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Standardized Catch Rates of Shortfin Mako Shark (*Isurus oxyrinchus*) caught by the Hawaii-based Pelagic Longline Fleet (1995-2019)

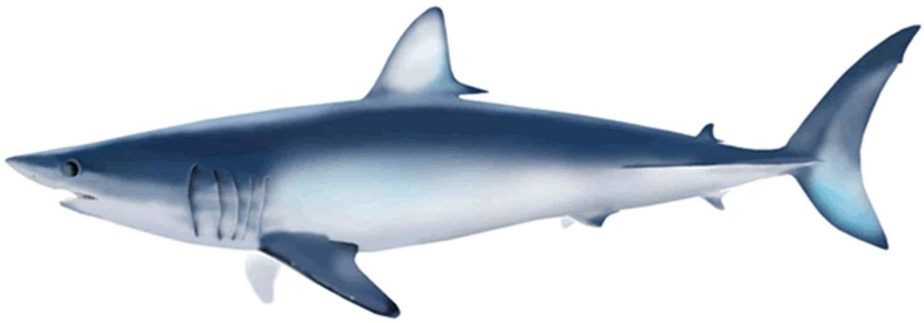
Felipe Carvalho[1]

1. NOAA Pacific Islands Fisheries Science Center

1845 Wasp Boulevard.

Honolulu, Hawaii 96818, USA

Email: felipe.carvalho@noaa.gov



Abstract

Catch and effort data from the Hawaii-based pelagic longline fishery operating in the North Pacific Ocean were analyzed to estimate indices of abundance for the shortfin mako shark between 1995 and 2019. The data come from the records of the Pacific Islands Regional Observer Program (PIROP) submitted to the Pacific Islands Fisheries Science Center (PIFSC). Nominal CPUEs were calculated separately for shallow-set (target: swordfish) and deep-set (target: bigeye tuna) sectors, and standardized with Generalized Linear Models (GLM), separately for each sector. Model validation was carried out with residual analysis. The best-fit models included variables year, quarter of the year, region, sea surface temperature, bait type, and interactions between quarter of the year and region. Overall, the standardized CPUE for the deep-set sector showed a stable trend from 1995 to 2016, followed by an increase in the last three years, while the standardized CPUE in shallow-set sector showed a slightly decrease up to 2012, followed by an increase in 2013.

Introduction

In recent years, there has been increasing concern about the deteriorating status of the world's pelagic shark and ray populations (Dulvy et al., 2008). A general lack of data and complex management jurisdictions present challenges to manage and conserve open water shark populations. Based on reported and estimated unreported landings globally. Most threatened shark species, including the shorfin mako (*Isurus oxyrinchus*), suffer high fishing mortality throughout their range and have low rates of population increase. The shortfin mako's low reproductive potential, late sexual maturity and long life span decrease resilience to fishing pressure and increase recovery times from harvest.

There are no directed commercial fisheries for shortfin mako shark in Hawaii, however, it is often caught as a bycatch in the Hawaii-based pelagic longline fishery. Shortfin mako shark comprised 2.8% of all captured sharks reported by fishery observers in 1995–2006 (Walsh et al., 2009). The population status of shortfin mako shark in waters fished by the Hawaii-based pelagic longline fleet is presently unclear. Walsh et al. (2009) conducted the first overview of shortfin mako shark caught in this fishery, and concluded that catch rates for this species were stable for the deep-set sector, and increased 389% between 1995-2000 and 2004-2006 in the shallow-set sector of this fishery. At present, it is unknown if this increase reflected a change in abundance or rather the influence of one or more operational factors. In contrast with these findings, Clarke et al. (2012) reported that standardized mako shark (*I. oxyrinchus* or *Isurus paucus*) CPUE from observed longline fishing in the northern hemisphere in regions overseen by the Western and Central Pacific Fisheries Commission (WCPFC) declined significantly between 1996 and 2010.

The objective of this working paper (WP) is to present the Shark Working Group of the ISC (SHARKWG) the standardized CPUE time series for shortfin mako shark from the Hawaii-based pelagic longline fishery between 1995 and 2019. The main source of data is operation-level reports for the fishery collected by observers in the NOAA Fisheries Pacific Islands Regional Observer Program (PIROP) and maintained in an Oracle database at the Pacific Islands Fisheries Science Center (PIFSC).

Materials and methods

Results for the standardized shortfin mako shark annual CPUE from observer records were presented separately for shallow-set (target: swordfish) and deep-set (target: bigeye tuna) sectors. The two set types were defined according Federal Register (Department of Commerce, 2004). Shallow-sets used < 15 hooks per float whereas deep-sets used ≥ 15 hooks per float (Walsh et al., 2009). Data from the shallow-set sector were tabulated from 1995–2000 and 2005–2013. The latter years represent the period after the reopening of this sector, and had mandatory 100% observer coverage (i.e., an observer was aboard all shallow-set trips). For the former period annual observer coverage in the shallow-set sector was generally below 5%. There are no 2001-2004 shallow-set data because the fishery was closed from mid-March 2001 until April 2004. In the latter part of 2000 observer coverage in the deep-set sector was increased and subsequently maintained at about 20% annually from 2001 to present. Prior to that, annual observer coverage in the deep-set sector was also generally below 5%. Observer data presented here thus represent a subsample of the fishery, and are only partially complete for the shallow-set sector from 2004 to present; in addition to the closure previously described, the shallow-set fishery was suspended in 2006, from mid-March through the end of the year, and again for the last several weeks of 2011. So, relative values of catch and effort for the deep-set and shallow-set sectors do not represent the real proportions of catch and effort between these sectors. The analysis presented in this WP range from 1995 to 2019 for the deep-set sector and 2005 to 2019 for the shallow-set sector.

The longline sets were distributed throughout a wide area in the north-central Pacific Ocean around the Hawaiian Islands, ranging from 50^0 N to 0^0 latitude and 180^0 W to 135^0 W longitude. This total fishing ground was divided into eight regions, based on Walsh and Teo (2012). Along with the increase in observer coverage in 2000, the observer sampling design was improved with the intent to provide a more unbiased and representative sample of the deep-set fishery, so that seasonality and geographic distribution of the observed data should reflect similar patterns as the entire sector.

Statistical modeling

For this analysis, 61% and 76%of the total longline sets had zero catches of shortfin mako shark in the shallow and deep set fishery sectors, respectively. There are numerous ways to deal with zero catches when standardizing CPUE (Maunder and Punt 2004). For the analysis presented here, we used a delta-lognormal approach, wherein CPUE was modeled as the product of two processes: a Bernoulli process modeling the probability of positive catches, and a positive process modeling the distribution of CPUE given a positive catch, which we assumed was lognormal. The response variable for the Bernoulli process was a binomial variable that was added to the dataset, indicating whether a shortfin mako shark was captured (1 = captured, 0 = not captured). The relationship between the response variable and the predictor variables was modeled as a Binomial distribution using a logit link function. The response variable for the positive process, which we hereafter refer to as the lognormal process, was the natural logarithm of CPUE from positive catches of shortfin mako shark. A Poisson and negative binomial distribution were also considered in place of the delta-lognormal as alternative ways to include zero catches, but were ultimately not used. Models using the Poisson distribution had higher overdispersion constants of greater than 570, where values of greater than zero suggest overdispersion (Cameron and Trivedi 1990), and models using the negative binomial distribution had convergence issues.

Model selection techniques were used for each of the Bernoulli and lognormal processes to select from the suite of possible predictors those predictors that most improved model fit. Predictor variables for model selection included a mix of categorical and continuous variables, as well as fixed and random effects. Each variable was considered to have some effect on shortfin mako CPUE that varied on an annual basis because of changes in the distribution of fish or the spatial pattern and effectiveness of fishing effort. Categorical variables included fishing year, region, quarter of the year, and bait type (saury, mackerel, sardine, mixed, Other) as first order variables, and area-fishing year and area-quarter as second-order interactions. Continuous variables included sea surface temperature (SST; °C) and hooks-per-float. Preliminary examination of the continuous variables showed some non-linearity in SST with positive CPUE, and so an additional term for the square of SST was included to allow a quadratic effect of SST. All variables were modeled as fixed effects.

Selection among CPUE standardization models was performed using Akaike's information criterion (AIC = 2*number of parameters – 2*log(likelihood evaluated at its maximum)) to judge the relative goodness of fit. Model selection was done using a forward-selection process, using a threshold of 0.05% of the previous model's AIC. Thus, if the improvement in AIC of a model after adding a new predictor was greater than 0.05% of the previous model's AIC, the added predictor was considered significant, and kept for the best fitting model. Statistical modeling was done with the lme4 package version 3.2 within the R software package version 5.2.

Index calculation

Once the set of factors that minimized AIC were selected and diagnostics indicated model assumptions were not violated, an index of relative abundance was generated using the best-fit models for each fishery sector, separately. Predicted values of the response variable from each model were calculated using the predict function in R. The predicted values from the positive process were multiplied by the exponential of one-half the residual variance to correct for bias when back-transforming from ln(CPUE) to CPUE. The index I_t was then calculated as the product of the mean probability of catching a shortfin mako shark in year t and the mean CPUE in year t calculated from positive catches of shortfin mako shark.

Results

Standardized CPUE

The best-fit model for the shortfin mako shark CPUE standardization for both fishery sectors are provided in Tables 1 and 2. The Bernoulli model for the Shallow set fishery sector included the variables year, quarter of the year, region, SST, and the interaction quarter of the year*region (Table 1). The best-fit model for the lognormal process model for the Shallow set fishery sector included year, quarter of the year, bait type, and the interaction quarter of the year*region (Table 1).

The best-fit model for the Bernoulli process for the Deep set sector included the variables year, quarter of the year, region, SST, and the interaction quarter of the year*region (Table 2). The best-fit model for the lognormal process model for the Deep set fishery sector included year, quarter of the year, region, the interaction quarter of the year*region (Table 2).

Regression diagnostics were used to qualitatively check model assumptions. Model fit was assessed through visual comparison of residuals plotted against predicted values of the response variable and against values of the predictor variables. Pearson residuals were used for all models for the lognormal process, and quantile residuals were used for all models for the Bernoulli process as recommended by Dunn and Smythe (1996). Plots of the quantiles of the standardized residuals to the quantiles of a standard normal distribution were also used for models for the lognormal process, to assess assumptions of normality.

Diagnostic residual plots and summary output of best-fit models show some deviation from assumptions about heteroscedasticity in models for the Bernoulli and lognormal process but, in general, models seemed appropriate. The histogram of quantile residuals did not indicate a violation of normality. Altogether, we do not consider the diagnostic plots to indicate serious violations in model assumptions for the Bernoulli and lognormal process.

Overall, the standardized CPUE time series for shortfin mako shark in the North Pacific Ocean showed some variability. The standardized CPUE for the deep-set sector showed a stable trend from 1995 to 2016, followed by an increase in the last three years for the deep-set sector (Figure 5). The shallow-set sector showed a decrease from 2006 to 2012, followed by an increase trend in 2013 (Figure 5). The final Standardized CPUE values as well as the calculated 95% Confidence Intervals and CV's are presented in Table 3.

References

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Table 1. Deviance of the parameters used to standardize the north Pacific shortfin mako shark CPUE series from the Shallow set fishery sector of the Hawaii-based longline fishery between 2005 and 2019.

Bernoulli process

Selected predictor	DF	Delta AIC	Explanation of null deviance (%)
Null		**0**	**-**
+ Year	**14**	**5612.12**	**8.54**
+ Region	**5**	**4809.84**	**7.57**
+ Quarter	**3**	**1858.77**	**4.32**
+ SST	**1**	**8556.80**	**11.91**
+ quarter*Region	**15**	**1700.62**	**4.16**

Lognormal process

Selected predictor	DF	Delta AIC	Explanation of null deviance (%)
Null		**676.16**	**4.47**
+ Year	**14**	**903.06**	**6.19**
+ Quarter	**3**	**1081.40**	**10.90**
+ Bait type	**4**	**343.18**	**3.21**
+ quarter*Region	**15**	**676.16**	**4.47**

Table 2. Deviance of the parameters used to standardize the north Pacific shortfin mako shark CPUE series from the Deep set fishery sector of the Hawaii-based longline fishery between 1995-2019.

Bernoulli process

Selected predictor	DF	Delta AIC	Explanation of null deviance (%)
Null		0	-
+ Year	24	862.26	4.77
+ Region	7	2151.08	7.38
+ Quarter	3	1928.23	6.80
+ SST	1	1295.81	6.07
+ Quarter*Region	20	2979.15	9.26

Lognormal process

Selected predictor	DF	Delta AIC	Explanation of null deviance (%)
Null		0	-
+ Year	24	592.05	7.38
+ Quarter	3	285.09	4.19
+ Region	7	669.06	10.27
+ Quarter*Region	20	148.33	1.88

Table 3. Nominal and standardized CPUEs for Shortfin mako caught by the Hawaii based pelagic longline fleet. The point estimates, 95% confidence intervals and the CV of the standardized index are presented separated by fishery sector.

Shallow set fishery sector

		Standardized CPUE index			
Year	Nominal	Estimate	Lower CI	Upper CI	CV (%)
2005	8.020108	8.21271	6.61332765	9.75861427	29.12
2006	8.891224	9.334593	7.92550537	10.7436805	21.04
2007	7.484725	7.554449	6.28397857	8.88211177	25.05
2008	7.496554	7.266799	6.17935705	8.35423913	29.05
2009	6.207766	6.671026	5.03340973	7.90784312	34.06
2010	8.111157	7.600257	6.03637465	9.1641397	41.08
2011	5.683052	6.312997	5.34737641	7.47901718	33.06
2012	5.939122	6.066627	4.79274378	7.29368756	25.07
2013	7.273976	7.713526	6.49064839	8.53560413	29.07
2014	7.923921	8.334046	7.15384814	9.51424351	38.13
2015	8.347464	8.012509	6.98097498	8.74006925	27.05
2016	7.861221	8.600166	7.72811037	9.5423466	35.07
2017	9.59855084	10.00795	7.9554154	9.79311264	29.97
2018	8.54907784	8.913711	8.41768954	10.3621719	31.38
2019	8.73469034	9.10724	10.1373816	12.479112	28.19

Table 4. Nominal and standardized CPUEs for Shortfin mako caught by the Hawaii based pelagic longline fleet. The point estimates, 95% Confidence Intervals and the CV of the standardized index are presented separated by fishery sector.

Deep set fishery sector

		Standardized CPUE index			
Year	Nominal	Estimate	Lower CI	Upper CI	CV (%)
1995	1.2880259	1.347814	0.452136	2.243493	37
1996	0.4204644	0.546626	0.157673	0.935567	24
1997	0.8558135	0.651327	0.167301	1.135354	22
1998	0.4053766	0.468388	0.089947	0.846832	19
1999	1.2245898	1.017824	0.561061	1.774579	21
2000	0.5268756	0.552504	0.092887	1.012121	18
2001	0.5151523	0.600327	0.277566	0.923034	30
2002	0.8437135	0.721185	0.336485	1.105889	23
2003	0.7434624	0.659821	0.331274	1.048367	24
2004	0.4281664	0.537544	0.202985	0.672102	17
2005	0.8099002	0.731651	0.343377	1.059926	24
2006	0.7828637	0.764726	0.368161	1.061291	26
2007	0.6925821	0.782918	0.362765	1.003076	25
2008	1.3515962	1.036740	0.596172	1.477308	19
2009	0.9759742	0.946721	0.469058	1.324385	18
2010	0.52068465	0.757408	0.368251	1.146565	19
2011	0.8169125	0.826971	0.488878	1.285051	29
2012	0.8266084	0.720464	0.395285	1.045647	24
2013	1.1019509	0.956302	0.528371	1.284233	21
2014	0.9969926	0.926769	0.539418	1.314126	20
2015	1.0802377	0.963097	0.616294	1.389967	18
2016	0.9999314	0.908549	0.527194	1.295638	21
2017	1.109923	1.00788	0.58497	1.4319	23
2018	1.284356	1.166276	0.676902	1.656933	25
2019	1.414347	1.284316	0.745412	1.824633	26

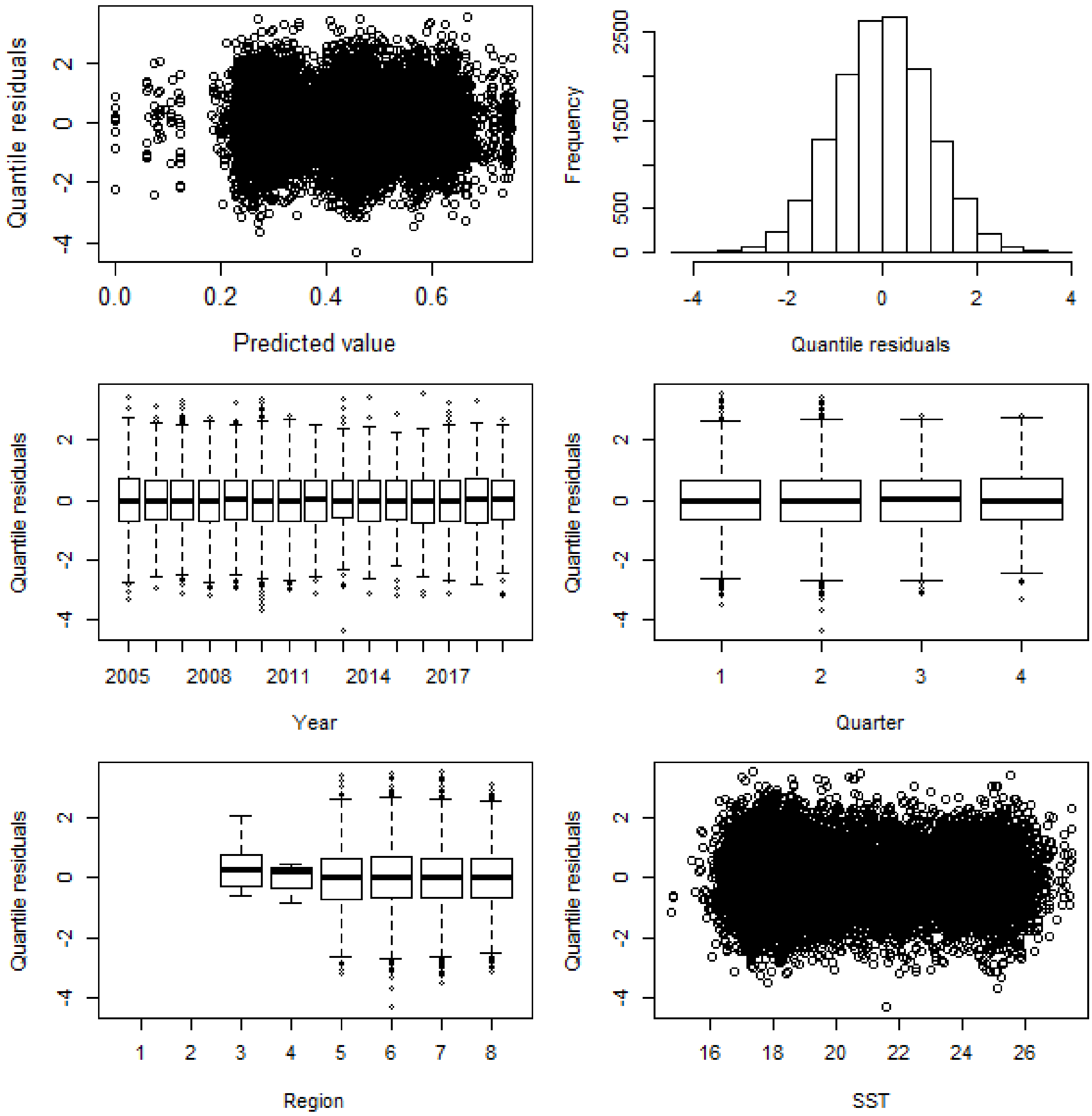

Figure 1. Model diagnostics for the best fit Bernoulli model for the Shallow set fishery sector. Diagnostic plots include plots of quantile residuals against model predicted values (to assess heteroscedasticity), histogram of quantile residuals (to assess normality), and plots of quantile residuals against values of each predictor variable (to assess patterning in the predictor variables).

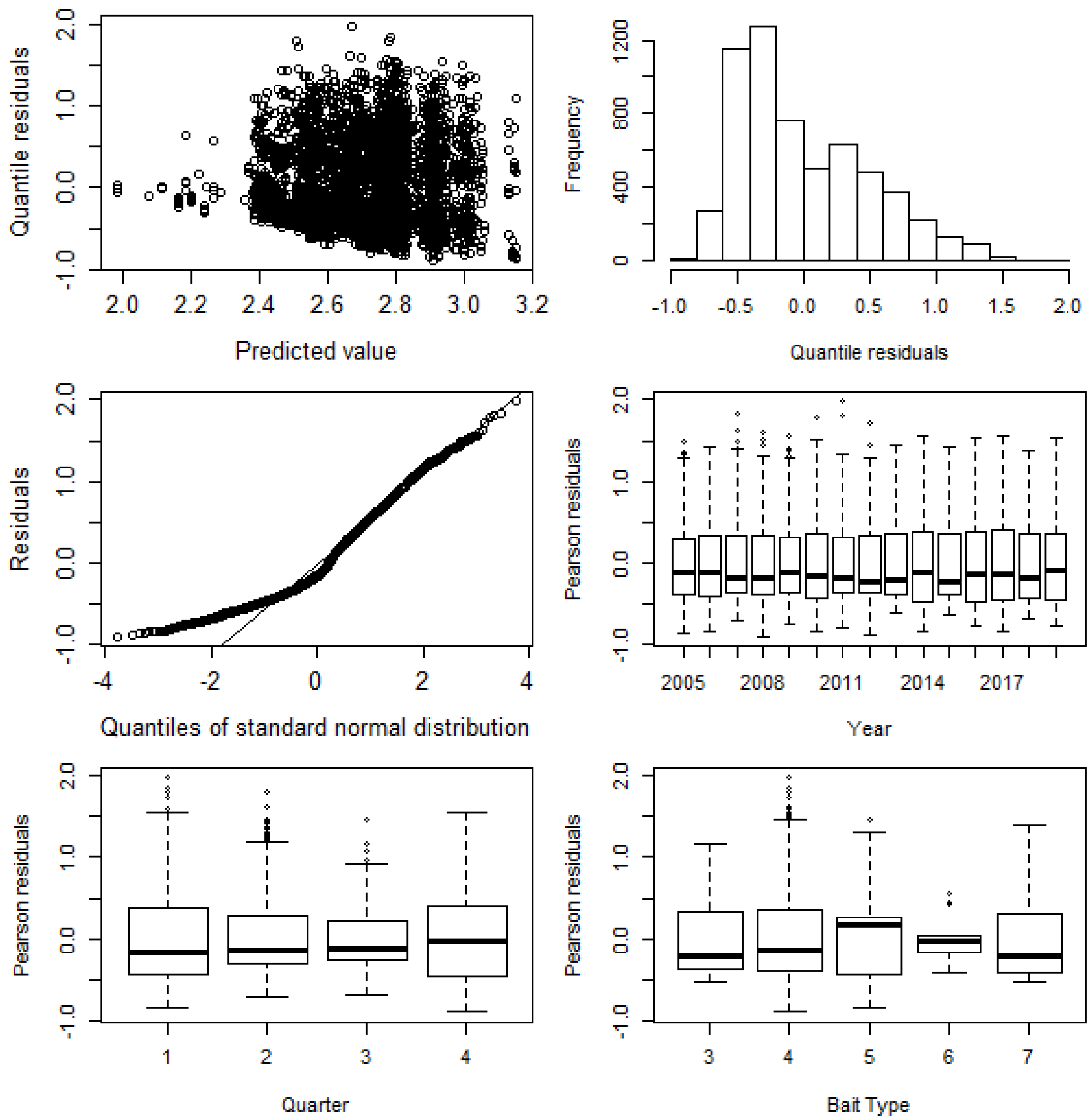

Figure 2. Model diagnostics for the best fit Lognormal model for the Shallow set fishery sector. Diagnostic plots include plots of quantile residuals against model predicted values (to assess heteroscedasticity), histogram of quantile residuals and the quantile-quantile plot (to assess normality), and plots of quantile residuals against values of each predictor variable (to assess patterning in the predictor variables).

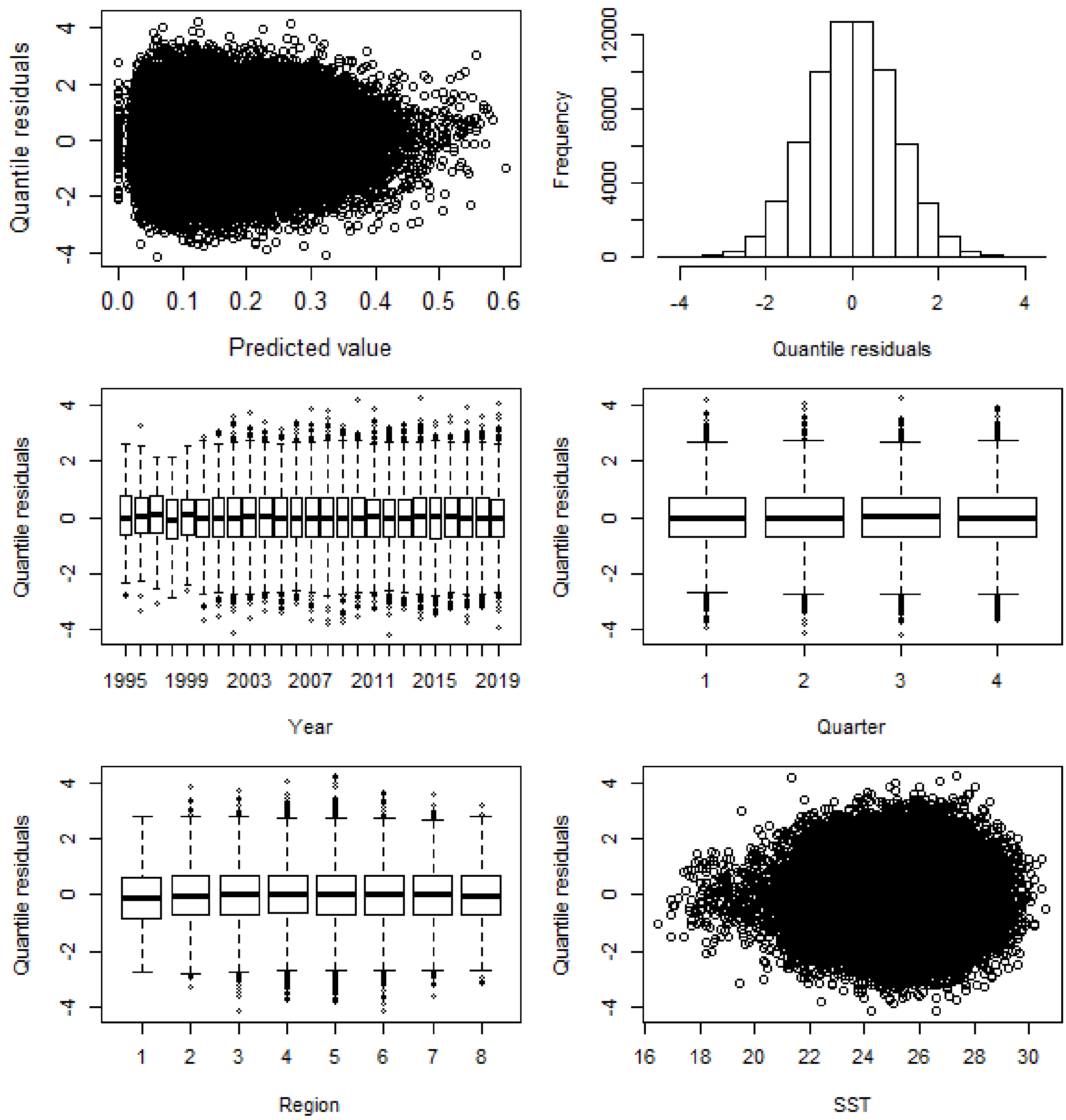

Figure 3. Model diagnostics for the best fit Bernoulli model for the Deep set fishery sector. Diagnostic plots include plots of quantile residuals against model predicted values (to assess heteroscedasticity), histogram of quantile residuals (to assess normality), and plots of quantile residuals against values of each predictor variable (to assess patterning in the predictor variables).

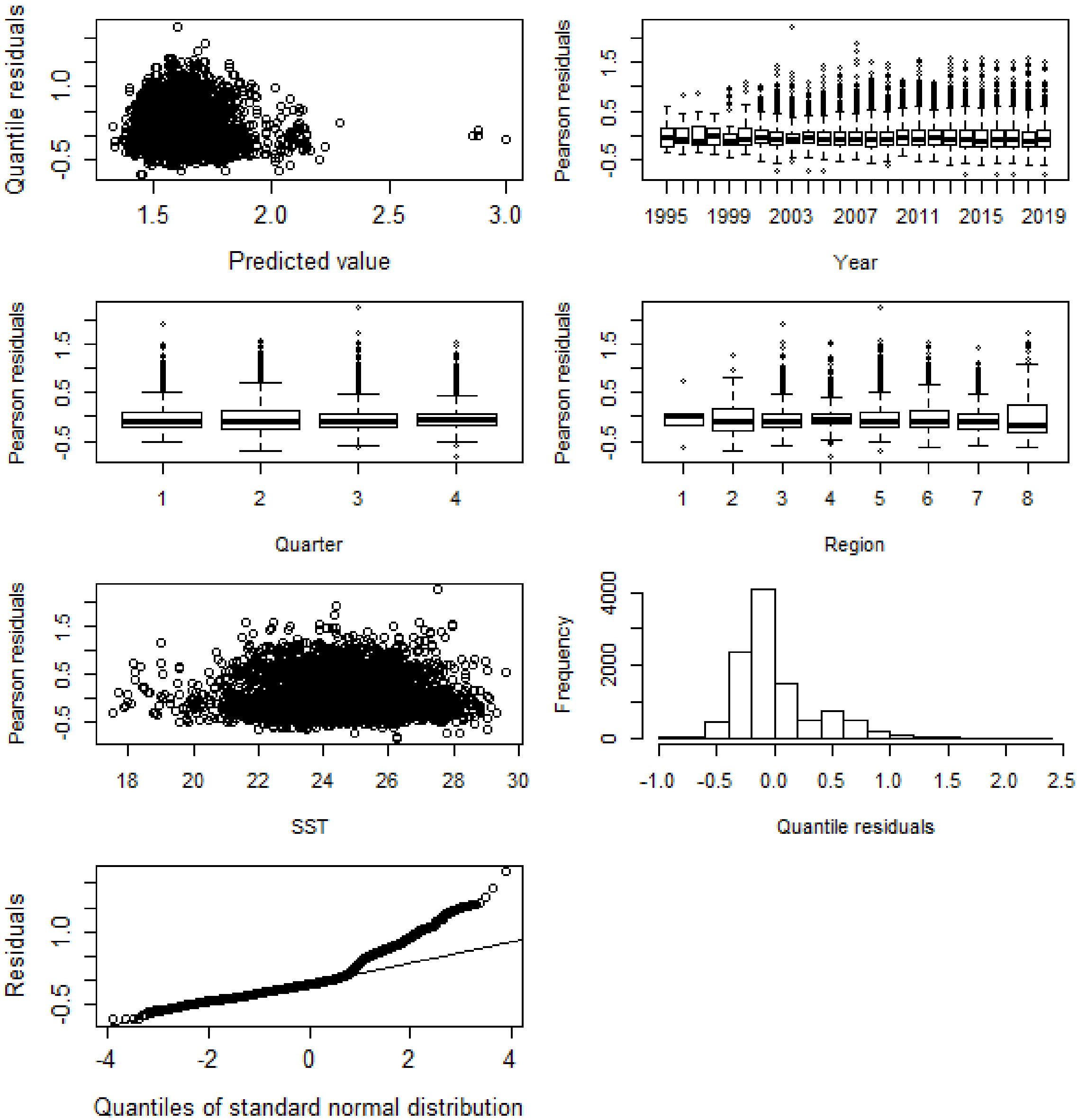

Figure 4. Model diagnostics for the best fit Lognormal model for the Deep set fishery sector. Diagnostic plots include plots of quantile residuals against model predicted values (to assess heteroscedasticity), histogram of quantile residuals and the quantile-quantile plot (to assess normality), and plots of quantile residuals against values of each predictor variable (to assess patterning in the predictor variables).

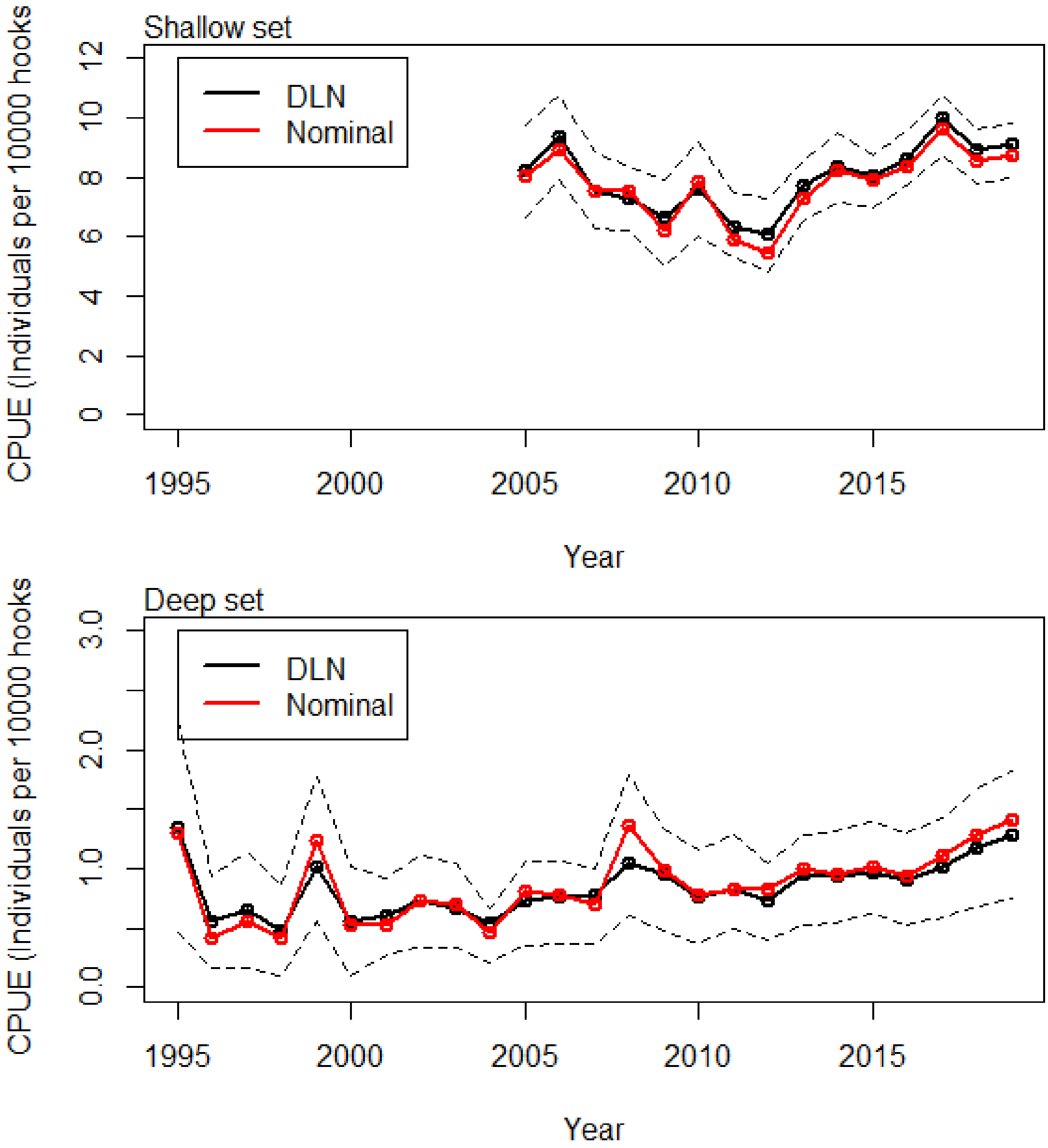

Figure 5. Nominal (red line) and standardized (black line) CPUE of shortfin mako sharks caught by the Hawaii-based longline fleet. Dotted lines are the 95% CI.