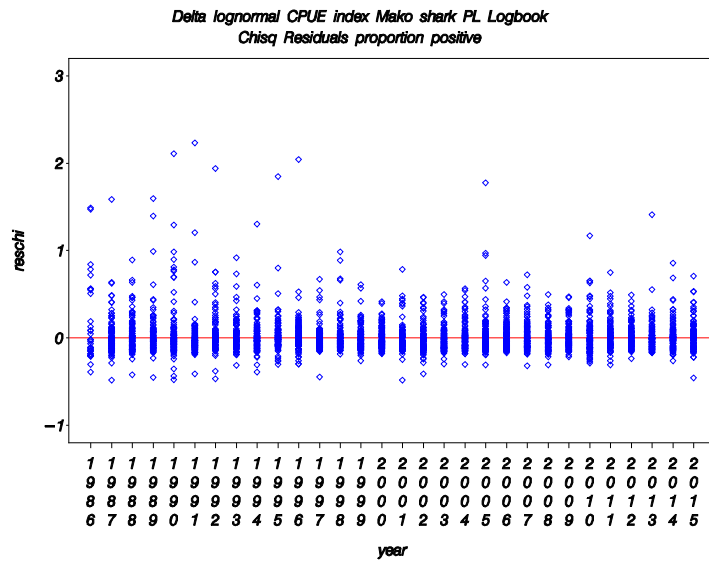
**Figure 2.** Mako sharks caught by ICCAT area as reported in the pelagic longline logbook (top) and observer (middle) programs. Mako sharks caught by year in all areas combined from both programs relative to total effort are shown in the bottom panel.



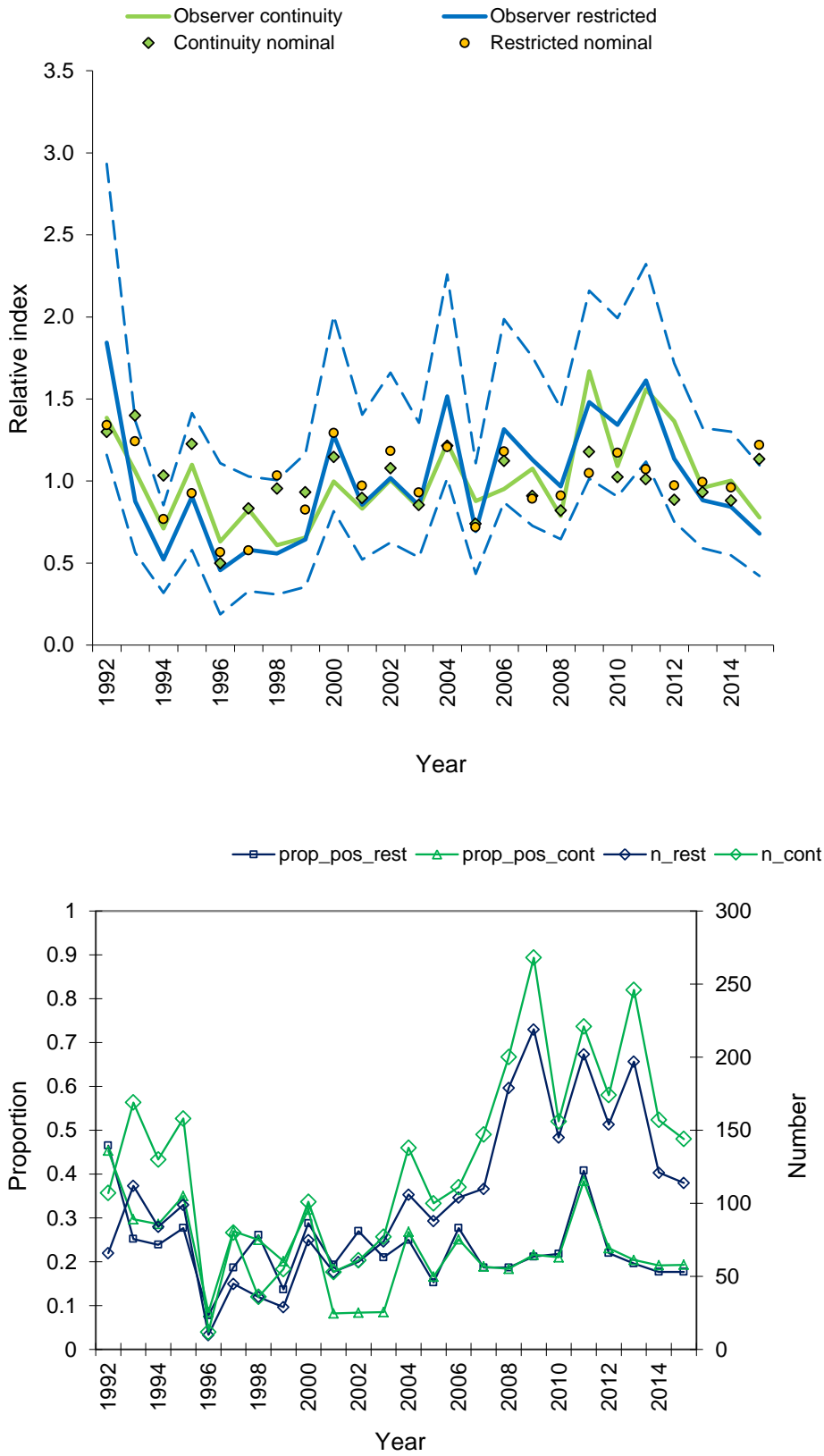
**Figure 3.** Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for mako sharks from the US pelagic longline logbook continuity and restricted analyses. The lower panel shows the proportion and number of positive sets by year.



**Figure 4.** Diagnostic plots of CPUE model from the US pelagic longline logbook continuity analysis for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

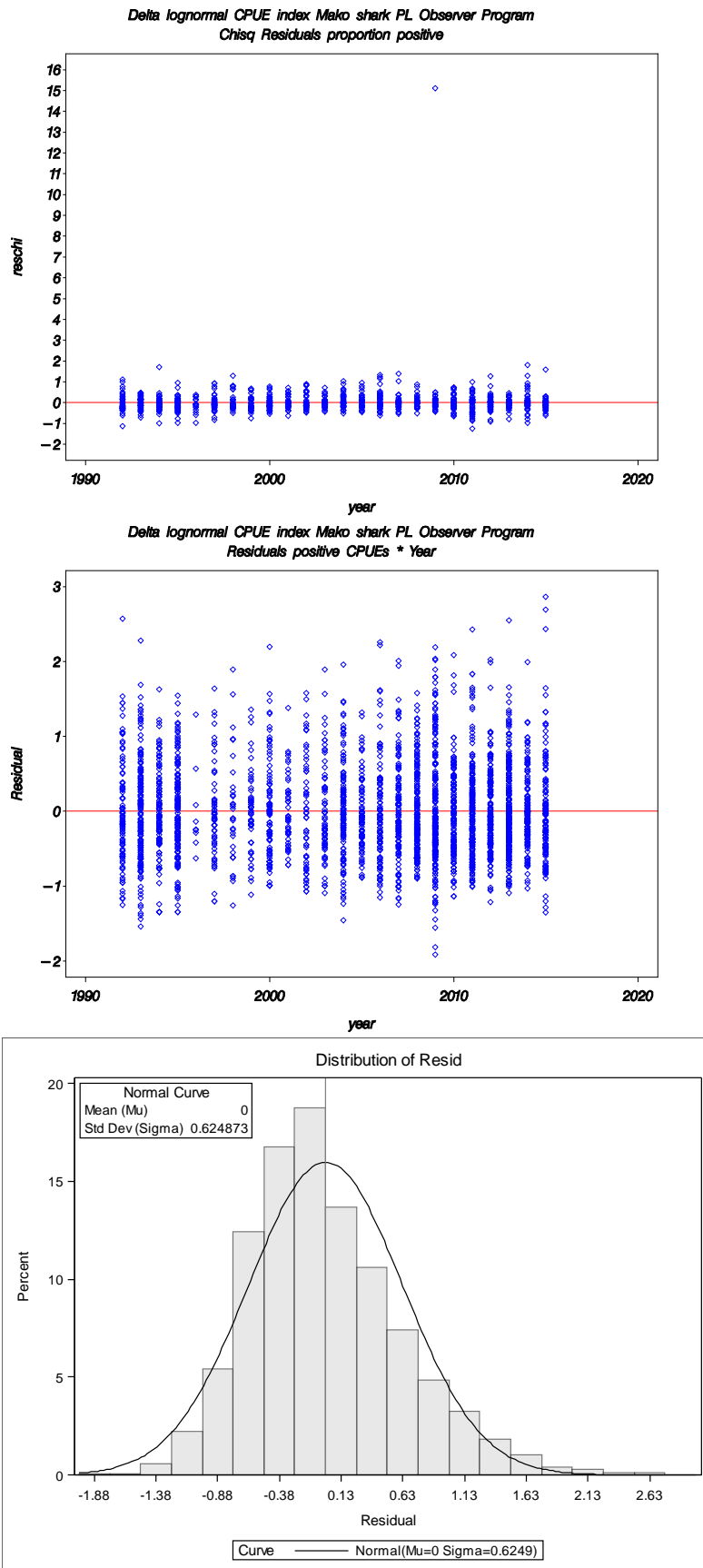


**Figure 5.** Diagnostic plots of CPUE model from the US pelagic longline logbook restricted analysis for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

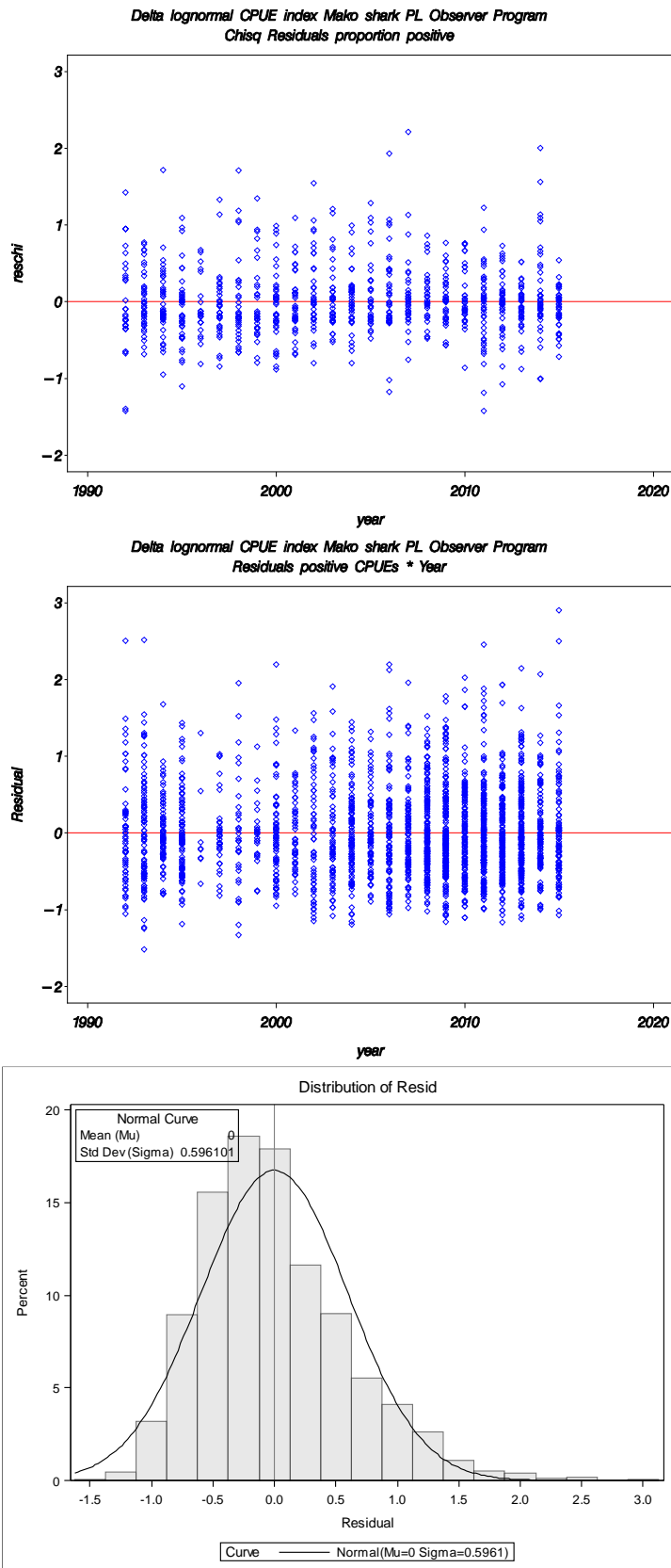


**Figure 6.** Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for mako sharks from the US pelagic longline observer program continuity and restricted analyses. The lower panel shows the proportion and number of positive sets by year.

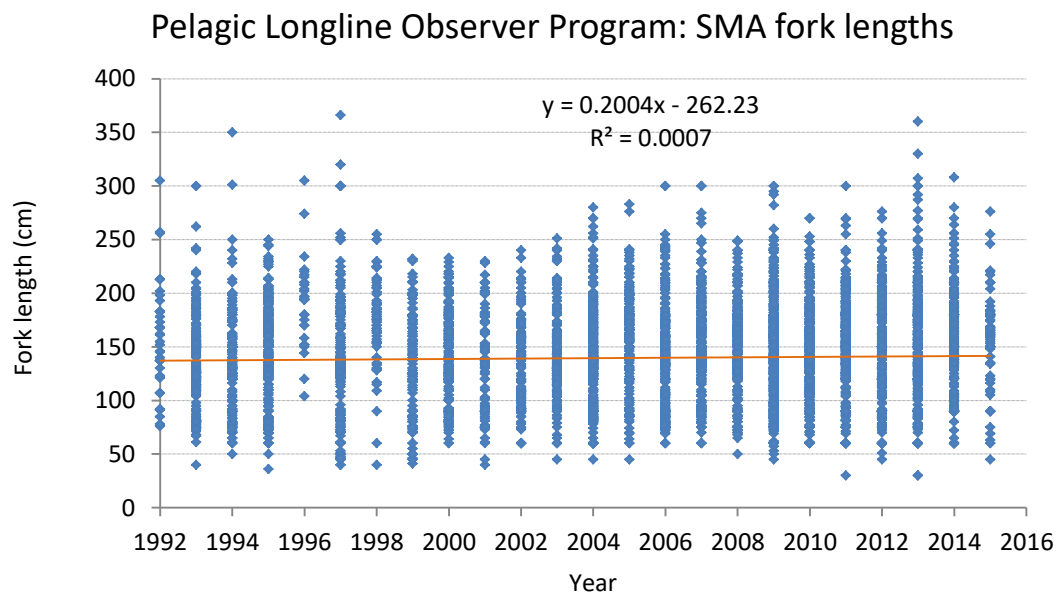




**Figure 7.** Diagnostic plots of CPUE model from the US pelagic longline observer continuity analysis for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

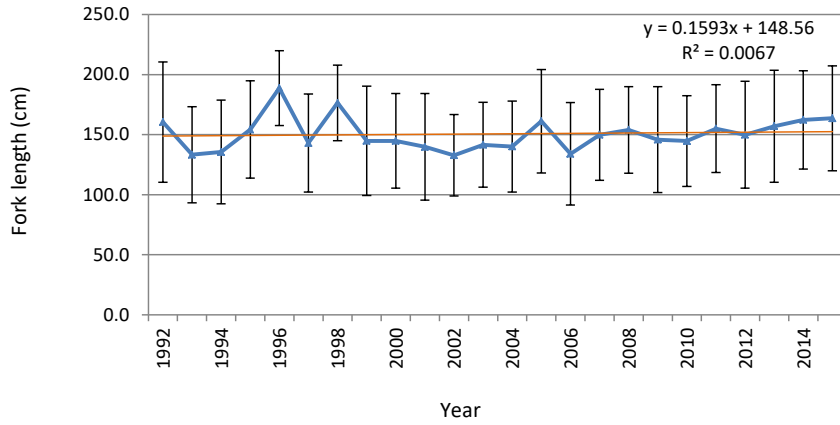


**Figure 8.** Diagnostic plots of CPUE model from the US pelagic longline observer restricted analysis for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

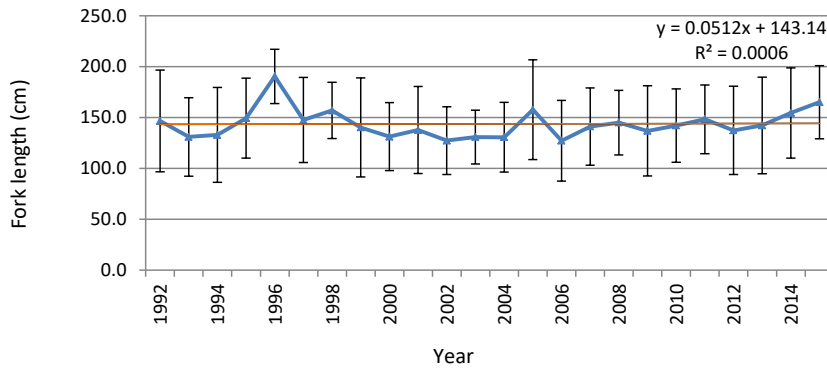


**Figure 9.** Scatter plot of shortfin mako lengths from the Pelagic Longline Observer Program, 1992-2015.

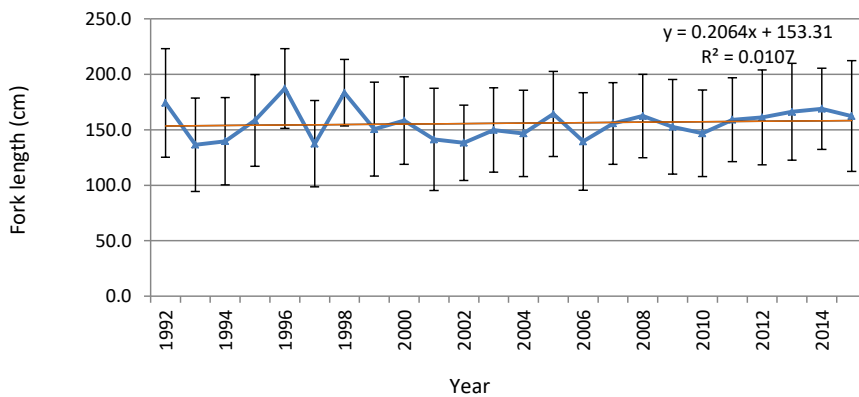
Average length of shortfin makos (sexes combined; PLLOP)



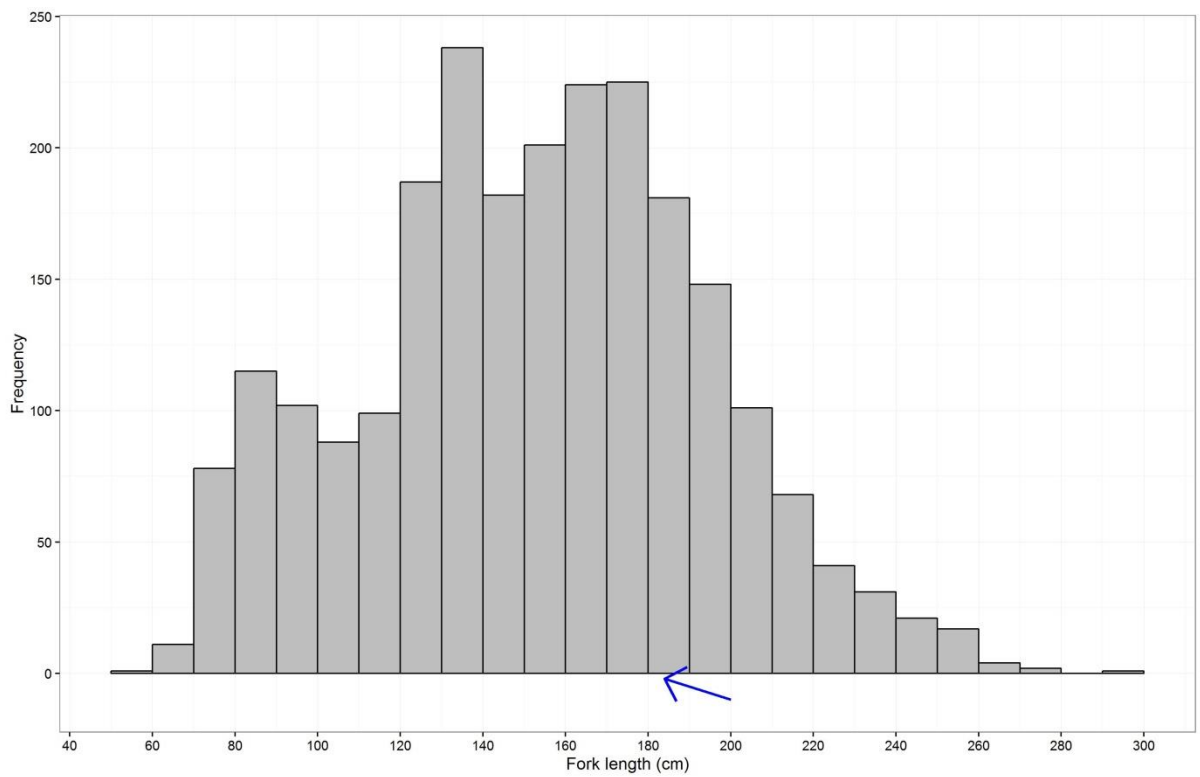
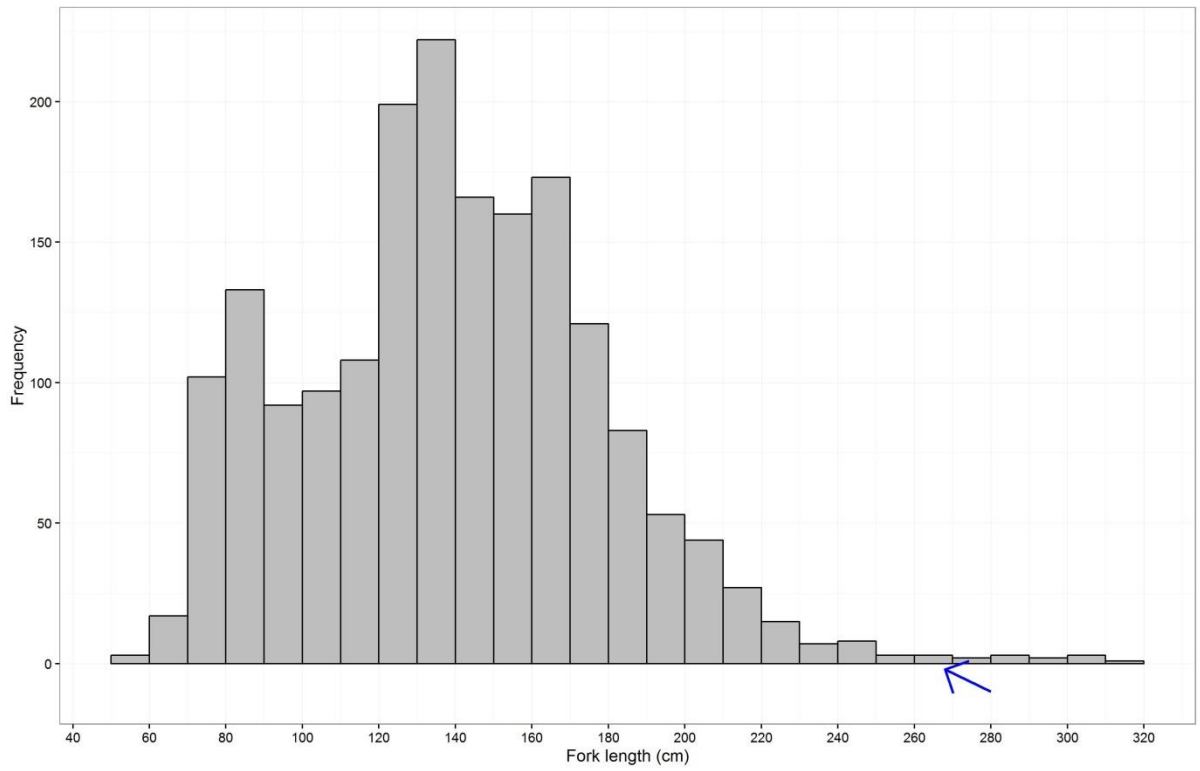
Average length of shortfin makos (females; PLLOP)



Average length of shortfin makos (males; PLLOP)



**Figure 10.** Average lengths of shortfin makos from the Pelagic Longline Observer Program, 1992-2015. Error bars are  $\pm 1$  SD.



**Figure 11.** Length-frequency of shortfin makos from the Pelagic Longline Observer Program, 1992-2015, for females (top) and males (bottom). The arrows indicate approximate size at maturity.

<b>Appendix table 1.</b> Deviance analysis table of explanatory variables in the delta lognormal model for MAKO shark catch rates (number of fish per 1000 hooks) from the US pelagic longline fishery <b>logbook continuity analysis</b> . Percent of total deviance refers to the deviance explained by the model; p value is the Chi-square probability between consecutive models.						
<b>Model factors proportion positives</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>	<b>% reduction</b>	<b>% of total deviance</b>	<b>p</b>
Null		310954				
Area	7	270106	40848	13.14%	87.8%	<0.0001
Area Sqr	3	265223	4883	1.81%	10.5%	<0.0001
Area Sqr Year	29	264441	782	0.29%	1.7%	<0.0001
<b>Model factors positive catch rates</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>		<b>% of total deviance</b>	<b>p</b>
Null		26568				
Area	7	23121	3447	12.97%	57.6%	<0.0001
Area Tqr	3	22588	533	2.31%	8.9%	<0.0001
Area Tqr Year	29	22213	375	1.66%	6.3%	<0.0001
Area Tqr Year Quarter	3	21852	361	1.63%	6.0%	<0.0001
Area Tqr Year Quarter Year*Area	201	21039	813	3.72%	13.6%	<0.0001
Area Tqr Year Quarter Year*Area Tqr*Area	21	20582	457	2.17%	7.6%	<0.0001
<b>GLM Mixed Model</b>	<b>deviance</b>	<b>AIC</b>	<b>AICc</b>	<b>BIC</b>		
<b>Proportion Positives</b>						
Area Sqr Year	1984.7	1986.7	1986.7	1991.5		
<b>Positive catch rates</b>						
Area Tqr Year Quarter Year*Area Tqr*Area	107684	107688	107688	107695		

<b>Appendix table 2.</b> Deviance analysis table of explanatory variables in the delta lognormal model for MAKO shark catch rates (number of fish per 1000 hooks) from the US pelagic longline fishery <b>logbook restricted analysis</b> . Percent of total deviance refers to the deviance explained by the model; p value is the Chi-square probability between consecutive models.						
<b>Model factors proportion positives</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>	<b>% reduction</b>	<b>% of total deviance</b>	<b>p</b>
Null		259455				
Area	7	229285	30170	11.63%	80.5%	<0.0001
Area Sqr	3	225336	3949	1.72%	10.5%	<0.0001
Area Sqr Quarter	3	222890	2446	1.09%	6.5%	<0.0001
Area Sqr Quarter Year	29	221981	909	0.41%	2.4%	<0.0001
<b>Model factors positive catch rates</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>		<b>% of total deviance</b>	<b>p</b>
Null		17816				
Area	7	16427	1389	7.80%	41.4%	<0.0001
Area Tqr	3	15798	629	3.83%	18.8%	<0.0001
Area Tqr Year	29	15508	290	1.84%	8.6%	<0.0001
Area Tqr Year Quarter	3	15226	282	1.82%	8.4%	<0.0001
Area Tqr Year Quarter Year*Area	201	14839	387	2.54%	11.5%	<0.0001
Area Tqr Year Quarter Year*Area Tqr*Area	21	14463	376	2.53%	11.2%	<0.0001
<b>GLM Mixed Model</b>	<b>deviance</b>	<b>AIC</b>	<b>AICc</b>	<b>BIC</b>		
<b>Proportion Positives</b>						
Area Sqr Quarter Year	8566.3	8568.3	8568.3	8574.2		
<b>Positive catch rates</b>						
Area Tqr Year Quarter Year*Area Tqr*Area	82070.3	82074.3	82074.3	82081		

<b>Appendix table 3.</b> Deviance analysis table of explanatory variables in the delta lognormal model for MAKO shark catch rates (number of fish per 1000 hooks) from the US pelagic longline <b>observer program continuity analysis</b> . Percent of total deviance refers to the deviance explained by the model; p value is the Chi-square probability between consecutive models.						
<b>Model factors proportion positives</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>	<b>% reduction</b>	<b>% of total deviance</b>	<b>p</b>
Null		15139				
Area	2	13467	1672	11.04%	45.0%	<0.0001
Area Sqr	3	12132	1335	9.91%	35.9%	<0.0001
Area Sqr Year	23	11880	252	2.08%	6.8%	<0.0001
Area Sqr Year Sqr*Area	9	11609	271	2.28%	7.3%	<0.0001
Area Sqr Year Sqr*Area Year*Quarter	70	11425	184	1.58%	5.0%	<0.0001
<b>Model factors positive catch rates</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>		<b>% of total deviance</b>	<b>p</b>
Null		1594				
Area	2	1332	262	16.44%	51.7%	< 0.0001
Area Year	23	1291	41	3.08%	8.1%	0.012
Area Year Sqr	3	1257	34	2.63%	6.7%	< 0.0001
Area Year Sqr Quarter	3	1235	22	1.75%	4.3%	< 0.0001
Area Year Quarter Sqr Year*Area	60	1158	77	6.23%	15.2%	0.069
Area Year Quarter Sqr Year*Area Year*Quarter	70	1104	54	4.66%	10.7%	0.921
Area Year Quarter Sqr Year*Area Year*Quarter Tqr*Area	12	1087	17	1.54%	3.4%	0.150
<b>GLM Mixed Model</b>	<b>deviance</b>	<b>AIC</b>	<b>AICc</b>	<b>BIC</b>		
<b>Proportion Positives</b>						
Area Sqr Year Sqr*Area Year*Quarter	3386.6	3388.6	3388.6	3393.3		
<b>Positive catch rates</b>						
Area Year Quarter Sqr Year*Area Year*Quarter Tqr*Area	5700.6	5706.6	5706.6	5714.1		



<b>Appendix table 4.</b> Deviance analysis table of explanatory variables in the delta lognormal model for MAKO shark catch rates (number of fish per 1000 hooks) from the US pelagic longline <b>observer program restricted analysis</b> . Percent of total deviance refers to the deviance explained by the model; p value is the Chi-square probability between consecutive models.						
<b>Model factors proportion positives</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>	<b>% reduction</b>	<b>% of total deviance</b>	<b>p</b>
Null		11884				
Area	2	10281	1603	13.49%	59.9%	<0.0001
Area Sqr	3	9719	562	5.47%	21.0%	<0.0001
Area Sqr Year	23	9553	166	1.71%	6.2%	<0.0001
Area Sqr Year Year*Area	60	9405	148	1.55%	5.5%	<0.0001
Area Sqr Year Sqr*Area Year*Quarter	70	9210	195	2.07%	7.3%	<0.0001
<b>Model factors positive catch rates</b>	<b>d.f.</b>	<b>Residual deviance</b>	<b>Change in deviance</b>		<b>% of total deviance</b>	<b>p</b>
Null		1021				
Area	2	937	84	8.23%	30.4%	< 0.0001
Area Sqr	3	901	36	3.84%	13.0%	< 0.0001
Area Sqr Year	23	865	36	4.00%	13.0%	0.041
Area Sqr Year Quarter	3	842	23	2.66%	8.3%	< 0.0001
Area Sqr Year Quarter Year*Quarter	70	789	53	6.29%	19.2%	0.935
Area Sqr Year Quarter Year*Quarter Year*Area	60	756	33	4.18%	12.0%	0.998
Area Sqr Year Quarter Year*Quarter Year*Area Tqr*Area	9	745	11	1.46%	4.0%	0.276
<b>GLM Mixed Model</b>	<b>deviance</b>	<b>AIC</b>	<b>AICc</b>	<b>BIC</b>		
<b>Proportion Positives</b>						
Area Sqr Year Sqr*Area Year*Quarter	2827.7	2833.7	2833.7	2840.5		
<b>Positive catch rates</b>						
Area Year Quarter Sqr Year*Area Year*Quarter Tqr*Area	4342.1	4348.1	4348.2	4355.8		