SCRS/2016/070 Collect. Vol. Sci. Pap. ICCAT, 73(8): 2891-2910 (2017)

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 (1986-2014) and observer (1992-2014) 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. The logbook time series showed a concave shape from the beginning of the series in the mid-1980s to 2009, 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 the most recent year of data, 2014. Overall, the logbook index did not show a substantial change in relative abundance since the late 1990s and the observer index showed an increasing tendency since the mid-1990s. The lack of strong trends in both series thus indicates that the status of the stock is stable. 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 (1986-2014) et d'observateurs palangriers pélagiques (1992-2014). 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 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, suivie d'une tendance à la baisse par la suite. Les séries temporelles des observateurs ont fait apparaître une forme concave depuis le début de la série au début des années 90 à 2014, l'année la plus récente de données. 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 croissante depuis le milieu des années 90. L'absence de fortes tendances dans les deux séries indique donc que l'état du stock est stable. 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 se 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 del palangre pelágico de Estados Unidos (1986-2014) y de programas de observadores (1992-2014). Los índices se calcularon utilizando un enfoque delta-lognormal de dos etapas que trata la proporción de lances positivos y la CPUE de capturas positivas por separado. 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, seguida de una tendencia descendente desde entonces. La serie temporal de los observadores presentaba una forma

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cóncava desde el inicio de la serie temporal a principios de los noventa hasta el año de datos más reciente, a saber, 2014. 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 creciente desde mediados de los noventa. La ausencia de fuertes tendencias en ambas series indica, por tanto, que el estado del stock es estable. 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, Abundance, 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 initial indicators of stock status and in preparation for 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), 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 1986-2014, and those from the US pelagic longline observer program, for 1992-2014. Both shortfin (mostly) and longfin makos (*Isurus paucus*) were included in the logbook analysis owing to potential mis-identification. Shortfin (n=6,776) and some unidentified makos (n=759) were included in the observer analysis as the latter are likely to be shortfin makos (only 486 longfin makos were positively identified as such). The observer dataset was restricted to areas 2, 5, 6, and 7 owing to insufficient and unbalanced observations by year in the remaining areas. Areas 2, 5, 6, and 7 accounted for ca. 90% of all observations in both the logbook and observer datasets (**Figure 2**).

Based on the methodology used in Brooks *et al.* (2005), Cortés (2007, 2009, 2013), 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).

Trends in fork length (cm) and length-frequency distributions of shortfin makos positively identified in the US pelagic longline observer program were also examined.

3. Results

Logbook data-In the 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 updated index is almost identical to that developed by Cortés (2013). In all, the entire time series showed a 58% decline since 1986 (r=-0.031, 95% CI:-0.097 to +0.036; **Figure 3**). The series declined from 1986 to 2001, increased from 2001 to 2009, and decreased again from 2009 to 2014. The earliest years, 1986-1992, and the period 2003-2012 showed the largest fluctuations in the index (**Figure 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 (33%) because the last two years of data showed an increasing trend 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 (**Figure 4**).

Observer data-In the 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, quarter, Sqr, year*quarter and year*area were retained (**Table 3**). The factor area explained 45% and 27% 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 4**. The observer index showed only a 30% decline since 1992 (r=-0.016, 95% CI: -0.191 to 0.159), but larger interannual variation than the logbook index, which shows a smoother trend for the overlapping years (**Figure 5**). The trends of both indices are similar, however, as was the trend for the nominal observer series. The sharper interannual fluctuations in the observer index may be due to the smaller sample sizes. Diagnostic plots showed good agreement with model assumptions and there were no systematic patterns in the residuals (**Figure 6**).

Trends in size-A scatter plot of individual lengths of shortfin makos observed in the pelagic longline observer program revealed no trend over the time period considered (**Figure 7**). Similarly, time series of average lengths for males, females, or sexes combined also failed to reveal any pattern (**Figure 8**). 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, length-frequency distributions revealed that most females were immature, but a substantial proportion of males encountered were mature (**Figure 9**).

4. Discussion

Trends in relative abundance predicted from analyses of the logbook dataset compared with those from the observer dataset were similar, with both series showing a concave shape, consisting of an initial decline followed by a recovery since about the late 1990s, although the logbook analysis showed a declining trend since 2009. 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 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 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. Approximately 30% of all makos were identified as longfin makos in the logbooks, whereas only 6% were identified as such by scientific observers. Given the low prevalence of longfin makos in the observer dataset, we assumed that unidentified makos that were not brought onboard 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 the logbook index from 2009 to 2014 does not seem to be related to any changes in management measures since no new measures that may have affected shortfin makos have been introduced since 2009.

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 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 index showed an overall declining trend whereas the observer index showed an overall increasing trend. The logbook index did not show a substantial change in relative abundance since the late 1990s and the observer index showed an increasing tendency since the mid-1990s. The lack of strong trends in both series thus indicates that the status of the stock is stable.

There were no discernible trends in size for all sharks combined or for females or males separately. Since the 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, both immature and mature males were substantially 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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Table 1. 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	355547	307017	-153509
Final model AREA SQR YEAR	355508	260953	-130476

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	55207	26227	-57790
Final model AREA TQR YEAR QUARTER YEAR*AREA TQR*AREA	54944	20293	-50710

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.

	Standardized		Nominal
Year	CPUE	CV	CPUE
1986	1.157	0.138	1.366
1987	1.16	0.085	1.309
1988	0.914	0.084	1.233
1989	1.06	0.080	1.272
1990	0.831	0.083	1.195
1991	0.737	0.085	1.050
1992	0.873	0.083	1.095
1993	0.766	0.084	1.024
1994	0.719	0.083	0.989
1995	0.693	0.082	0.900
1996	0.618	0.085	0.844
1997	0.569	0.087	0.834
1998	0.537	0.089	0.727
1999	0.525	0.091	0.807
2000	0.556	0.091	0.838
2001	0.506	0.093	0.834
2002	0.531	0.094	0.790
2003	0.572	0.095	0.805
2004	0.675	0.092	0.928
2005	0.679	0.093	0.870
2006	0.528	0.098	0.770
2007	0.801	0.093	0.946
2008	0.673	0.091	0.820
2009	0.861	0.091	0.948
2010	0.754	0.092	0.810
2011	0.704	0.092	0.743
2012	0.512	0.093	0.682
2013	0.541	0.094	0.819
2014	0.489	0.096	0.913

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.

Proportion positive	Degrees of freedom	Deviance	Log-likelihood
Null model	14298	14661	-7331
Final model AREA SQR YEAR SQR*AREA YEAR*QUARTER	14190	11042	-5521

Positive catches	Degrees of freedom	Deviance	Log-likelihood
Null model	2054	1215	-2376
Final model AREA YEAR QUARTER SQR YEAR*QUARTER YEAR*AREA	1925	876	-2040

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.

			Nominal
Year	Mean CPUE	CV	CPUE
1992	1.140	0.206	1.028
1993	0.839	0.172	1.108
1994	0.564	0.189	0.818
1995	0.899	0.176	0.970
1996	0.471	0.471	0.395
1997	0.657	0.232	0.660
1998	0.472	0.308	0.755
1999	0.520	0.243	0.737
2000	0.789	0.198	0.908
2001	0.631	0.243	0.710
2002	0.779	0.239	0.853
2003	0.661	0.214	0.676
2004	0.989	0.177	0.962
2005	0.679	0.195	0.585
2006	0.744	0.190	0.889
2007	0.842	0.176	0.720
2008	0.622	0.164	0.649
2009	1.333	0.153	0.933
2010	0.922	0.174	0.810
2011	1.306	0.161	0.801
2012	1.074	0.174	0.701
2013	0.775	0.156	0.738
2014	0.800	0.169	0.697

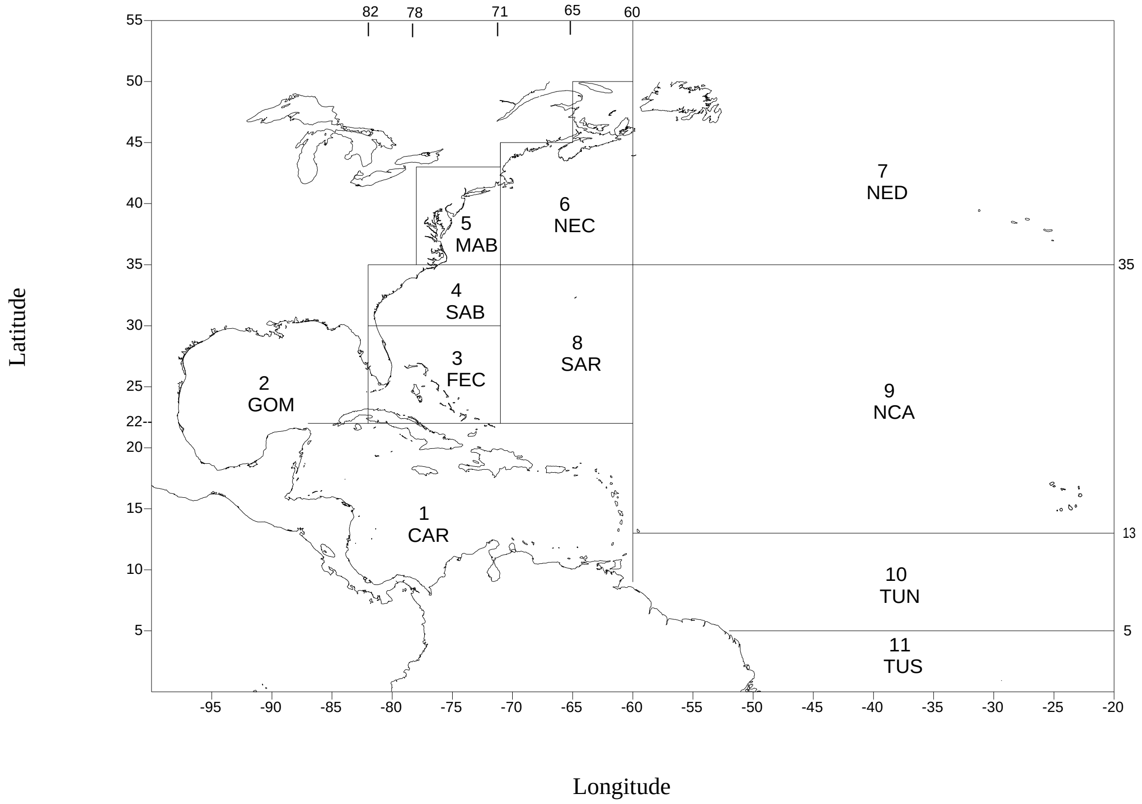
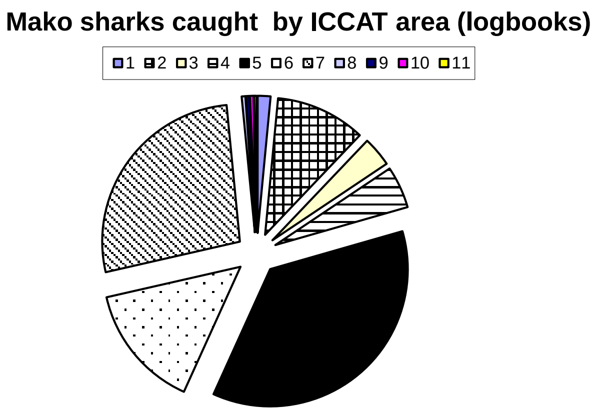
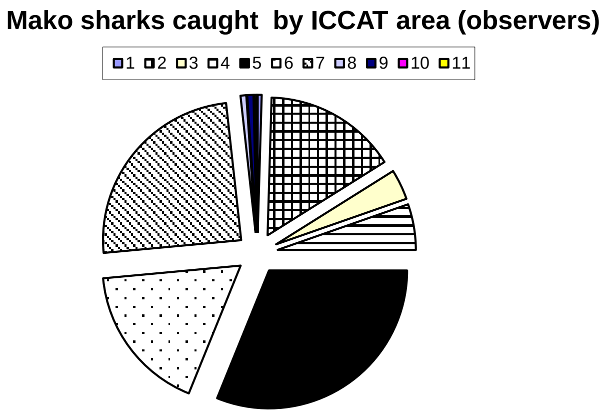


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean; 2) Gulf of Mexico;3) Florida East Coast; 4) South Atlantic Bight; 5) Mid Atlantic Bight; 6) Northeast Coastal; 7) Northeast Distant; 8) Sargasso; 9) North Central Atlantic; 10) Tuna North; 11) Tuna South.





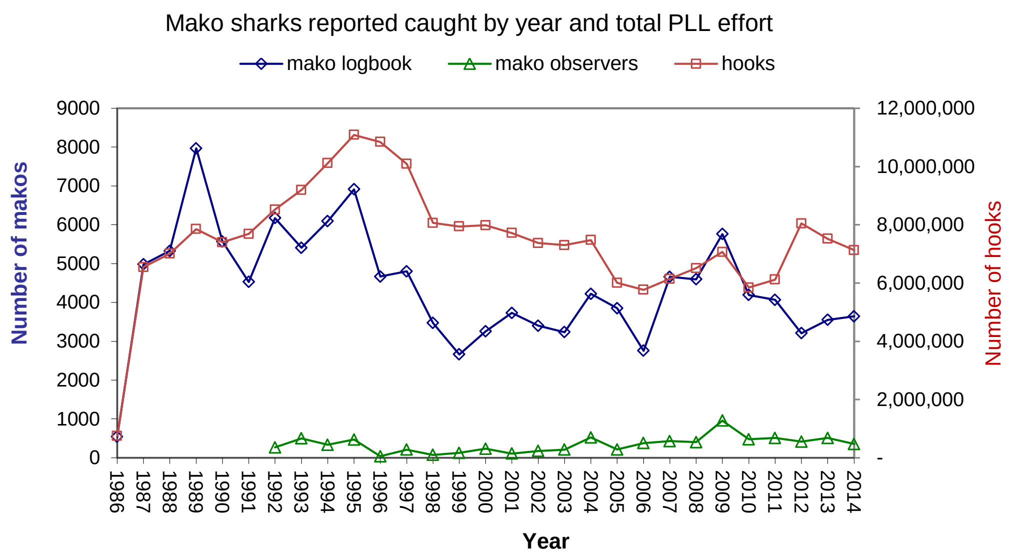
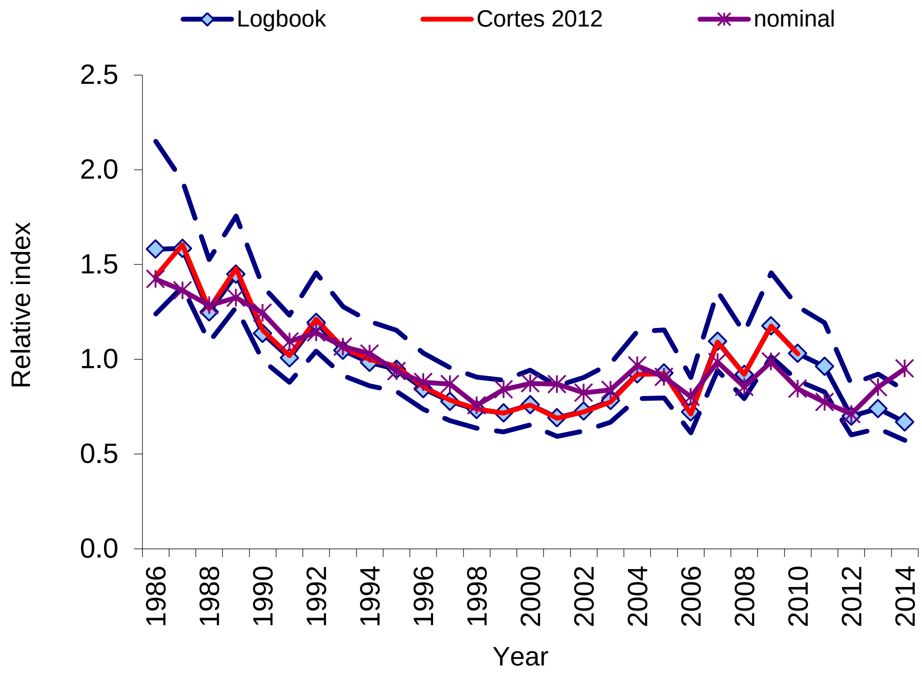


Figure 2. Mako sharks caught by ICCAT area as reported in the pelagic longline logbook (top) and observer (middle) programs. Mako sharks caught by year in all areas from both programs relative to total effort are shown in the bottom panel.



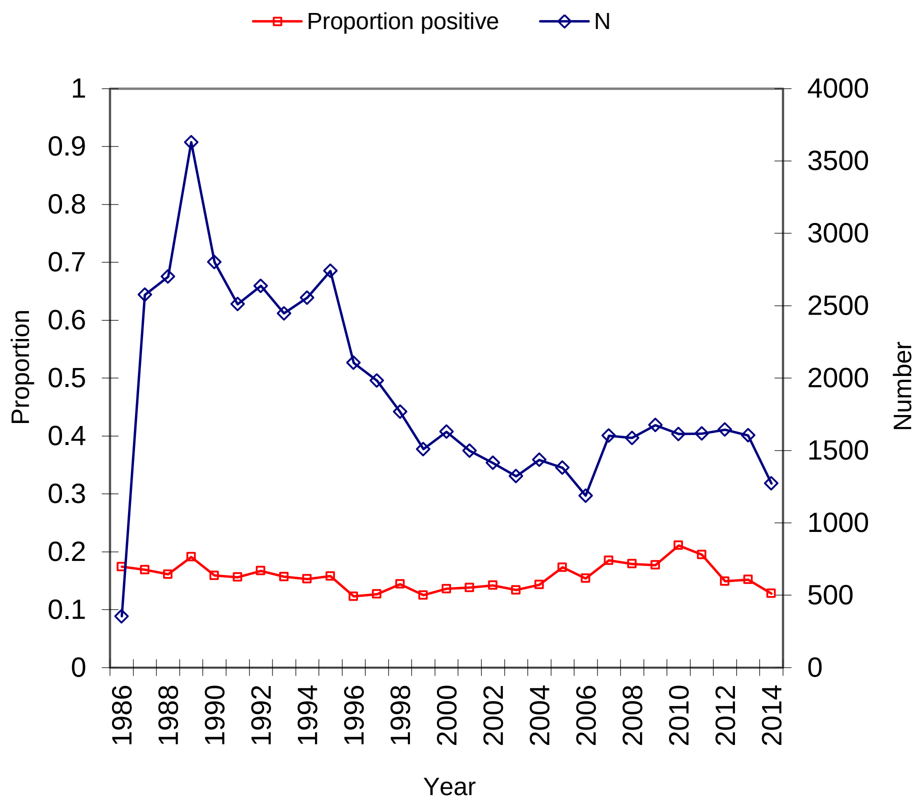


Figure 3. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for mako sharks from the US pelagic longline logbook compared to a previous study. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets by year.

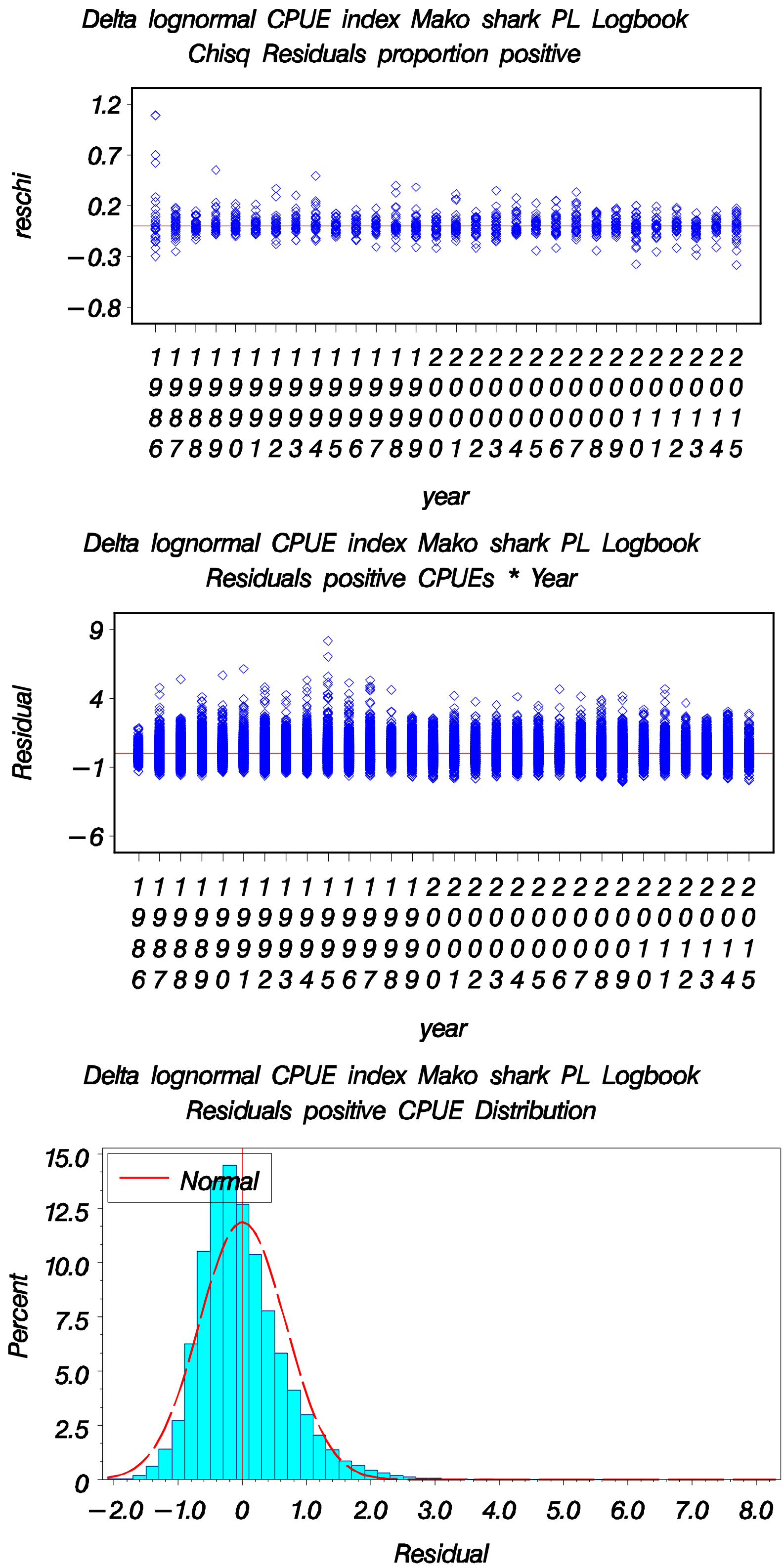


Figure 4. Diagnostic plots of CPUE model from US pelagic longline logbook data for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

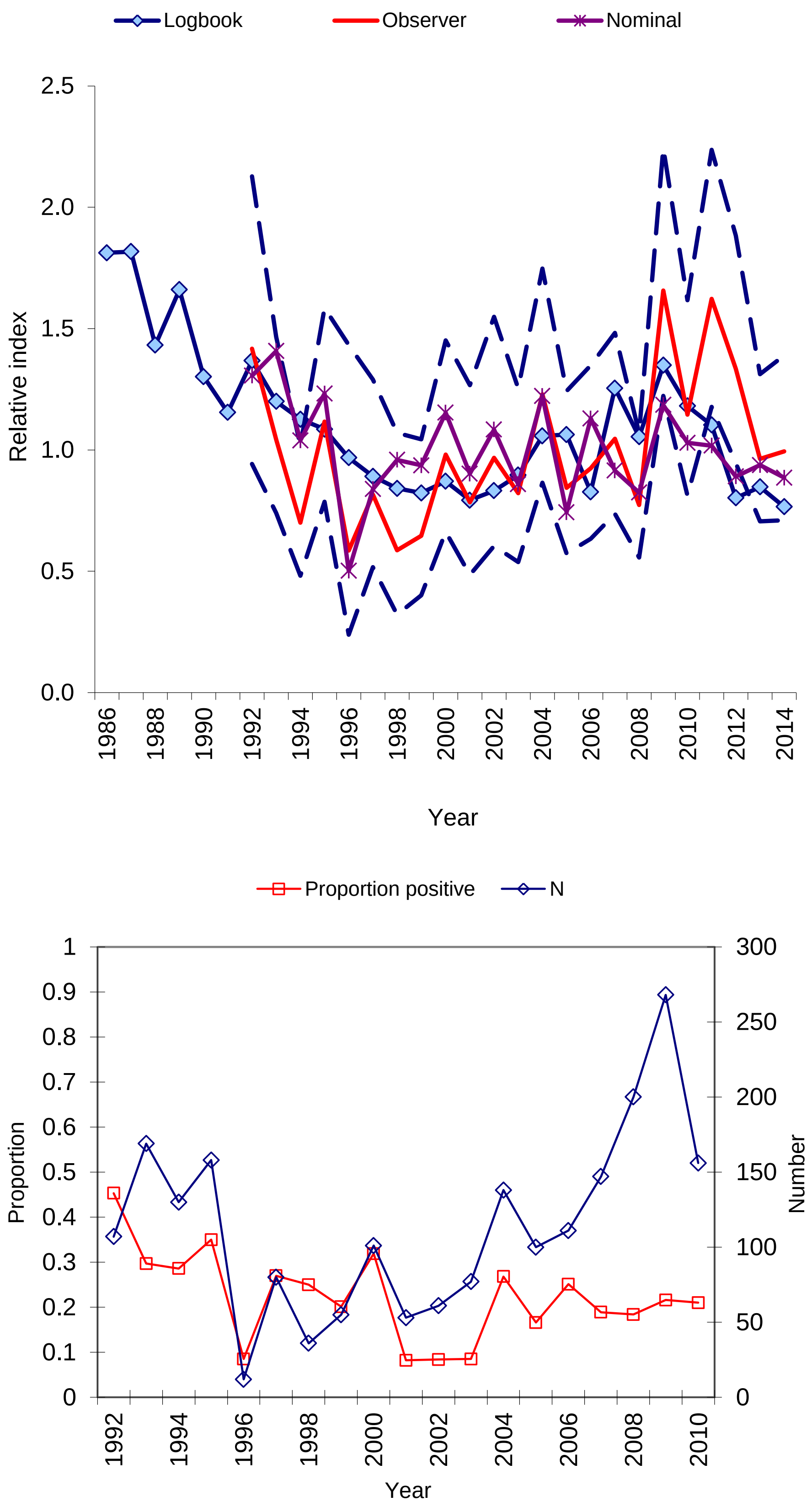


Figure 5. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for mako sharks from the US pelagic longline observer program compared to the logbook program. All indices are standardized to the mean of the overlapping years. The lower panel shows the proportion and number of positive sets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

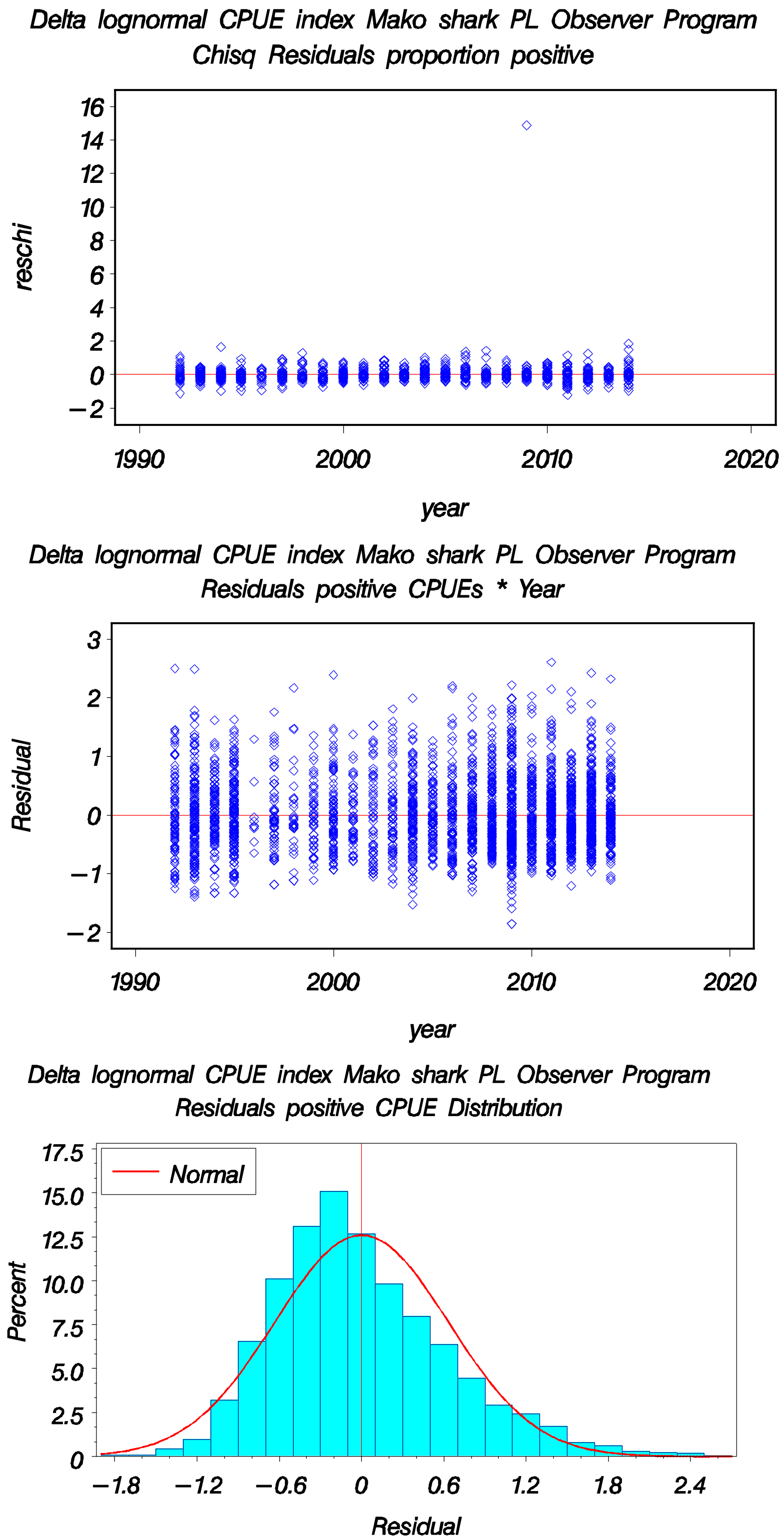


Figure 6. Diagnostic plots of CPUE model from US pelagic longline observer data for mako sharks. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution.

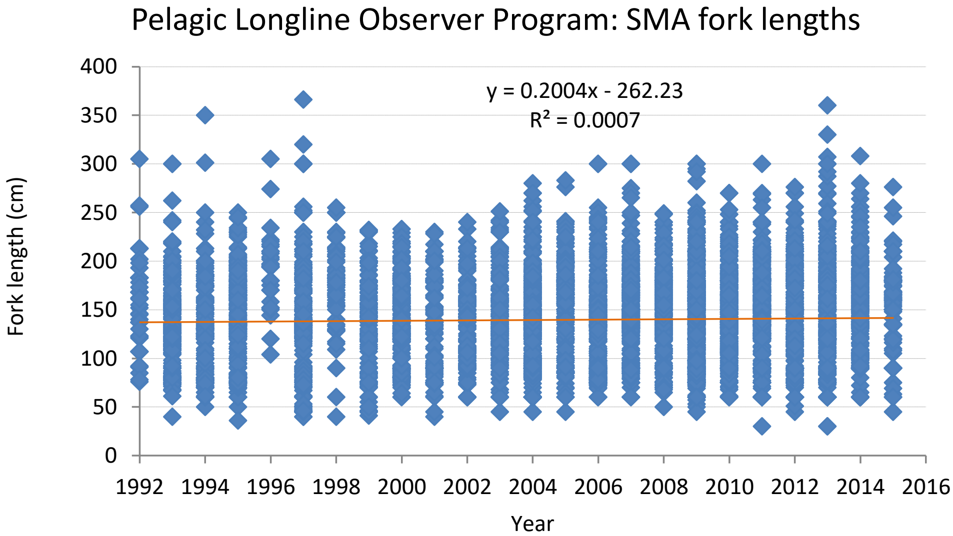
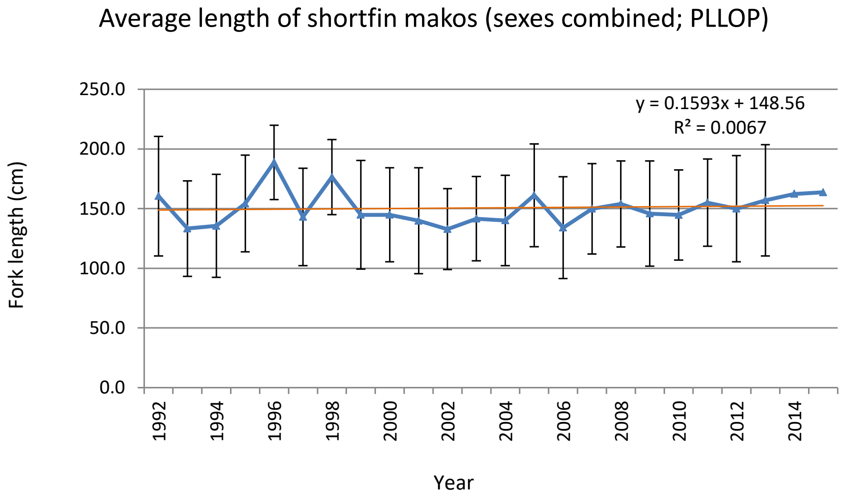
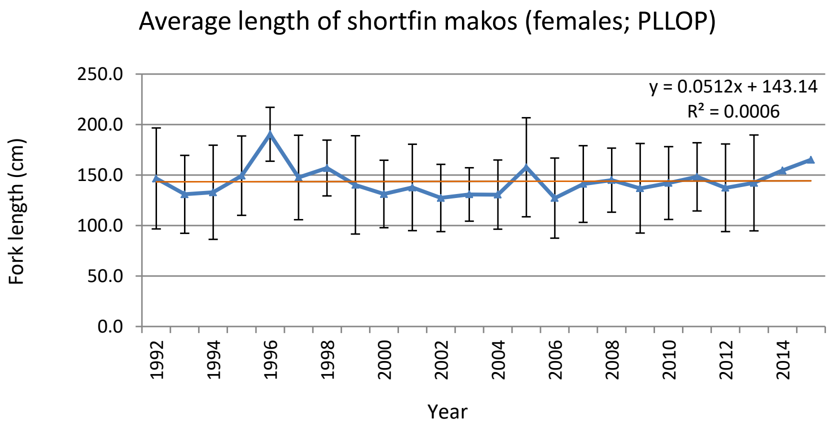


Figure 7. Scatter plot of shortfin mako lengths from the Pelagic Longline Observer Program, 1992-2014.





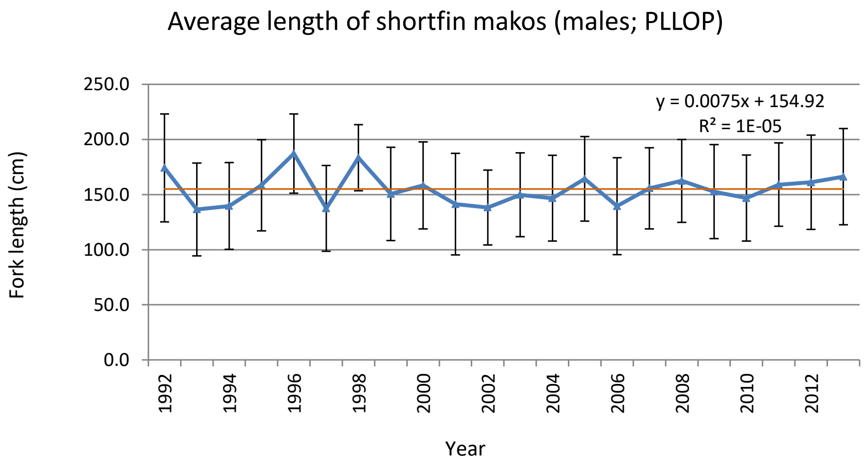
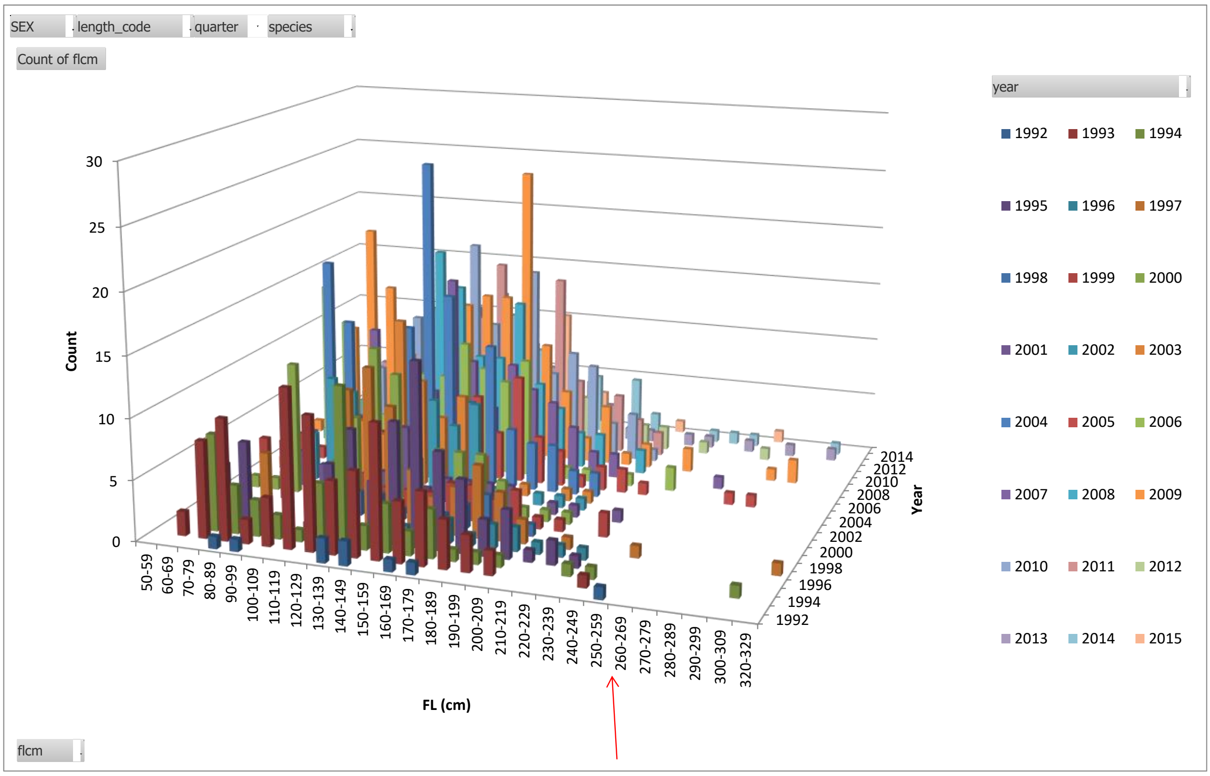


Figure 8. Average lengths of shortfin makos from the Pelagic Longline Observer Program, 1992-2014. Error bars are ±1 SD.



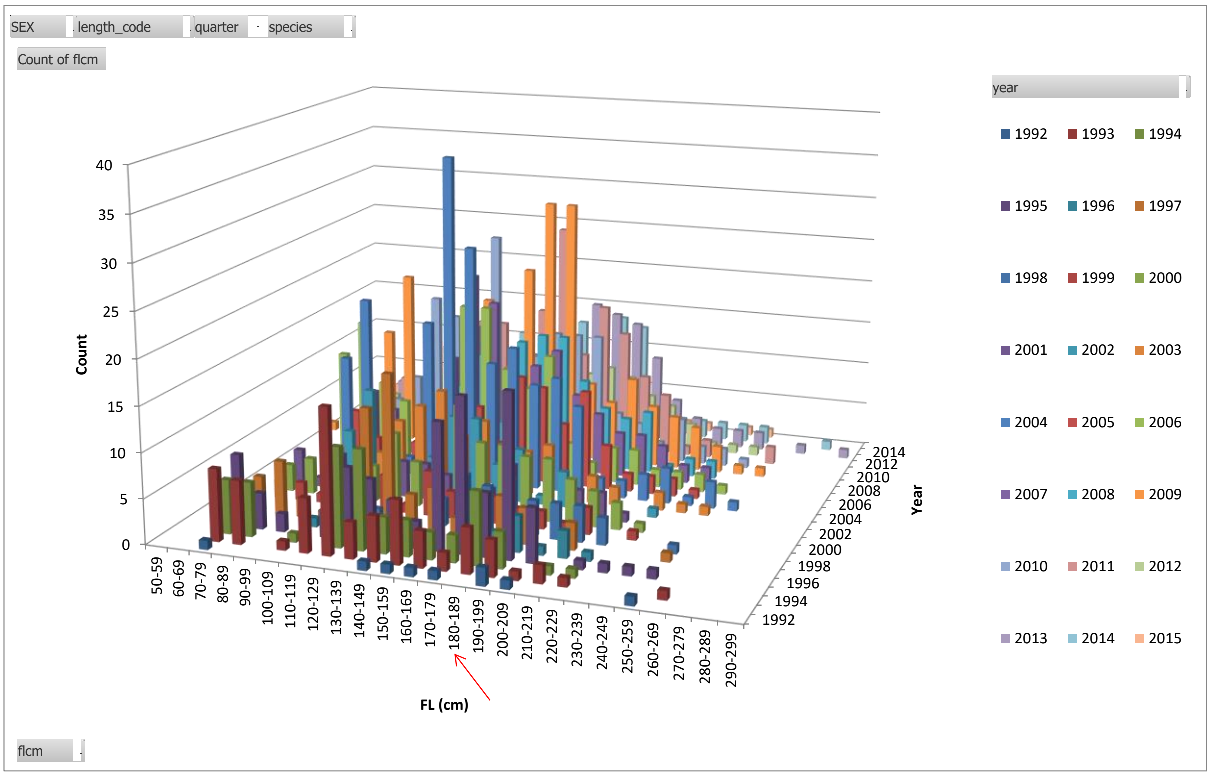


Figure 9. Length frequencies of shortfin makos from the Pelagic Longline Observer Program, 1992-2014, for females (top) and males (bottom). The arrows indicate approximate size at maturity.

Appendix table 1. 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 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		307017				
Area	7	266415	40602	32.10%	88.1%	<0.0001
Area Sqr	3	261688	4727	1.78%	10.3%	<0.0001
Area Sqr Year	29	260953	735	0.77%	1.6%	<0.0001

Model factors positive catch rates	**d.f.**	**Residual deviance**	**Change in deviance**		**% of total deviance**	***p***
Null		26227				
Area	7	22807	3420	39.26%	57.6%	<0.0001
Area Tqr	3	22284	523	4.77%	8.8%	<0.0001
Area Tqr Year	29	21904	380	3.09%	6.4%	<0.0001
Area Tqr Year Quarter	3	21553	351	6.08%	5.9%	<0.0001
Area Tqr Year Quarter Year*Area	200	20734	819	1.15%	13.8%	<0.0001
Area Tqr Year Quarter Year*Area Tqr*Area	21	20293	441	-3.78%	7.4%	<0.0001

GLM Mixed Model	**deviance**	**AIC**	**BIC**
Proportion Positives			
Area Sqr Year	2007	2009	2013
Positive catch rates			
Area Tqr Year Quarter Year*Area Tqr*Area	106445	106449	106456

Appendix table 2. 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 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	% reduction	% of total deviance	*p*
Null		14661				
Area	3	13024	1637	32.10%	45.2%	<0.0001
Area Sqr	3	11730	1294	1.78%	35.8%	<0.0001
Area Sqr Year	23	11489	241	0.77%	6.7%	<0.0001
Area Sqr Year Sqr*Area	9	11224	265	100.77%	7.3%	<0.0001
Area Sqr Year Sqr*Area Year*Quarter	70	11042	182	200.77%	5.0%	<0.0001

Model factors positive catch rates	d.f.	Residual deviance	Change in deviance		% of total deviance	*p*
Null		1215				
Area	2	1122	93	39.26%	27.4%	<0.0001
Area Year	23	1066	56	4.77%	16.5%	<0.0001
Area Year Quarter	3	1020	46	3.09%	13.6%	<0.0001
Area Year Quarter Sqr	3	995	25	6.08%	7.4%	<0.0001
Area Year Quarter Sqr Year*Quarter	60	922	73	1.15%	21.5%	<0.0001
Area Year Quarter Sqr Year*Quarter Year*Area	38	876	46	-3.78%	13.6%	<0.0001

GLM Mixed Model	deviance	AIC	BIC
Proportion Positives			
Area Sqr Year Sqr*Area Year*Quarter	3276	3278	3283
Positive catch rates			
Area Year Quarter Sqr Year*Quarter Year*Area	5484	5490	5497