Standardization of Pacific Blue Marlin Catch Per Unit Effort in the Hawaii Longline Fishery from 1995-2019

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Abstract

This working paper provides the standardization of the Hawaii-based longline fishery blue marlin (*Makaira mazara*) catch per unit effort (CPUE) data. Three different distributions with up to 14 different explanatory variables were explored for the combined and deep-set sector dataset. The lognormal generalized linear mixed model (GLMM) provided the best fit to the data based upon percent deviance explained. Results showed that the deep-set sector standardized CPUE was very similar to the combined dataset except in the first few years of the time series. The shallow-set CPUE series was higher than the other CPUE time series and highly variable making it a poor candidate for inclusion in the assessment model. The diagnostics of the deep-set dataset do not suggest any problems with poorly fitted data; therefore, it was recommended to use the deep-set dataset GLMM standardized CPUE for the 2021 blue marlin base-case assessment model.

Introduction

Indo-Pacific blue marlin (*Makaira mazara*) is a tropical and subtropical species of billfish found in the Pacific Ocean. It is often caught as a non-target species in longline fisheries targeting tuna and swordfish, although it is targeted in some commercial and recreational fisheries. The most recent stock assessment of Indo-Pacific blue marlin was in 2016, which was not overfished ($SSB > SSB_{MSY}$) and overfishing was not occurring ($F < F_{MSY}$, ISC BILLWG, 2016). This was an update assessment based upon the 2013 assessment model. The billfish working group (BILLWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) has agreed to do a benchmark assessment of the Pacific blue marlin in 2021. This assessment considers blue marlin to be a pan-Pacific stock.

The Hawaii-based longline fishery catches blue marlin as non-target species in both the swordfish-targeting shallow-set sector and the tuna-targeting deep-set sector. This fishery spans from approximately 180° to 120°W. The majority of the catch is derived from the deep-set sector. This working paper details the methods and results of the standardization of striped marlin from the Hawaii-based fishery.

Methods

Data

The Pacific Islands Regional Fishery Observer Program (PIROP) provides detailed set-by-set data on the Hawaii-based longline fishery including catch in numbers of fish and a variety of operational variables, among them: location as latitude and longitude, vessel ID, hooks per float, total number of hooks set, type of bait used, and time longlines were set, following the procedures outline in the PIROP observer manual (Pacific Islands Regional Office, 2017). The standardization uses this data set instead of the commercial logbook data to ensure the analyses were conducted according to ISC standards on using the best available science.

Data were extracted from the PIROP database on 10 October 2020 for this analysis. There were 85,173 total records after filtering erroneous data, there were 82,792 sets to analyze and 99% of these were positive catches. There were 118,496 fish recorded in the observer data from the deep-set sector, which accounts for 86% of the catch; 19,957 fish were recorded in the shallow-set sector or 14% of the catch.
Observers were first placed onboard Hawaii-based longline vessels in 1994. Observer coverage varied significantly prior to 2000, with observer coverage between 3.3 and 10.4% annually for the entire fishery (NMFS, 2017). Due to interactions with protected species the shallow-set sector was closed from 2001–2004. When it was reopened, 100% observer coverage was implemented on shallow-set trips and ~20% observer coverage was implemented on deep-set trips (Gilman *et al.,* 2007). The deep-set trips are typically further south than the shallow-set trips, which are concentrated around the sub-tropical frontal zone (STFZ) where large swordfish are caught (Sculley *et al*., 2017). After the closure, shallow sets were defined as sets with fewer than 15 hooks per float, however, prior to the closure most sets targeting tuna used 10 or more hooks per set. Dividing the catch into deep-set and shallow-set sectors was based upon the work presented in Sculley (2019) and used in the striped marlin CPUE analysis. Deep-set sector catches were defined as 10 or more hooks per float prior to 2004, and 15 or more hooks per float from 2004 through the present.

In general, the deep-set sector has a higher encounter probability while the shallow-set sector catches more blue marlin (higher positive CPUE) when encountered (Figure 1). The combined nominal CPUE mimics the deep-set sector CPUE for most years after 2000, but is much greater than the deep-set CPUE prior to 2000. The nominal CPUE for the shallow-set sector is highly variable and generally higher than the deep-set and combined nominal CPUEs. Overall, CPUEs decrease over time and do not indicate any spatial patterns (Figure 2). Because the catch was 99% positive catches, it was decided to standardize only the positive catches in the lognormal GLM. Both the combined dataset and deep-set sector dataset was used for the standardization and the percent deviance explained by each model was used to determine the best choice for the assessment.

Environmental variables used in the standardization were obtained from publically available data sets. Sea Surface temperatures (SST) from January 1994 to 2017 were based on monthly 0.5° resolution composites from the NOAA GOES-E/W satellite downloaded from Pacific Islands Fisheries Science Center (PIFSC) OceanWatch (2017). Both the Southern Oscillation Index (SOI) and the Pacific Decadal Oscillation Index (PDO) were monthly region wide indices (NOAA NCDC, 2017).

CPUE Standardization

It was decided that three different distributions would be used to standardize the CPUE data: lognormal generalized linear mixed model (GLMM), Poisson generalized linear model (GLM), and negative binomial GLM. The lognormal GLMM included 13 potential explanatory variables. Year, Quarter, Month, bait type, begin, and set type were included as factors. Sea surface temperature, latitude, longitude, the Pacific Decadal Oscillation (PDO) index, the Southern Oscillation Index (SOI), hooks per float, and the begin set time were included as continuous variables. Vessel, based upon the permit number, was included as a random effect to account for differences in fishers behaviors. In addition, the Poisson and negative binomial models included log(HPSet) as an offset where HPSet is the number of hooks per set. Both the Poisson and negative binomial models with Vessel as a random effect failed to converge, so no random effect was included in those distributions.

Begin is a factor with four levels describing the time of day in which the set was initially deployed with 1 = midnight – 0600, 2 = 0600-1200, 3 = 1200-1800, and 4 = 1800-2400. Set type was a factor with two levels indicating if the set was shallow or deep. Bait type is a code that indicates the type of bait used when setting the hooks; these are typically some kind of baitfish such as mackerel, squid, or a combination of baits. Begin set time was the time (in hours) the set was initially deployed. In the first round of model selection, models with set type and hooks per float, begin and begin set time, and month and quarter were compared and the models with the lowest AIC were included in future model selection steps. For all three distributions, begin, month, and set type had lower AICs than begin set time, quarter, and hooks per float and were used in subsequent model selection steps. For the deep-set sector only model runs, hooks per float was considered in model selection steps.

Explanatory variables were added using forward stepwise selection with variables being selected based upon the lowest AIC, most deviance explained, and if they were statistically significant based upon a Chi-squared likelihood ratio test. Additional variables were not included if they were not significant based upon the likelihood test (Bigelow *et al.*, 1999) or increased the model deviance explained by less than 0.1% compared to the simpler model. Final models for each time series are presented in

Tables
Table *1*.

Annual mean CPUE was calculated from the final lognormal models using the estimated marginal means package in R (emmeans, Lenth *et al*., 2017; R version 3.4.0, R Core Team, 2017) which accounts for the unbalanced nature of the data and missing values, not allowing for large numbers of observations in a level of a factor to have an undue influence on the average of the values. Annual mean CPUE and standard deviations were then back-transformed into normal space and bias corrected.

Results and Discussion

Comparing the percent deviance explained between the three models, the lognormal model explained the most deviance in the data (combined data = 21% deviance explained, deep-set data = 32% deviance explained) compared to the Poisson GLM (13% deviance explained) and negative binomial GLM (13% deviance explained). Since the model on the deep-set sector data was able to explain more of the deviance than for the full dataset, and there is a divergence in the two indices prior to 2000, it is recommended to only consider the models on the deep-set data for inclusion in the blue marlin assessment. Final model configurations for all three models are in

Tables
Table *1*. The correlations between CPUE and the environmental and spatial variables were generally very low (Table 2 エラー！参照元が見つかりません。). Neither did they show any obvious trends with CPUE (Figure 3 through Figure *5*).

The standardized deep-set CPUE trend was very similar to the nominal CPUE trend, with the standardized values less variable than the nominal values (Figure 6, Table 3). Diagnostics for the lognormal GLMM with the deep-set dataset may show some minor deviations from the assumption of normality. Pearson residuals for the positive catch lognormal model appeared to be slightly negatively biased but with a long positive tail and deviated from the normal Q-Q line at the extremes of the dataset (Figure 7). When the residuals are compared to each explanatory variable, there appears to be a slight negative bias for year and month, but not latitude nor bait type (Figure 8).

Conclusions

While there is likely some bias in the estimates of CPUE as the slight negative bias in the residuals indicate, these data are the best available science and are likely consistent with the trends in abundance of the blue marlin available to the Hawaii-based longline fishery. The best-fit model was the lognormal generalized linear model, which explained 32% of the deviance in the deep-set sector. It is recommended to use the deep-set dataset for the standardized CPUE values in the stock assessment model, as the percent deviance explained is higher and the trends between the combined dataset and deep-set dataset diverge at the beginning of the time-series. Furthermore, the shallow-set time series would not be a useful indicator of relative abundance as it is highly variable. It is interesting to note that the environmental variables included in this standardization do not appear to be highly correlated to blue marlin CPUE and additional research should be done to identify any environmental covariates that may be important to blue marlin catch rates.

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Tables

Table 1. Final models and percent deviance explained for each distribution tested.

Model		**% Deviance Explained**
Combined lognormal GLMM	Log(CPUE) ~ Bait + Year + Begin + Month + Lat + Lon + Vessel	21%
Deep-set lognormal GLMM	Log(CPUE) ~ Year + Bait + Month + Lat + Vessel	32%
Deep-set Poisson	Number of Fish Caught ~ Year + Bait + Month + HPF + Lat –offset(log(HPSet))	12.6%
Deep-set Negative Binomial	Number of Fish Caught ~ Year + Bait + Month + HPF + Lat -offset(log(HPSet))	12.6%

Table 2. Correlations and p-values between striped marlin CPUE and candidate environmental and spatial variables.

Parameter	SOI	PDO	SST	Begin Set Time	Lon	Lat
CPUE	-0.013	-0.014	-0.039	-0.036	-0.090	-0.043
p-value	4.99E-4	1.49E-4	<2.2E-16	<2.2E-16	<2.2e-16	<2.2e-16

Table 3. Nominal and standardized CPUE values and CVs for the deep-set sector of the Hawaii-based longline fishery.

Year	Standardized CPUE	CV	Nominal CPUE
1995	1.21	0.053	1.24
1996	1.06	0.052	1.05
1997	1.01	0.052	0.97
1998	0.98	0.052	1.03
1999	0.90	0.052	0.92
2000	0.82	0.052	0.77
2001	0.96	0.051	1.30
2002	0.78	0.051	0.82
2003	0.89	0.051	0.92
2004	0.76	0.051	0.76
2005	0.75	0.051	0.70
2006	0.76	0.051	0.76
2007	0.66	0.051	0.65
2008	0.67	0.051	0.64
2009	0.66	0.051	0.64
2010	0.62	0.051	0.61
2011	0.65	0.051	0.65
2012	0.57	0.051	0.56
2013	0.58	0.051	0.58
2014	0.61	0.051	0.62
2015	0.65	0.051	0.66
2016	0.58	0.051	0.58
2017	0.59	0.051	0.60

Figures

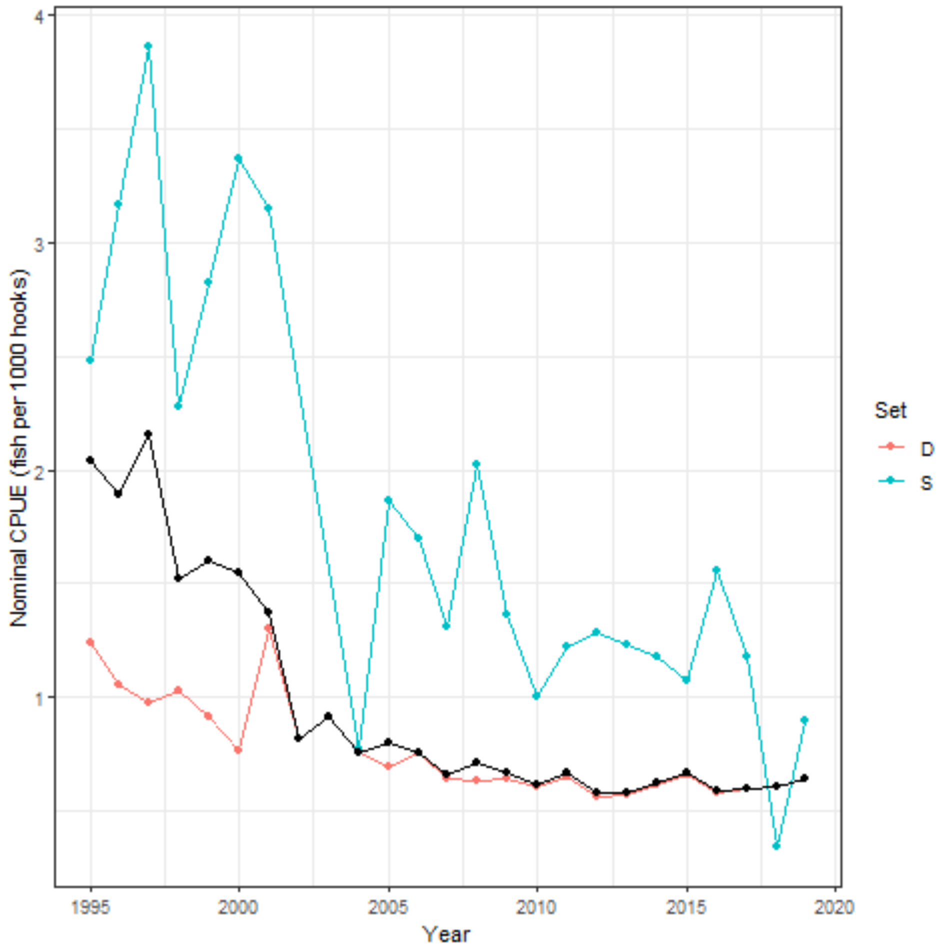

Figure 1. Nominal CPUE in fisher per 1000 hooks by set (deep = red, shallow = blue) and combined (black) for the Hawaii longline blue marlin fishery.

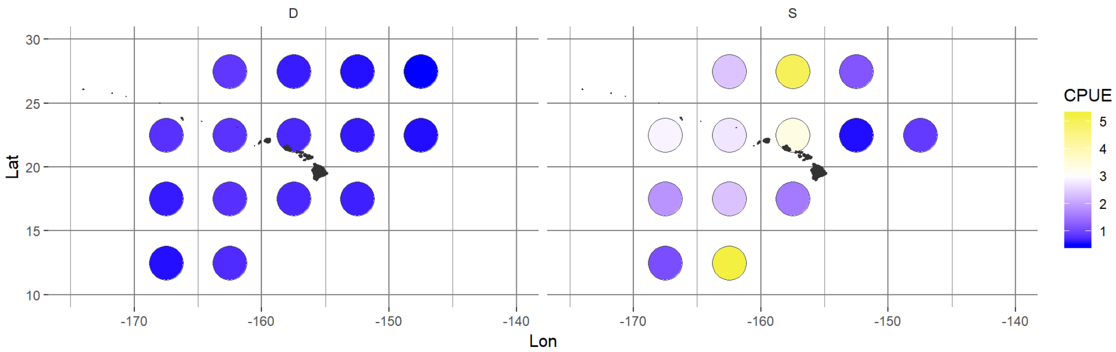

Figure 2. Spatial distribution of blue marlin CPUE catch in the Hawaii-based longline fishery by set (Deep on the left and shallow on the right). Yellow indicates higher CPUE and blue indicates lower CPUE. Data are filtered to remove grids where fewer than three vessels fished to ensure confidentiality.

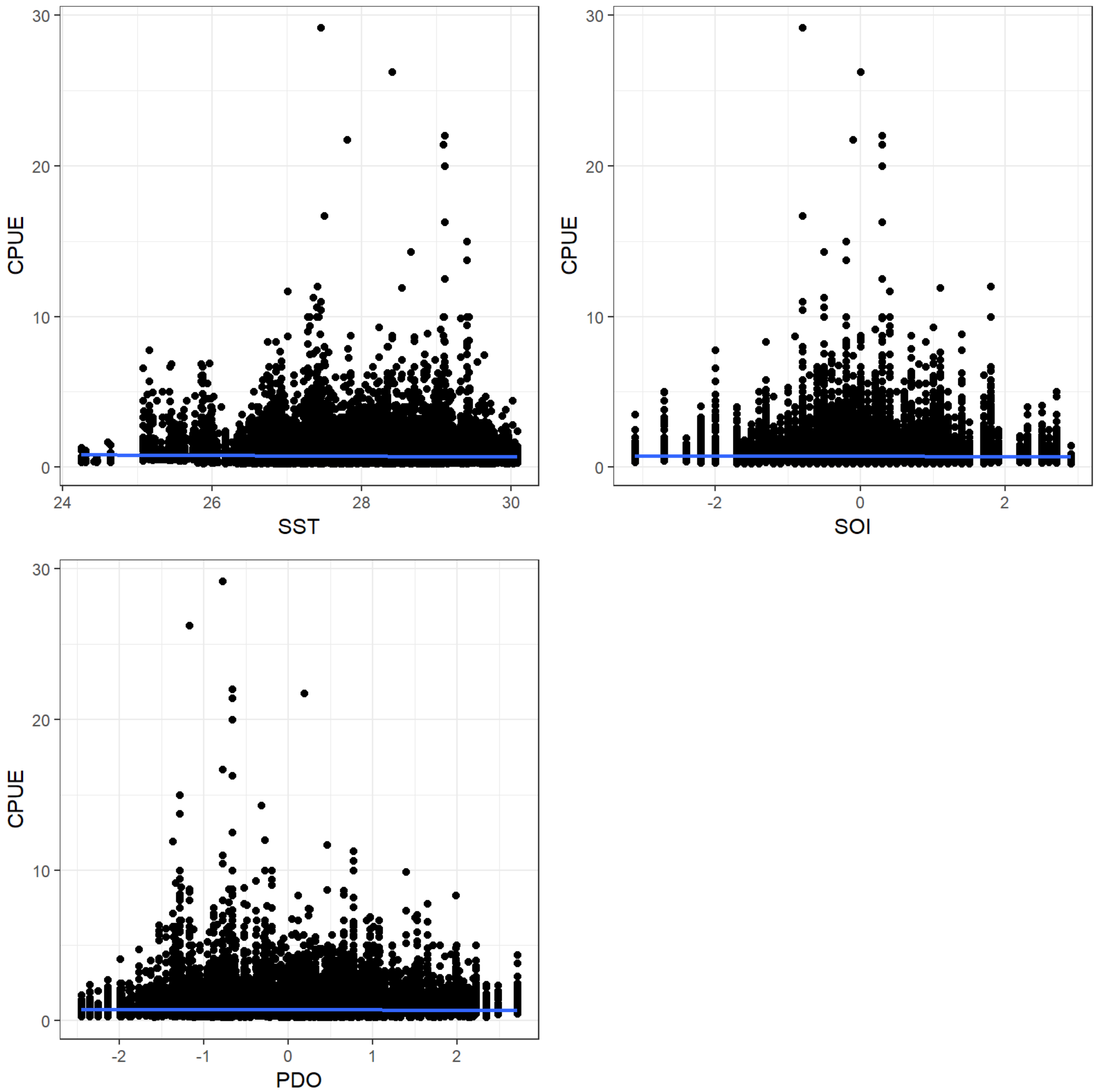

Figure 3. Plots of blue marlin CPUE vs environmental variables from the combined dataset of the Hawaii-based longline fishery. Top left is SST, top right is SOI, and bottom is PDO. Blue line indicates GAM smoother fit to the data.

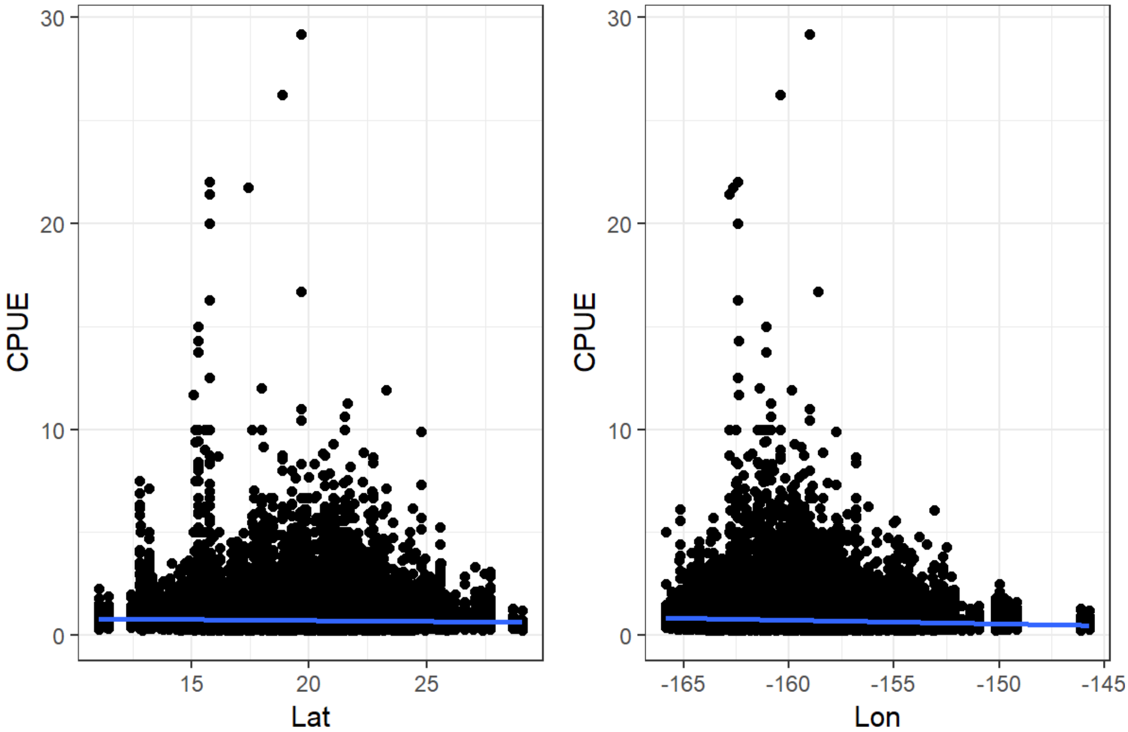

Figure 4. Plots of latitude (left) and longitude (right) vs blue marlin CPUE from the Hawaii-based longline fishery. Blue line indicates GAM smoother fit to the data.

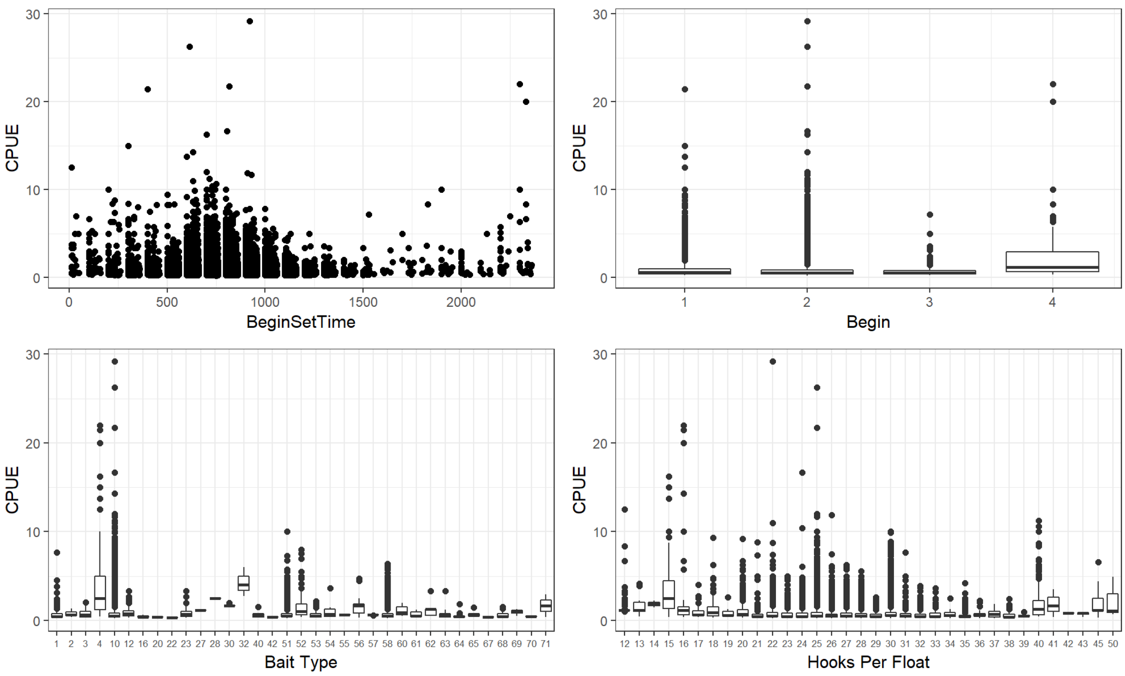

Figure 5. Plots of blue marlin CPUE vs operational variables from the combined dataset of the Hawaii-based longline fishery. Top left is Begin Set Time, top right is begin, bottom left is bait type, and bottom right is hooks per float. An explanation of the parameters are available in the methods section. Blue line

indicates GAM smoother fit to the data.

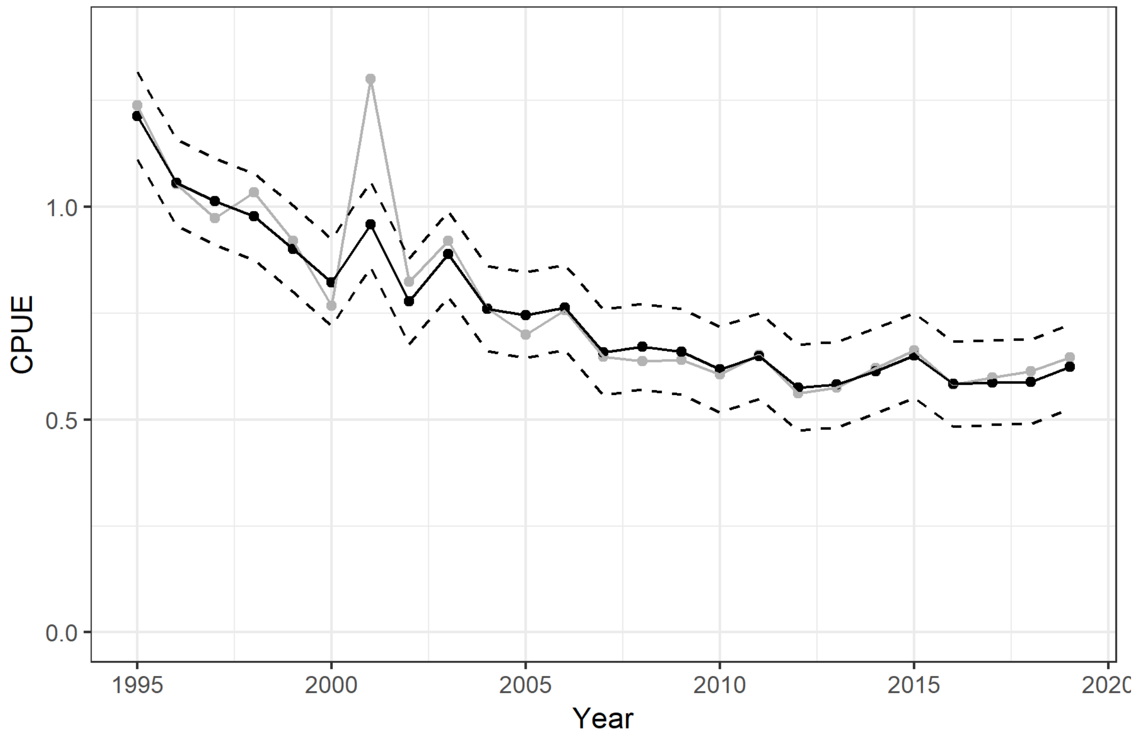

Figure 6. Nominal (grey) vs standardized (black, 95% CI in grey dashed lines) for blue marlin CPUE caught in the Hawaii-based longline deep-set sector.

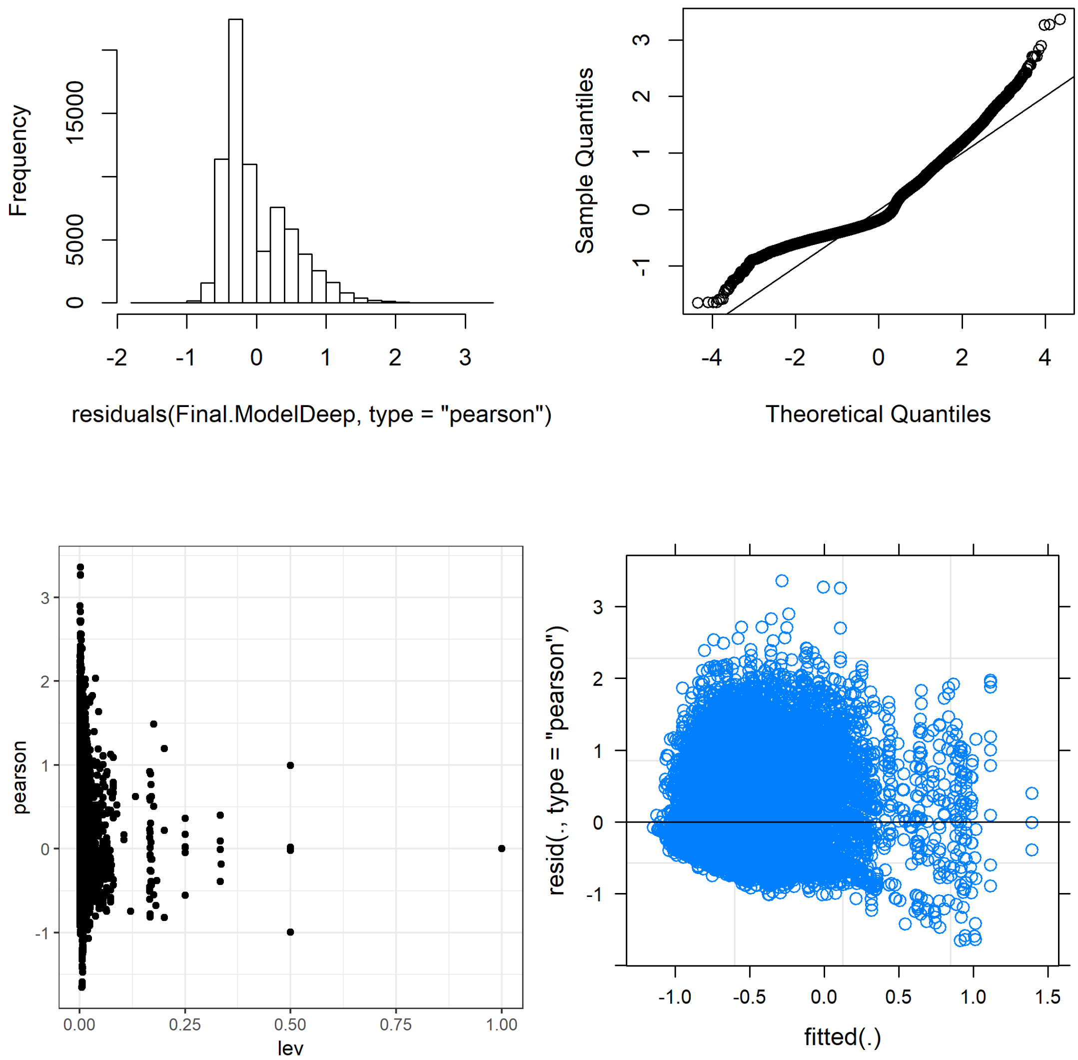

Figure 7. Diagnostic plots for positive catches: Histogram of standardized Pearson residuals (upper left) Normal Q-Q plot (upper right); Pearson residuals leverage plot (bottom left); Pearson residuals vs fitted values (bottom right).

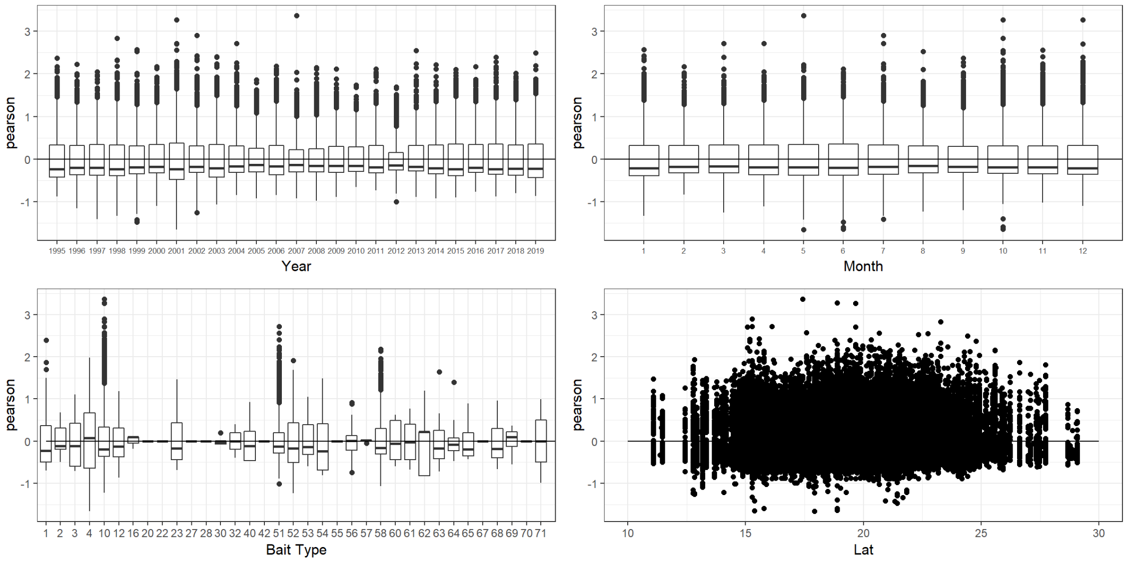

Figure 8. Residuals vs the explanatory variables in the deep-set sector lognormal GLMM model. Top left is year, top right is month, bottom left is bait type, and bottom right is latitude.