

STANDARDIZED CATCH RATES OF MAKO SHARKS IN THE WESTERN NORTH ATLANTIC OCEAN FROM THE U.S. PELAGIC LONGLINE OBSERVER PROGRAM 1992-2023

Xinsheng Zhang¹, Dean Courtney, and John Carlson

SUMMARY

An updated index of abundance was developed for mako sharks (Isurus spp.) from the U.S. pelagic longline fishery observer program (1992-2023). The index was 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 excluded from the analysis. The standardized index, reported with 95% confidence intervals, showed a concave pattern from the early 1990s to 2011, followed by a declining trend to 2020, except for 2 anomalously high values in 2016 and 2017. From 2020 to 2023, the index showed a subsequent increase.

RÉSUMÉ

Un indice d'abondance actualisé a été développé pour l'Isurus spp. à partir du programme d'observateurs de la pêcherie palangrière pélagique des États-Unis (1992-2023). L'indice a été calculé au moyen d'une approche delta-lognormale en deux étapes qui traite séparément la proportion d'opérations positives et la CPUE des captures positives. Les observations affectées par les réglementations en matière de pêche (fermetures spatiotemporelles ou restrictions concernant les appâts) ont été exclues de l'analyse. L'indice standardisé, présenté avec des intervalles de confiance de 95%, a montré une tendance concave du début des années 1990 à 2011, suivie d'une tendance à la baisse jusqu'en 2020, à l'exception de deux valeurs anormalement élevées en 2016 et 2017. De 2020 à 2023, l'indice a connu une nouvelle hausse.

RESUMEN

Se desarrolló un índice de abundancia actualizado para los marrajos (Isurus spp.) a partir del programa de observadores de la pesquería de palangre pelágico de Estados Unidos. (1992-2023). El índice se calculó utilizando un enfoque delta-lognormal en dos pasos que trata por separado la proporción de lances positivos y la CPUE de capturas positivas. Se excluyeron del análisis las observaciones afectadas por reglamentos de pesca (vedas espaciotemporales o restricciones de cebo). El índice estandarizado, notificado con intervalos de confianza del 95 %, mostró un patrón cóncavo desde principios de la década de 1990 hasta 2011, seguido de una tendencia decreciente hasta 2020, excepto por dos valores anómalamente altos en 2016 y 2017. De 2020 a 2023, el índice registró un aumento posterior.

KEYWORDS

Catch/effort, Commercial fishing, Longlining, Pelagic fisheries, Shark fisheries, Bycatch, Observer programs, Mako sharks

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

1. Introduction

A relative abundance index from the U.S. commercial pelagic longline fishery using data collected by the U.S. pelagic longline observer program was generated and used in the 2004, 2008, 2012, and 2017 ICCAT assessments of shortfin mako sharks (ICCAT 2005, 2009, 2013, 2018). In this document, the pelagic longline commercial series is updated to examine recent trends in the relative abundance of mako sharks for use in the 2025 stock assessment of the North Atlantic shortfin mako stock. Indices of abundance for mako sharks from the U.S. commercial pelagic longline fishery observer program were previously developed by Brooks et al. (2005), Cortés (2007, 2009, 2013, 2016, 2017), and Cortés et al. (2007). The U.S. pelagic longline observer program managed by the U.S. NOAA/NMFS/Southeast Fisheries Science Center currently has a target coverage of 8% of the pelagic longline sets deployed by the fleet.

2. Materials and Methods

2.1 Data

The pelagic longline fishing grounds for the U.S. fleet traditionally extended from the Grand Banks in the North Atlantic to latitudes of 5-10° south, off the South American coast, including the Caribbean and the Gulf of America (Gulf of Mexico). However, the area of operation of the U.S. pelagic longline fleet has been spatially reduced for the past several years. For analysis purposes, the U.S. historically defined eleven domestic geographical areas of pelagic longline fishing are defined for classification (**Figure 1**): the Caribbean (CAR), Gulf of America (Gulf of Mexico) (GOM), Florida East Coast (FEC), South Atlantic Bight (SAB), Mid-Atlantic Bight (MAB), New England coastal (NEC), Northeast distant waters (NED or Grand Banks), Sargasso (SAR), North Central Atlantic (NCA), Tuna North (TUN), and Tuna South (TUS).

Data from the U.S. pelagic longline observer program were available since 1992. The observer dataset was restricted to areas GOM, MAB, NEC, and NED (north of 35° North latitude) due to insufficient and unbalanced observations across years in the remaining areas. These four areas collectively accounted for almost 90% of shortfin and unidentified mako sharks recorded in the observer dataset (**Figure 2**). Following Cortés (2017), shortfin and unidentified mako sharks were grouped as mako sharks in the observer analysis to account for mis-identification problems, especially in the early years of the time series. Shortfin mako shark comprised 86% of the combined total of shortfin and unidentified mako sharks recorded in areas GOM, MAB, NEC, and NED in the observer dataset.

Several data restrictions were implemented in the present analysis to account for time-area closures or bait restrictions following Walter and Laretta (2015) and Cortés (2017). 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 America (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 America (Gulf of Mexico) Gear Restricted Areas, closed April-May (**Figure 1**).

Based on the methodology used in Brooks et al. (2005), Cortés (2007, 2009, 2013, 2016, 2017), and Cortés et al. (2007), the following factors were considered in the analysis: year, area, quarter (January-March, April-June, July-September, October-December), presence or absence of light sticks, and 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 mako sharks 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, 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 in numbers 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 (i.e., pelagic longline sets that caught at least one mako shark) 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 positive 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 the 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 (-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. 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).

3. Results

Factors retained for modeling the proportion of positive sets were area, Sqr, year, year*quarter, and year*area; while the factors retained for modeling the positive catches were area, year, Tqr, Sqr, quarter, year*quarter, year*area, and Tqr*area (**Table 1**). The factor area explained 63.8% of the deviance for the proportion of positive sets and 37.8% for the positive catches (**Table 2**). The estimated standardized CPUE and CV values are given in **Table 3**. Trends in the nominal and the standardized indices were highly similar for most years (**Figure 3**). The standardized index, reported with 95% confidence intervals, showed a concave pattern from the early 1990s to 2011, followed by a declining trend through 2020, except for two anomalously high values in 2016 and 2017 (**Figure 3**). From 2020 to 2023, the index showed a subsequent increase (**Figure 3**). In contrast, the nominal index showed a decreasing trend during the last three years (2021-2023) (**Figure 3**). The sometimes large interannual fluctuations in the observer indices may be due to small sample sizes (14 - 248 positive sets per year; **Figure 3**). Diagnostic plots indicated good agreement with model assumptions, with no systematic patterns in the residuals (**Figure 4**).

4. Discussion

Trends in relative abundance predicted by this analysis were consistent with those from a previous study (Cortés 2017) during the overlapping years (1992–2015). Both series showed a concave pattern from the early 1990s to 2011, followed by a declining trend thereafter (**Figure 3**). The observer dataset has small sample sizes leading to large 95% confidence intervals and interannual variation. Sharp interannual changes in abundance, such as those sometimes displayed in 2016 and 2017, are inconsistent with the biology of most sharks, whose stock abundance is 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 U.S. 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). Other factors, such as hook size and type,

were not included in the analysis 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.

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Table 2. Deviance analysis table of explanatory variables in the delta lognormal model of the proportion of positive sets and the catch rates of positive sets of mako sharks from the U.S. pelagic longline fishery observer program data.

Model factors proportion positives	Deviance	Change in deviance	% of total deviance
Null	17642		
Area	15387	2255	63.8%
Area Sqr	14796	591	16.7%
Area Sqr Year	14535	261	7.4%
Area Sqr Year Year*Quarter	14359	176	5.0%
Area Sqr Year Year*Quarter Year*Area	14109	250	7.1%
Model factors positive catch rates	Deviance	Change in deviance	% of total deviance
Null	1756		
Area	1541	215	37.8%
Area Year	1446	95	16.7%
Area Year Tqr	1393	53	9.2%
Area Year Tqr Sqr	1368	26	4.5%
Area Year Tqr Sqr Quarter	1345	23	4.0%
Area Year Tqr Sqr Quarter Year*Quarter	1267	78	13.6%
Area Year Tqr Sqr Quarter Year*Quarter Year*Area	1206	61	10.8%
Area Year Tqr Sqr Quarter Year*Quarter Year*Area Tqr*Area	1187	19	3.4%

Table 3. Estimates of standardized 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	Standardized CPUE	CV	Nominal CPUE
1992	1.087	0.242	1.018
1993	0.787	0.222	1.104
1994	0.559	0.239	0.803
1995	0.848	0.219	0.949
1996	0.397	0.432	0.396
1997	0.513	0.282	0.668
1998	0.459	0.319	0.755
1999	0.430	0.279	0.765
2000	0.812	0.234	0.910
2001	0.626	0.275	0.682
2002	0.824	0.265	0.866
2003	0.666	0.253	0.686
2004	1.097	0.227	0.856
2005	0.874	0.224	0.650
2006	0.999	0.232	0.863
2007	0.840	0.246	0.603
2008	0.758	0.226	0.658
2009	1.085	0.217	0.736
2010	1.018	0.220	0.843
2011	1.267	0.205	0.798
2012	0.976	0.227	0.721
2013	0.768	0.224	0.790
2014	0.660	0.242	0.661
2015	0.563	0.260	0.900
2016	1.029	0.228	1.195
2017	1.340	0.231	1.536
2018	0.478	0.288	0.613
2019	0.426	0.289	0.562
2020	0.341	0.327	0.630
2021	0.445	0.282	0.917
2022	0.524	0.266	0.799
2023	0.644	0.264	0.604

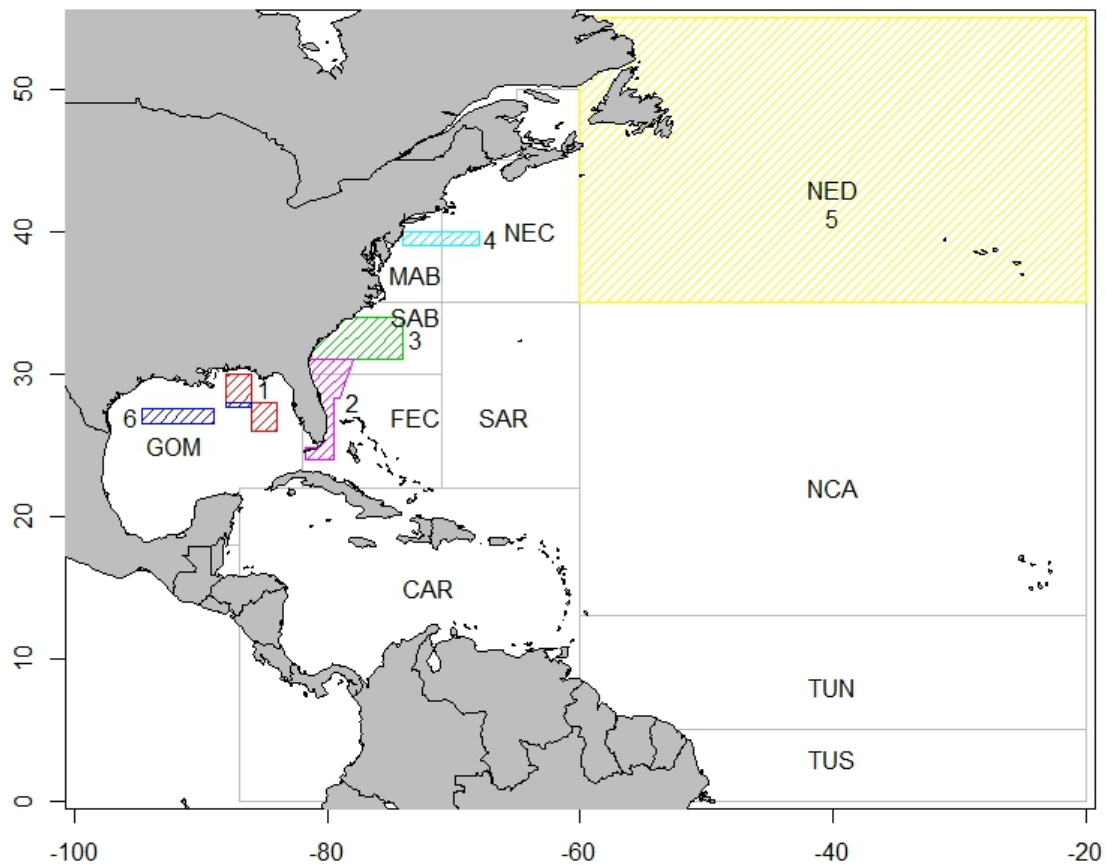


Figure 1. Eleven U.S. domestic geographical areas of pelagic longline fishing are as follows: CAR=Caribbean; GOM= Gulf of America (Gulf of Mexico); FEC=Florida East Coast; SAB=South Atlantic Bight; MAB=Mid-Atlantic Bight; NEC=Northeast Coastal; NED=Northeast Distant; SAR=Sargasso; NCA=North Central Atlantic; TUN=Tuna North; TUS=Tuna South. Time-area closures (designated by numbers on 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 America (Gulf of Mexico).

Mako sharks caught by U.S. domestic area of pelagic longline fishing (observers)

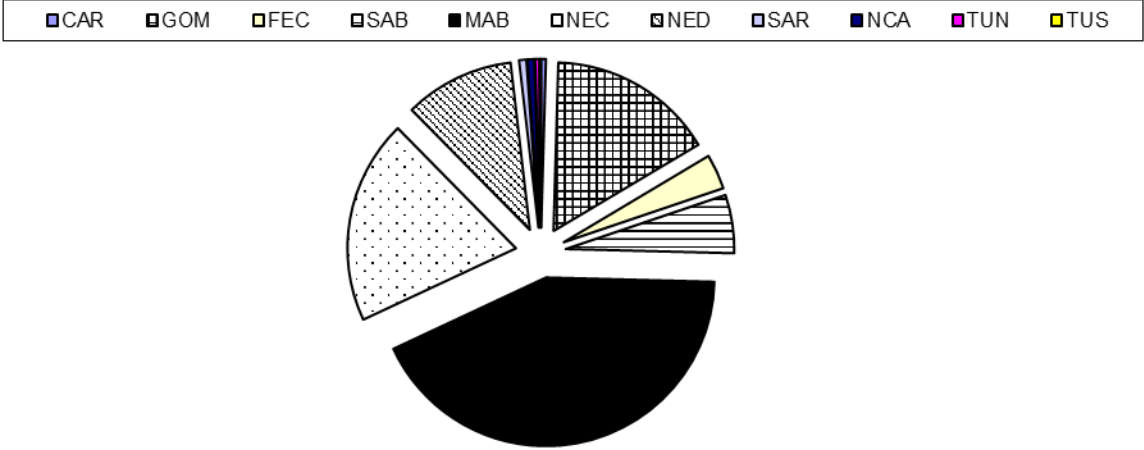


Figure 2. Mako sharks caught by the U.S. domestic area as reported in the pelagic longline observer program.

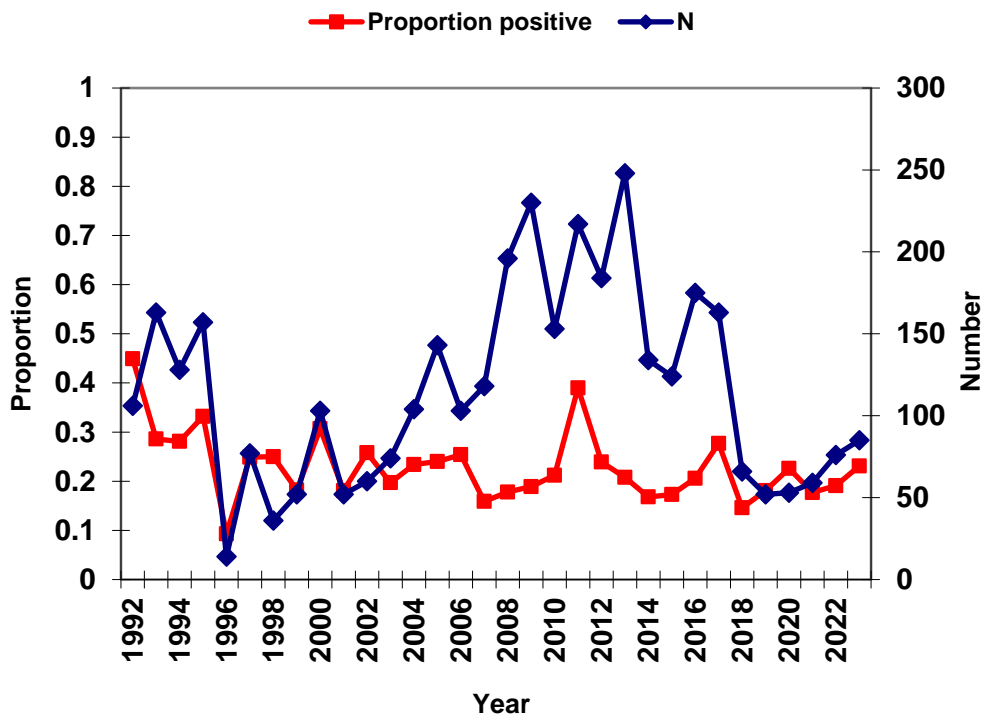
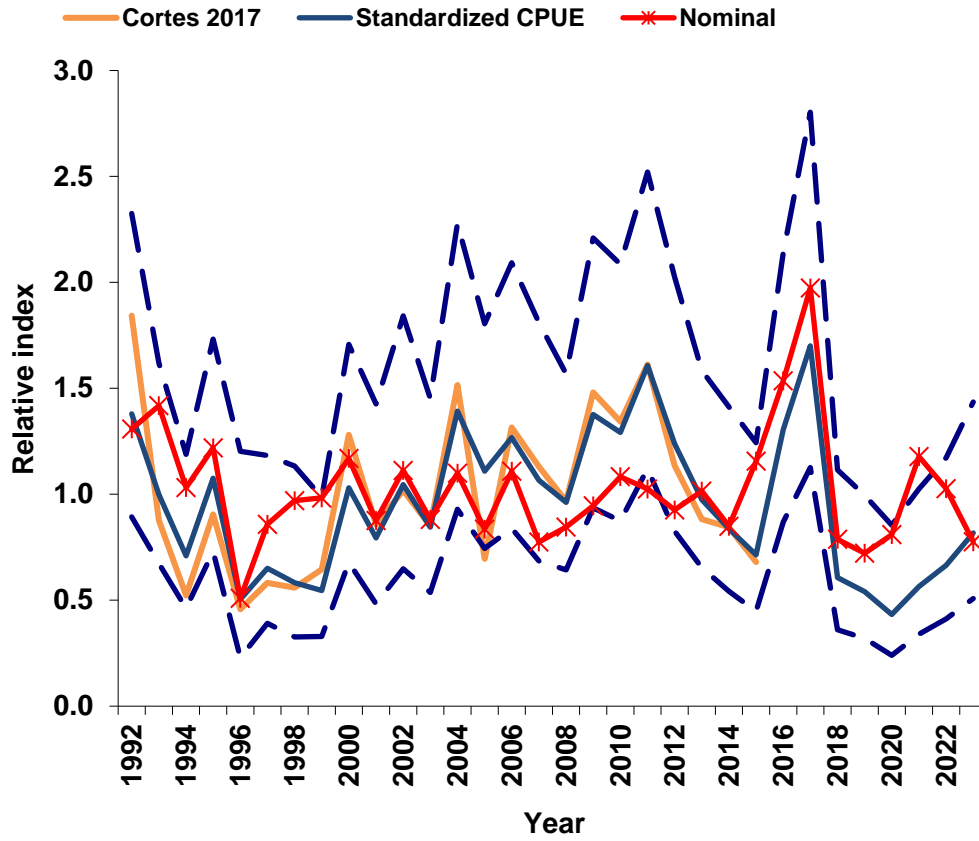


Figure 3. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals (dashed line) for mako sharks from the U.S. pelagic longline observer program compared to a previous study. All indices are scaled to the mean of the overlapping years (1992-2015). The lower panel shows the proportion and number of positive sets by year.

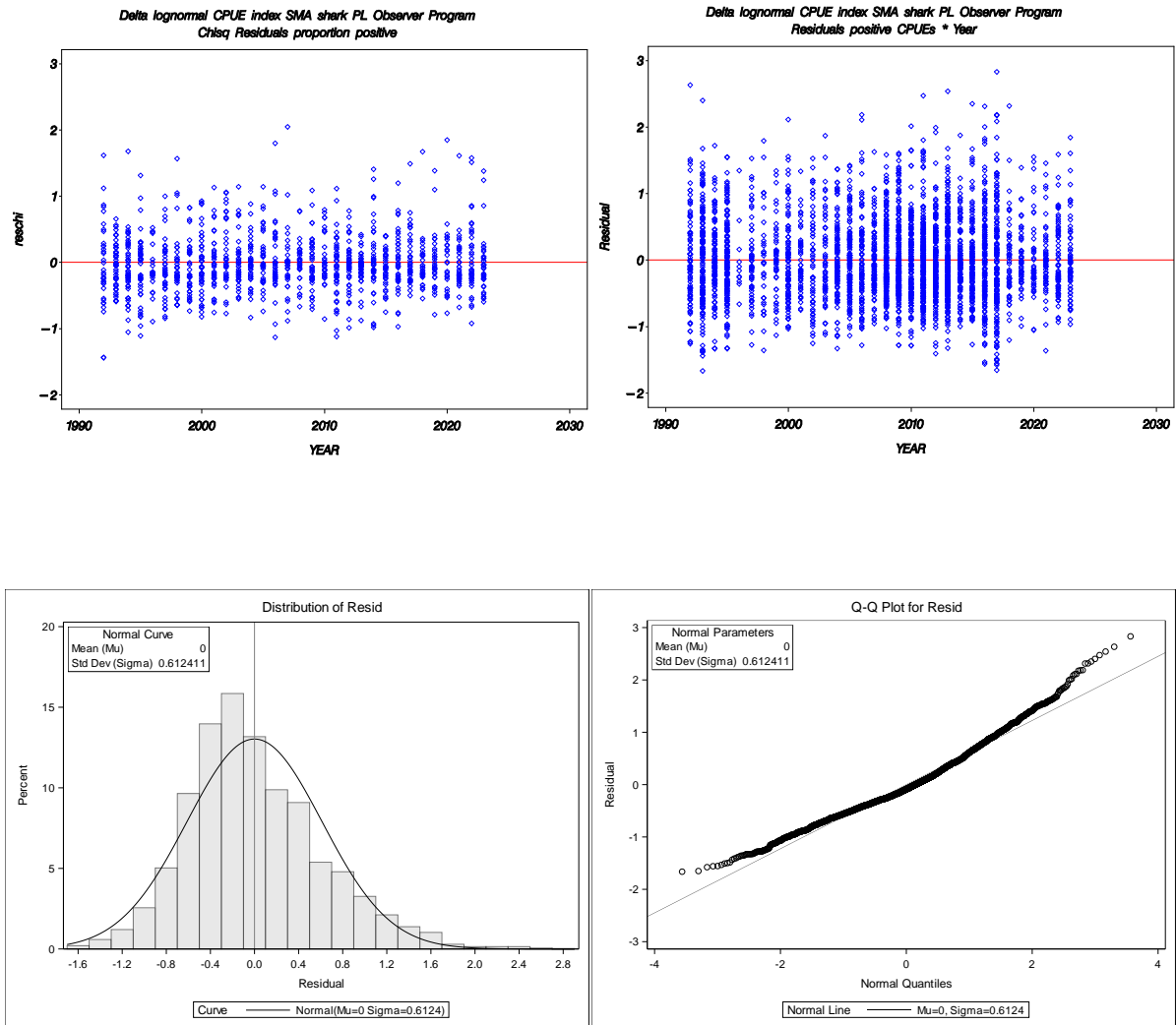


Figure 4. Diagnostic plots of CPUE model from U.S. pelagic longline observer data for mako sharks. Top left: residuals of proportion positive sets; top right: residuals of positive catch; bottom left: residual positive catch distribution; bottom right: QQ plot of residuals of positive catch.