Standardization of the Striped Marlin (*Kajikia audax*) Catch per Unit Effort Data Caught by the Hawaii-based Longline Fishery from 1994-2020 Using Generalized Linear Models

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Working document submitted to the ISC Billfish Working Group Virtual Meeting, International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 12-17 December 2020. Document not to be cited with author's permission.

Abstract

This working paper provides the standardization of the Hawaii-based longline fishery striped marlin (*Kajikia audax*) catch per unit effort (CPUE) data. Two analyses with 15 different potential explanatory variables were explored for the complete dataset and the deep-set only data. The delta-lognormal generalized linear mixed model (DL-GLMM) has been shown to provide the best fit to the data based upon percent deviance explained in previous standardizations and was used in this work. Results showed that the deep-set sector standardized CPUE was very similar to the combined dataset. The diagnostics of the either models do not suggest any problems with poorly fitted data; therefore, it is recommended to use the combined dataset DL-GLMM standardized CPUE for the 2022 striped marlin base-case assessment model, as it is consistent with previous assessments.

Introduction

Striped marlin (*Kajikia audax*) is a tropical and subtropical species of billfish found in the Pacific Ocean. It is primarily caught as a bycatch species in longline fisheries targeting tuna and swordfish, although it is occasionally targeted in commercial and recreational fisheries. The most recent stock assessment of striped marlin was in 2019 of the Western and Central North Pacific stock, which was found to be overfished and overfishing was occurring (ISC BILLWG, 2019). 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 Western and Central North Pacific striped marlin in 2022 to address some of the concerns noted during the 2019 assessment. This assessment will be bounded by the boundaries of the Western and Central Pacific Fisheries Commission at 150°W latitude and the equator.

The Hawaii-based longline fishery catches striped marlin as bycatch in both the swordfish-targeting shallow-set sector and the tuna-targeting deep-set sector. This fishery spans from approximately 180°W to 120°W, therefore only a portion of the fishery will be included in the 2019 assessment. However, approximately 90% of the catches of striped marlin occur west of 150°W, therefore the majority of the Hawaii-based fishery will be included in this assessment. This working paper details the methods and results of the standardization of striped marlin from the Hawaii-based fishery.

Methods

Data

The US Federal logbook program to monitor the Hawaii-based longline fishing fleet began in November 1990 to manage US domestic fisheries for tuna, swordfish, and other economically important pelagic species. Logbooks are filed by all operators of fishing vessels conducting longline fishing operations on the High Seas and within the U.S. Exclusive Economic Zone in American Samoa, Guam, Hawaii, the Northern Mariana Islands, and U.S. possessions in the western Pacific and offloading in U.S. ports and provide set-by-set information on environmental and operational aspects of fishing operations. The Hawaii-based longline fishery can be divided into two sectors, the tuna-targeting deep-set sector comprises the majority of the fish fleet and the swordfish-targeting shallow-set sector. Data were extracted from the Oracle database on 24

September 2021. After filtering for incomplete and erroneous entries, there were 335,876 sets available for inclusion from 1 January 1995 to 31 December 2020.

Both sectors have had observer coverage since 1994, which varied significantly prior to 2000, with observer coverage between 3.3 and 10.4% 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 mandatory on shallow-set trips and 20% observer coverage was mandatory 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., 2018). 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. Consistent with the CPUE standardization in for the 2019 assessment, deep-set trips were defined as using 10 hooks per float or more as the division prior to 2004, and using 15 hooks per float or more from 2004 through the present (Sculley, 2019).

There is a known issue of misidentification and discards of striped marlin from the Hawaii longline fishery (Walsh *et al.*, 2007). Discards of striped marlin prior to 2004 were estimated to be 7% and striped marlin catches were estimated to be underreported by approximately 5% due to misidentification (Walsh *et al.,* 2007). It should be noted, however, that estimated misidentification rates for striped marlin varied inversely with observer coverage rates, which suggests that misidentification rates were lower after 2004 when observer rates were much higher.

The deep-set sector has a higher encounter probability (40% positive catches versus 30% for the shallow-set sector) while the both sectors have similar catch when encountered (3.2 fish per 1000 hooks for deep sets and 3.1 fish per 1000 hooks for shallow sets, Figure 1). The combined nominal CPUE mimics the deep-set sector CPUE as the majority of the data come from the deep-set sector. Only 8% of the total number of striped marlin caught are from the shallow-set fishery. The nominal CPUE for the shallow-set sector is highly variable, relatively flat, and generally higher than the deep-set and combined nominal CPUEs. Due to the highly variable nature of the shallow-set CPUE and the frequent closures of the fishery after 2000, it was decided to only standardize the complete data set, which has been used for previous assessments, and the deep-set sector dataset.

The environmental variables used in the standardization were obtained from publically available data sets. Sea Surface temperatures (SST) from January 1994 present were based on monthly 0.5° resolution composites from the NOAA GOES-E/W satellite downloaded from Pacific Islands Fisheries Science Center (PIFSC) OceanWatch (2021). The Southern Oscillation Index (SOI), the Pacific Decadal Oscillation Index (PDO), and the el Niño Southern Oscillation Oceanic Niño Index (ONI) were monthly region wide indices (NOAA NCDC, 2021). Mixed layer depth (MLD) were based on 0.33° × 1° monthly means of GODAS data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA[1].

[1] http://www.esrl.noaa.gov/psd/

CPUE Standardization

After reviewing previous standardization attempts of the Hawaii-based longline fishery striped marlin data (Langseth 2015; Walsh and Chang 2015, Sculley 2019), it was decided that the delta-lognormal generalized linear mixed model (GLMM) would be used to standardize the CPUE data, as other distributions, which is consistent with previous standardizations. The delta-lognormal GLMM included 15 potential explanatory variables. Year, Quarter, Month, Hooks per float, bait type, begin set time, and set type were included as factors. Sea surface temperature, mixed layer depth, latitude, longitude, the Pacific Decadal Oscillation (PDO) index, the Southern Oscillation Index (SOI), 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 for the positive catches lognormal model, the binomial model for encounter probability failed to converge with a random effect.

Begin is a factor with four levels describing the time of day in which the set was begun 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 with shallow sets identified as detailed above. 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 begun. 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 and largest percent deviance explained were included in future model selection steps. For all models, begin set time and hooks per float had lower AICs than begin and were used in subsequent 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). Final models for each time series are presented in Table 1.

Annual mean CPUE was calculated from the final binomial and lognormal models using the estimated marginal means package in R (emmeans, Lenth *et al*., 2017; R version 4.0.5, R Core Team, 2021) 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 was then back-transformed into normal space and bias corrected. Then the means from the binomial model were multiplied with the means from the lognormal model to obtain the final standardized annual CPUE values. Standard deviations were estimated in a similar manner: individual model values were back transformed into normal space then combined for each time series based upon the Goodman (1960) estimator (Lauretta *et al.*, 2016).

Results and Discussion

For the combined dataset, the positive component of the delta-lognormal model explained 22% of the deviance and the encounter probability model explained 6% of the deviance. For the deep-set data, the positive component of the delta-lognormal model explained 17% of the deviance and the encounter probability model explained 7% of the deviance. Final model configurations for all models are in Table 1. Overall, environmental variables were not included in the final models and did not explain much of the variance in the data, with the exception of the mixed layer depth. The correlations between CPUE and the environmental variables was generally very low (Table 2). Correlations were strongest with the spatial variables latitude and longitude (Figure 2). Positive catches were similar in the deep- and shallow-set sectors; however, the deep-set sector was more likely to have a positive encounter (Figure 3). Only one environmental variable suggested a trend related to catch rates: there tended to be higher catch rates at MLDs shallower than 100m (Figure 4). Neither PDO nor SOI showed any obvious trends with CPUE.

The standardized combined and deep-set CPUE trend was very similar to the nominal CPUE trend, with the standardized values slightly lower than the nominal values (Figure 5, Table 3). Comparing the standardized CPUEs from the combined dataset and the deep-set trend, the deep-set CPUE is very similar to the combined CPUE in both scale and trend (Figure 5). Since the CPUE standardization has a higher percent deviance explained for the combined dataset, and the combined dataset has been used in past assessments, it is recommended to use the combined CPUE series for the 2022 striped marlin assessment, noting that both CPUE series are almost identical. Furthermore, the residual plots from the positive catches lognormal GLMM does not indicate any patterns related to the type of set (Figure 6 and 7), and it could be concluded that using the complete CPUE series would be reasonable for this assessment.

Diagnostics for the delta-lognormal GLMM with the combined dataset show no significant deviations from the assumption of normality. Pearson residuals for the positive catch lognormal model appeared to be randomly distributed around zero and only deviated from the normal Q-Q line at the extremes of both datasets (Figure 6 and 7). When the residuals are compared to each explanatory variable, there appears to be a slight negative bias for the operational variables (Figures 8-11). Diagnostics for the encounter probability binomial model also show little patterning except at the extremes of the data (Figure 12 and 13). The binned residual plot shows that except at these extremes when the residuals tend to be positive, the majority of the residuals fall within the 95% confidence interval, indicating a good fit. The plots of the quantile residuals compared to each explanatory variable do not appear to be biased, but generally have a median value of zero (Figures 14-17).

The CPUE standardization from the 2019 assessment (Sculley 2019) has a very similar trend and pattern to the standardization prepared for the 2022 assessment (Figure 1Figure 188). The 2019 standardization is slightly lower than either 2022 time series, but overall provides the same information as the 2022 standardizations.

Conclusions

While there is likely some bias in the estimates of CPUE due to the problems in misidentification and discards, these data are the best available science and are likely consistent with the trends in abundance of the striped marlin available to the Hawaii-based longline fishery. The best-fit model was the delta-lognormal generalized linear model on the complete dataset, which explained 22% of the deviance in the positive catch rates and 6% of the deviance in the encounter rates. It is recommended to use the combined dataset for the standardized CPUE values in the stock assessment model, as the diagnostics do not show any significant patterning between the deep-set data and the shallow-set data. Furthermore, the combined dataset trends are consistent with the deep-set CPUE time series. It is interesting to note that the environmental variables included in this standardization do not appear to be highly correlated to striped marlin CPUE and additional research should be done to identify any environmental covariates that may be important to striped marlin catch rates.

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Tables

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

Model		**% Deviance Explained**
Combined Positives DL-GLMM	Log(CPUE) ~ Year + HPF + Month + Bait + Lon + Lat + MLD + Vessel	22%
Combined Encounter probability	Proportion Positive ~ Year + Month + Bait + MLD + BeginSetTime + Lon+ Lat	6.3%
Deep-set Positives DL-GLMM	Log(CPUE) ~ Year + Month + HPF + Lat + Lon + Bait + MLD + BeginSetTime + Vessel	17%
Deep-set Encounter Probability	Proportion Positive ~ Year + Month + Lat + Lon + BeginSetTime + Bait + MLD	7.1%

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

Parameter	**MLD**	**SOI**	**PDO**	**SST**	**Begin Set Time**	**Lon**	**Lat**
CPUE	-0.0359	0.0018	0.063	-0.057	0.0622	-0.0846	0.0515
p-value	<2.2e-16	0.286	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16

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

	Complete Dataset			Deep-set Dataset		
Year	**Standardized CPUE**	**CV**	**Nominal CPUE**	**Standardized CPUE**	**CV**	**Nominal CPUE**
1995	1.47	0.63	2.06	1.63	0.62	2.46
1996	1.07	0.76	1.49	1.06	0.78	1.62
1997	0.85	0.89	1.20	0.75	0.98	1.12
1998	0.89	0.87	1.12	0.80	0.95	1.07
1999	0.89	0.84	1.10	0.80	0.93	1.02
2000	0.62	1.10	0.75	0.50	1.29	0.53
2001	0.94	0.80	1.03	0.83	0.89	0.98
2002	0.53	1.21	0.53	0.48	1.31	0.51
2003	1.05	0.74	1.17	0.93	0.82	1.17
2004	0.72	0.96	0.70	0.65	1.04	0.70
2005	0.68	0.98	0.77	0.61	1.08	0.69
2006	0.69	0.98	0.76	0.64	1.05	0.78
2007	0.38	1.54	0.37	0.35	1.63	0.36
2008	0.51	1.20	0.64	0.45	1.33	0.59
2009	0.34	1.64	0.38	0.30	1.78	0.35
2010	0.23	2.25	0.20	0.21	2.39	0.19
2011	0.49	1.22	0.65	0.44	1.33	0.64
2012	0.36	1.51	0.46	0.32	1.66	0.48
2013	0.35	1.54	0.45	0.32	1.66	0.43
2014	0.43	1.32	0.55	0.40	1.41	0.54
2015	0.39	1.41	0.50	0.36	1.50	0.49
2016	0.35	1.52	0.41	0.32	1.64	0.39
2017	0.38	1.42	0.45	0.35	1.53	0.43
2018	0.37	1.47	0.44	0.33	1.58	0.45
2019	0.42	1.32	0.47	0.39	1.41	0.48
2020	0.34	1.55	0.34	0.31	1.64	0.35

Figures

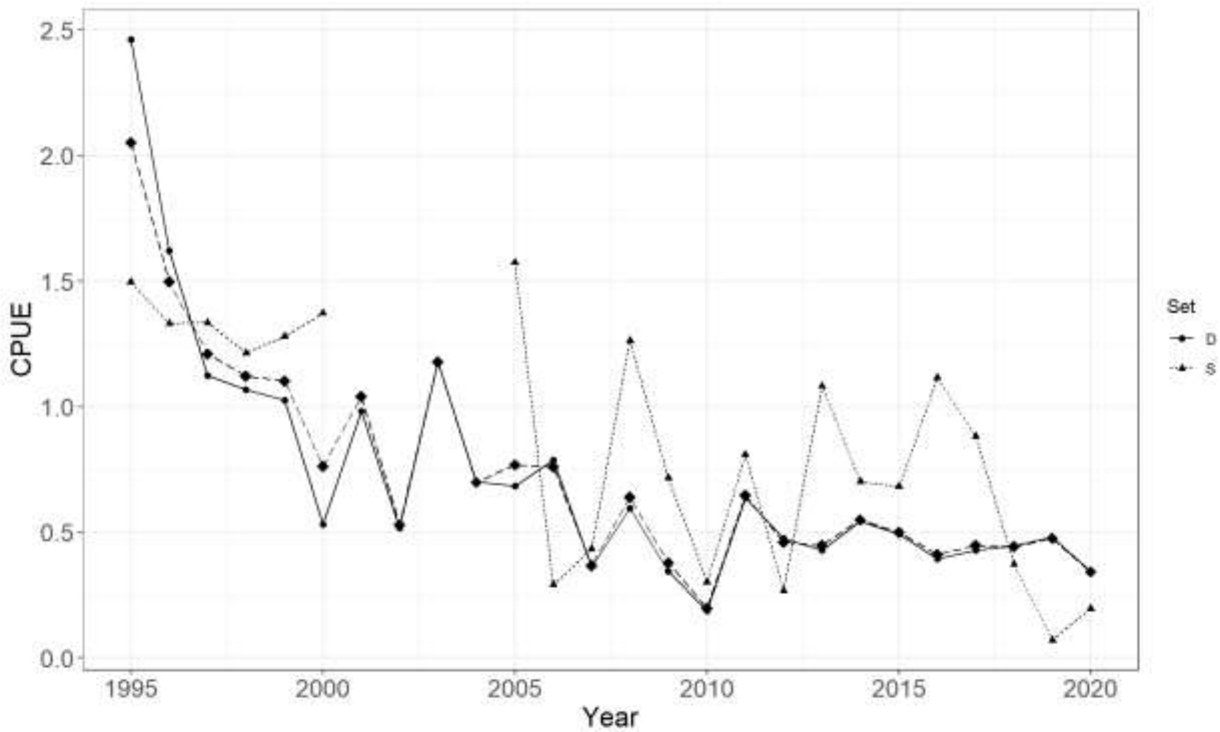

Figure 1. Nominal CPUE by set determined by a 10 HPF cutoff for shallow sets prior to 2004 and 15 HPF after 2004. Dashed diamond = combined CPUE; dotted triangles = shallow-set only CPUE; solid circles = deep-set only CPUE.

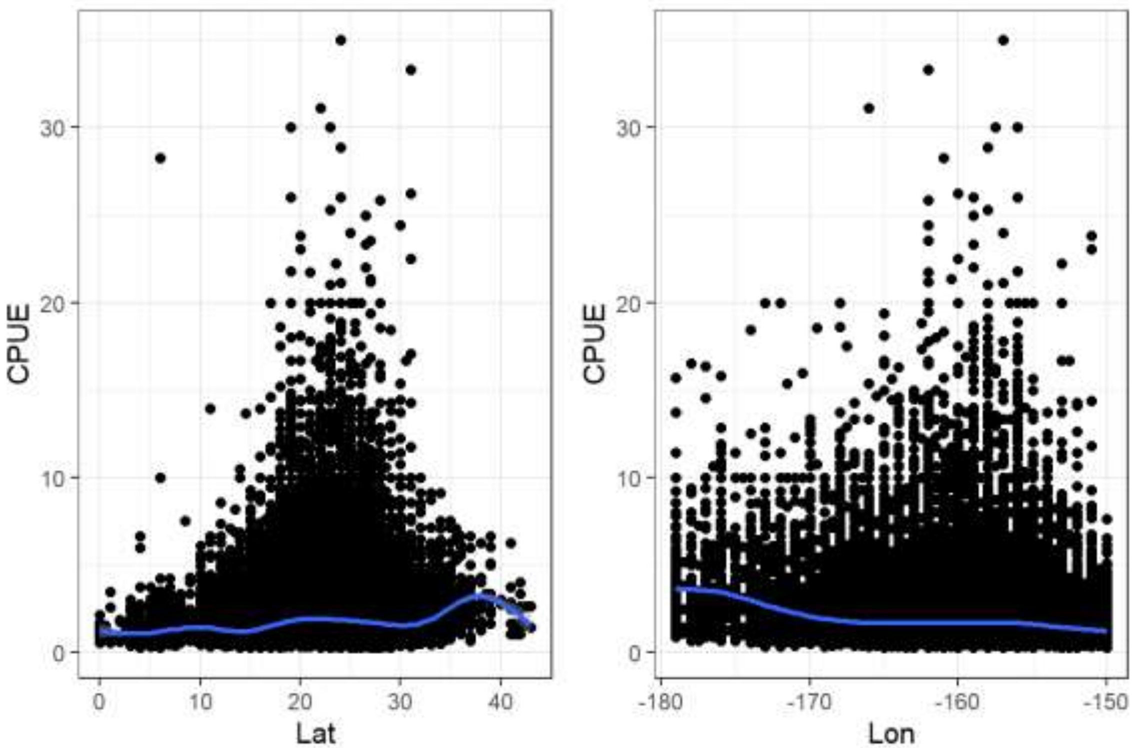

Figure 2. Nominal positive CPUE for the complete dataset vs latitude and longitude. Blue line indicates trend of a Generalized Additive Model.

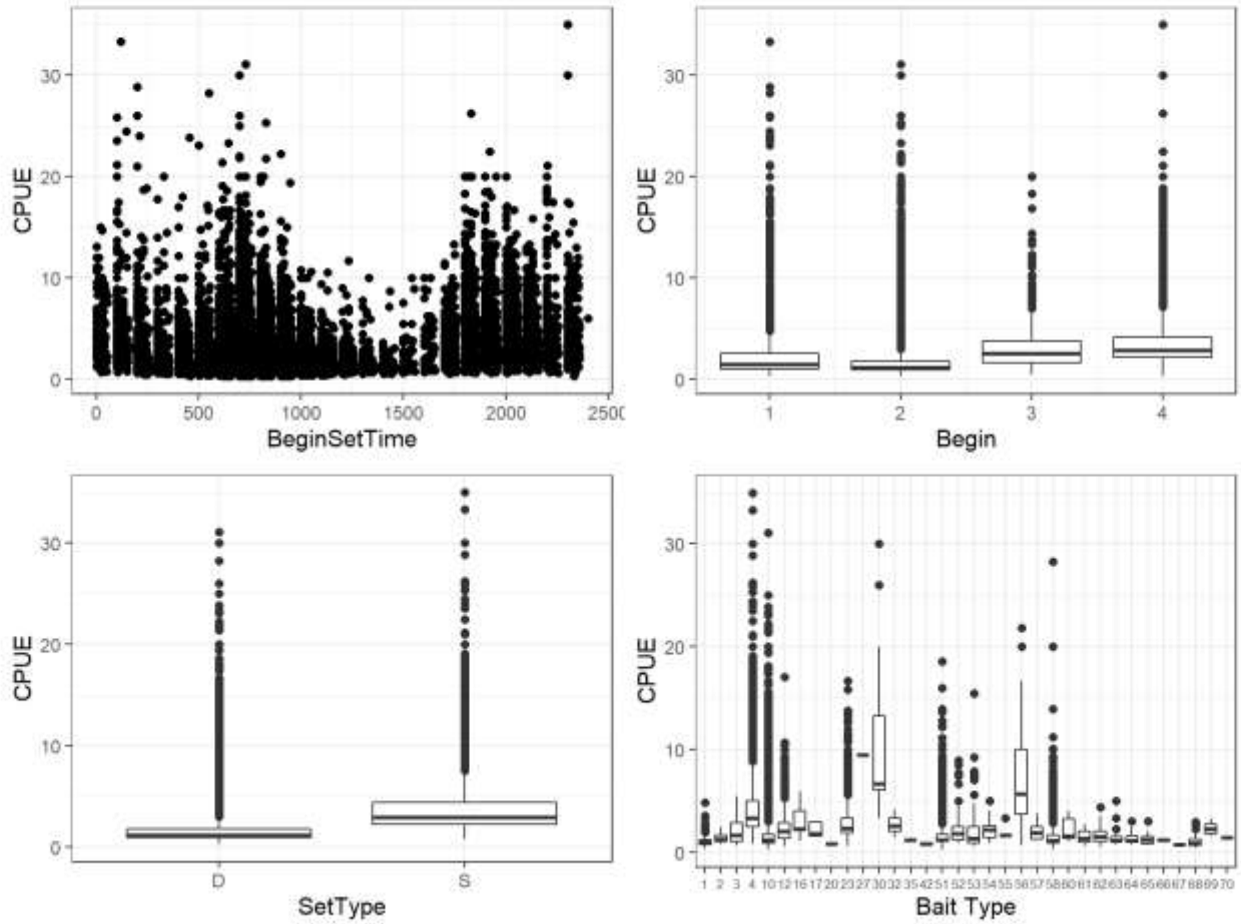

Figure 3. Nominal positive CPUE versus Begin Set Time (upper left), Begin (upper right), Set type (lower left), and Bait type (lower right) for the complete dataset.

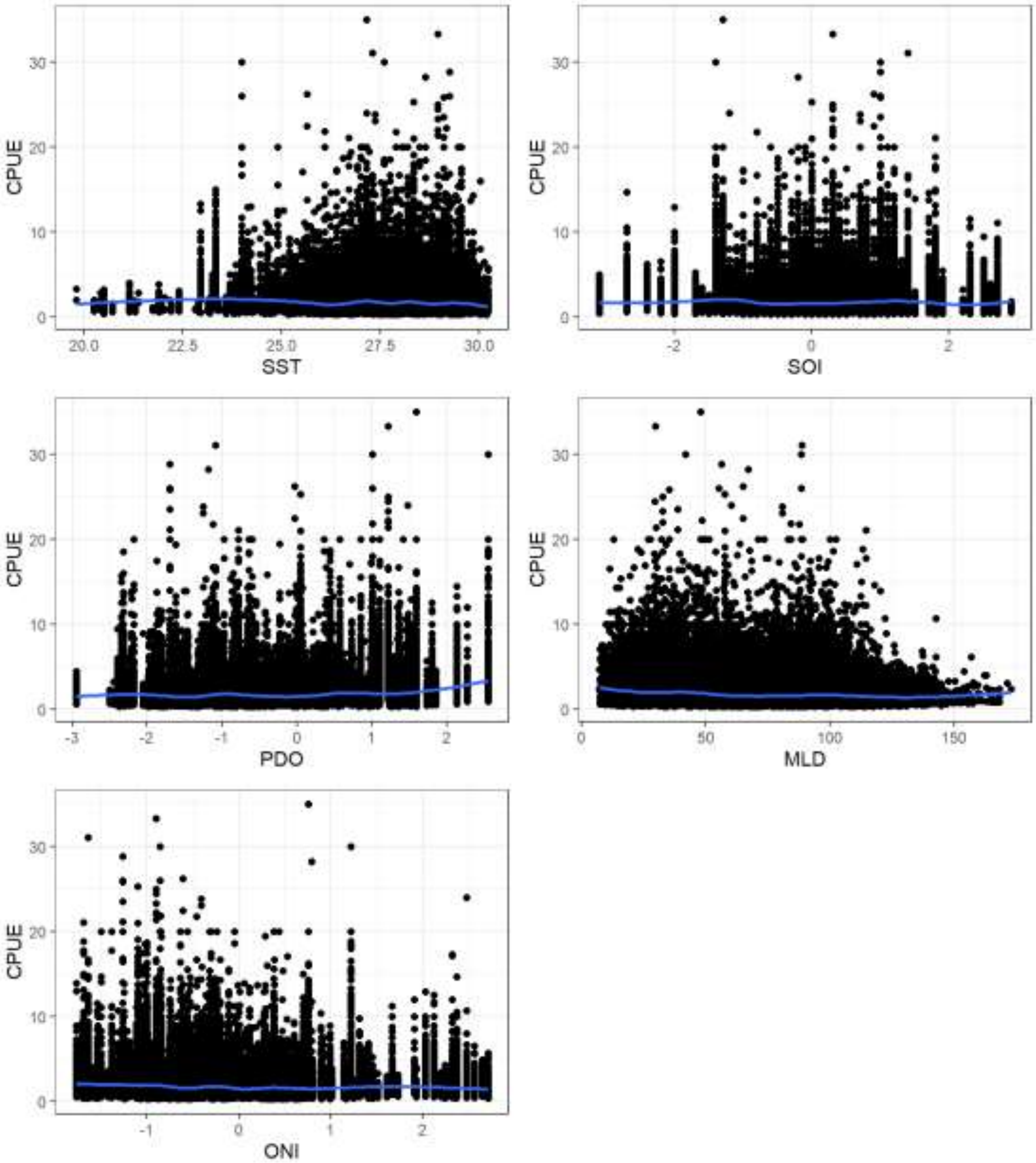

Figure 4. Positive complete CPUE versus the five environmental variables included in the analysis: Sea surface temperature (top left); Southern Oscillation Index (top right); Pacific Decadal Oscillation Index (center left); mixed layer depth (center right), and el Niño Southern Oscillation ONI (bottom left). Blue line indicates GAM smoother fit to the data.

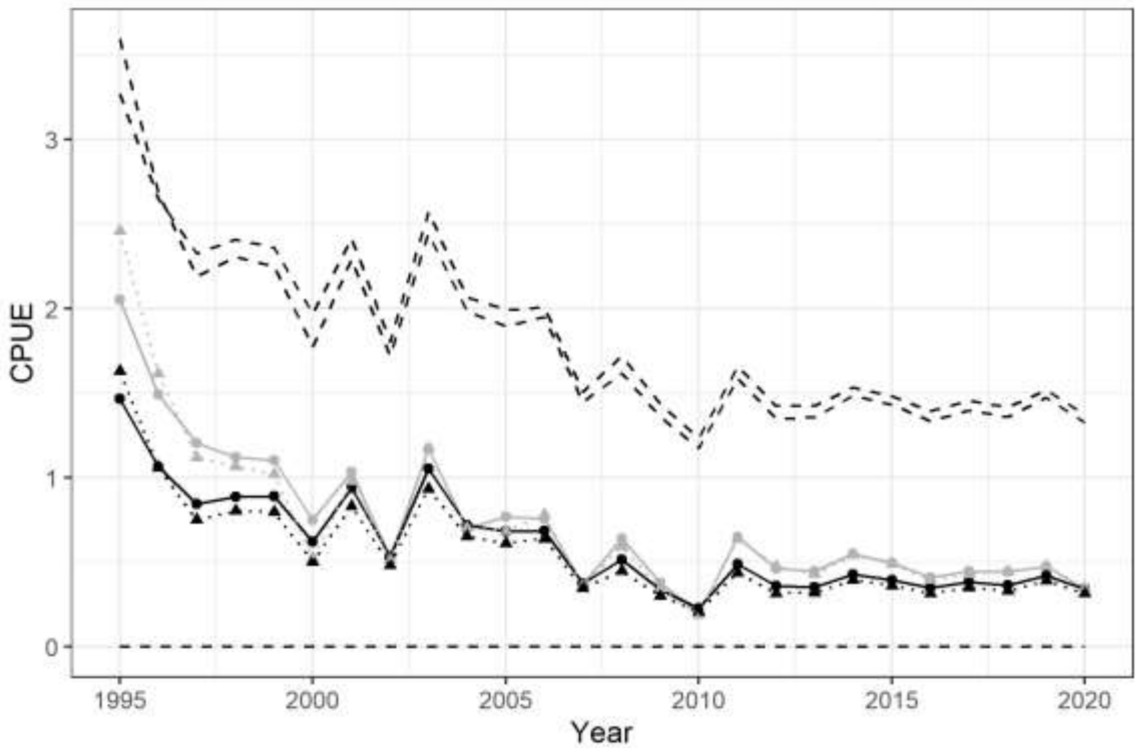

Figure 5. Nominal (grey) and standardized CPUE (black) with 95% confidence interval around the standardized CPUE (black dashed lines) for the complete dataset (solid line, circles) and the deep-set data (dotted line, triangles).

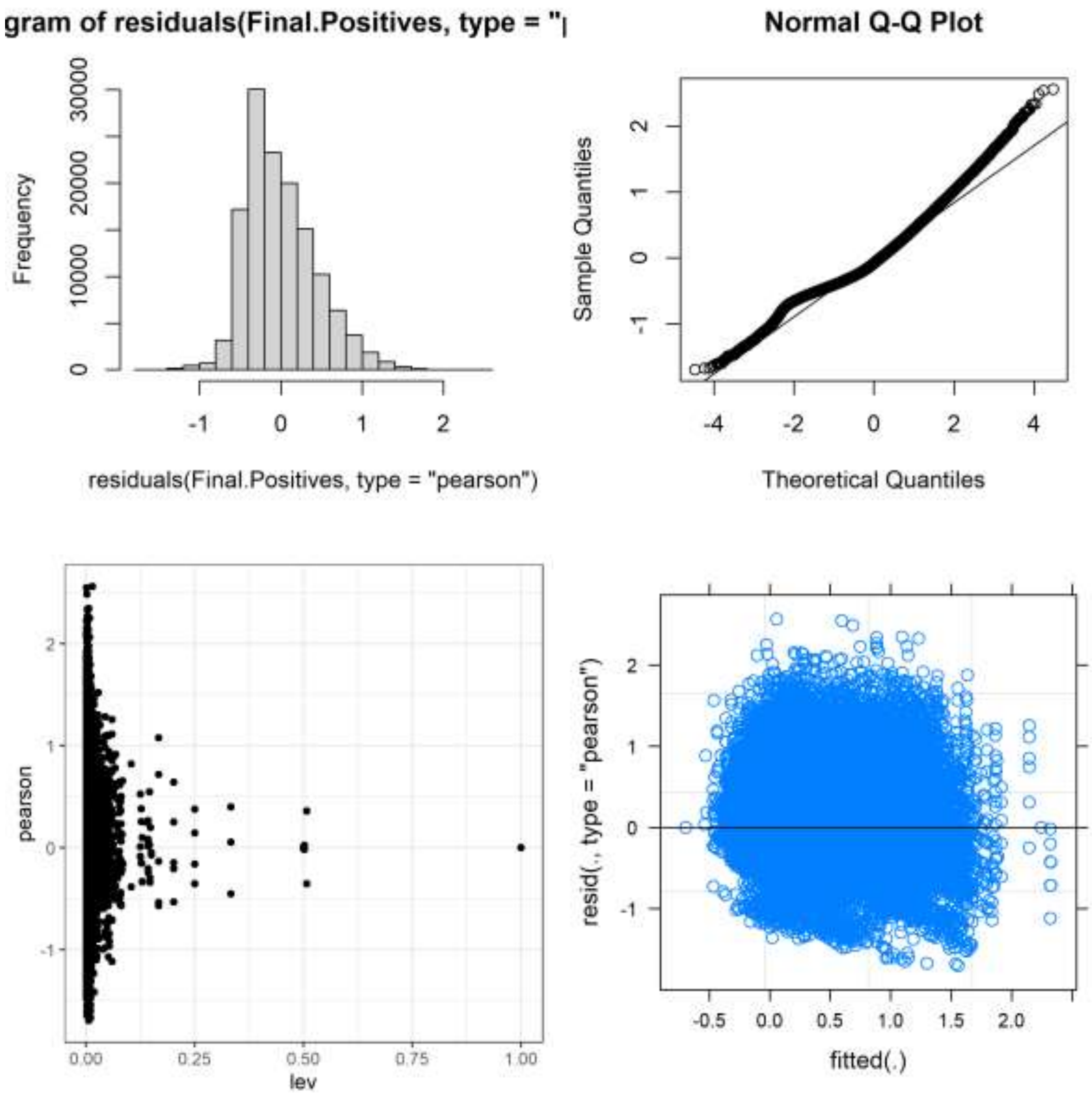

Figure 6. Diagnostic plots for positive catches in the complete dataset: Histogram of standardized Pearson residuals (upper left) Normal Q-Q plot (upper right); Pearson residuals leverage plot (bottom left); Pearson residuals vs fitted values (bottom right).

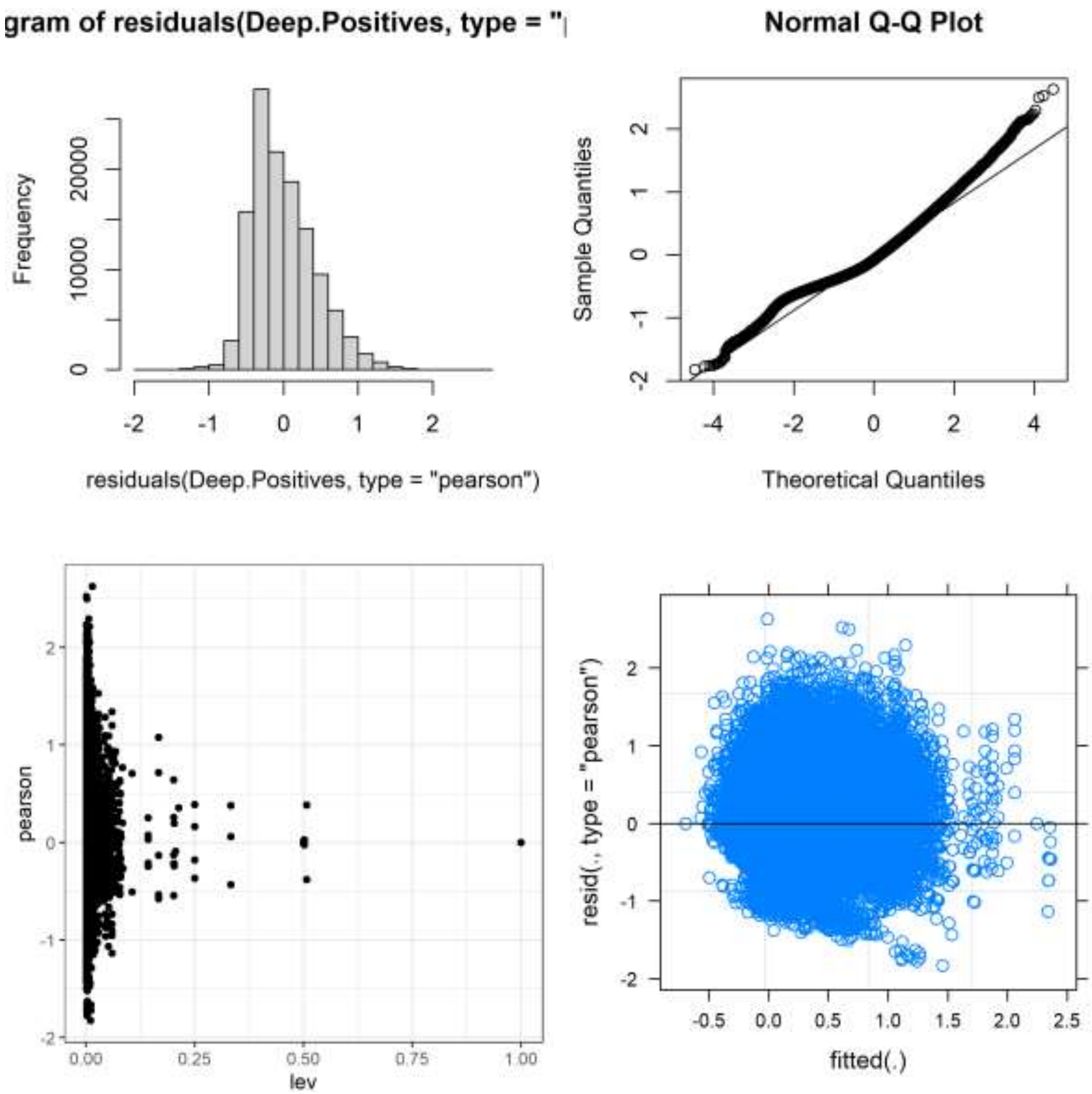

Figure 7. Diagnostic plots for positive catches in the deep-set dataset: Histogram of standardized Pearson residuals (upper left) Normal Q-Q plot (upper right); Pearson residuals leverage plot (bottom left); Pearson residuals vs fitted values (bottom right).

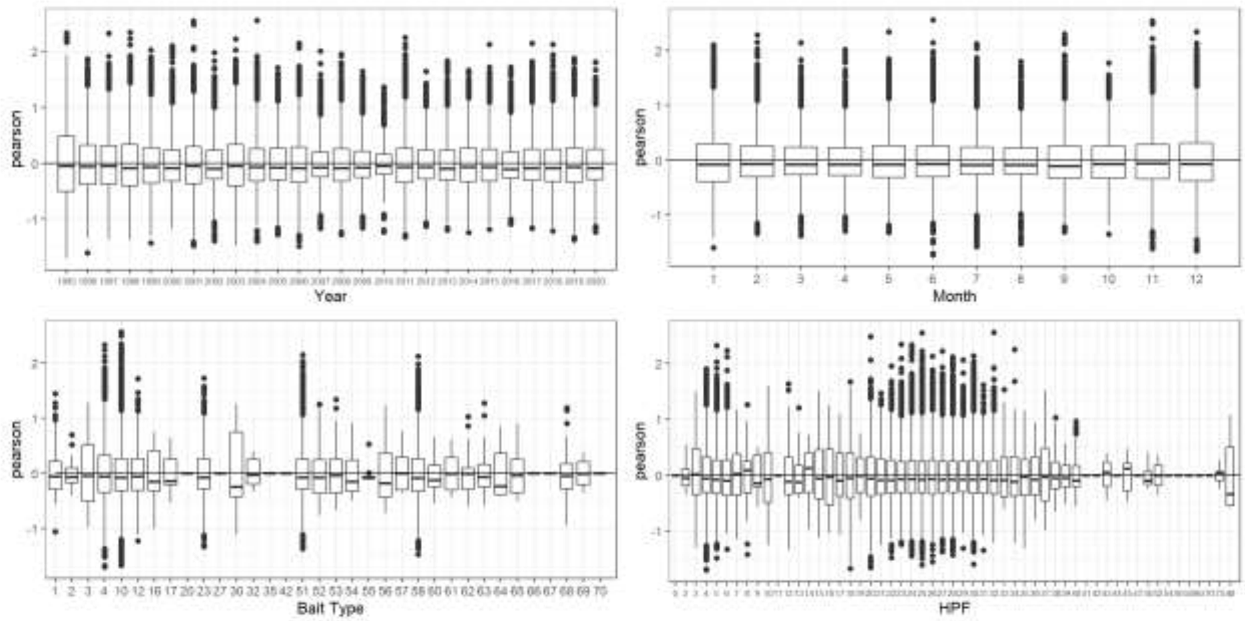

Figure 8. Residuals vs explanatory variables, positive catches in the complete dataset: Year (upper left); Month (upper right); Bait type (lower left); and Hooks Per Float (lower right).

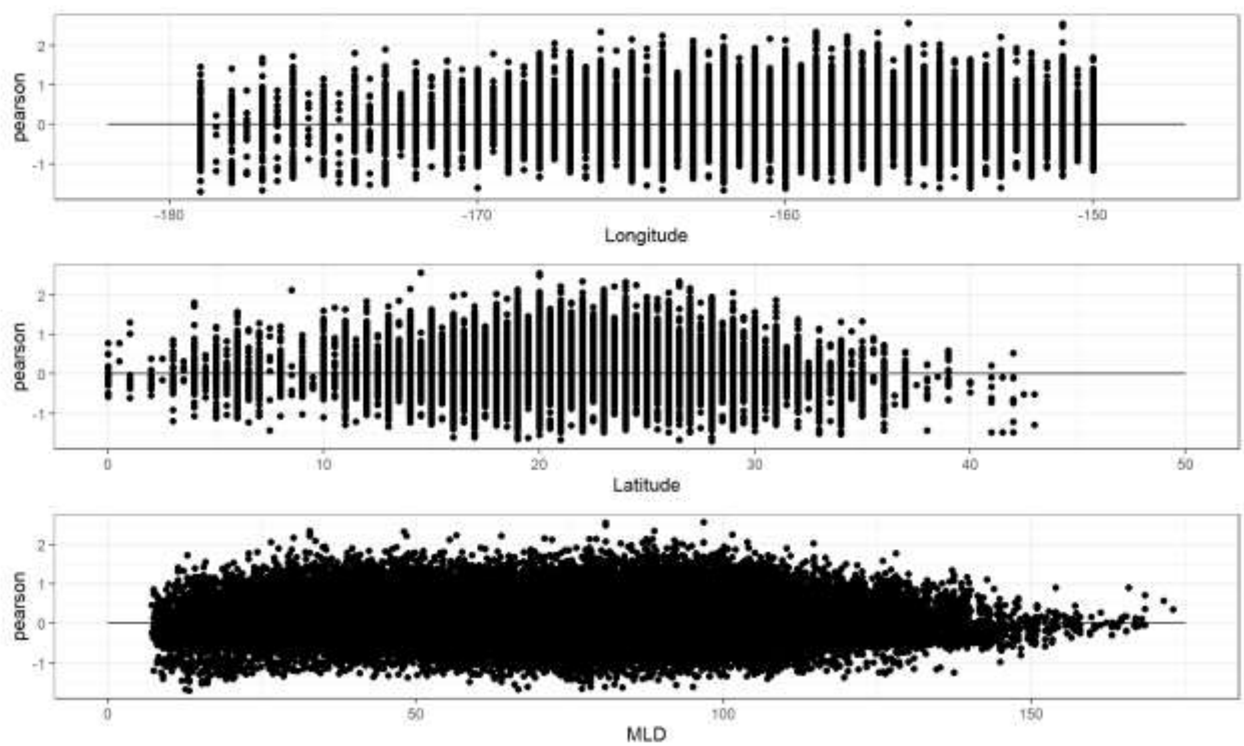

Figure 9. Residuals vs explanatory variables, positive catches in the complete dataset: longitude (top); latitude (center); and mixed layer depth (bottom).

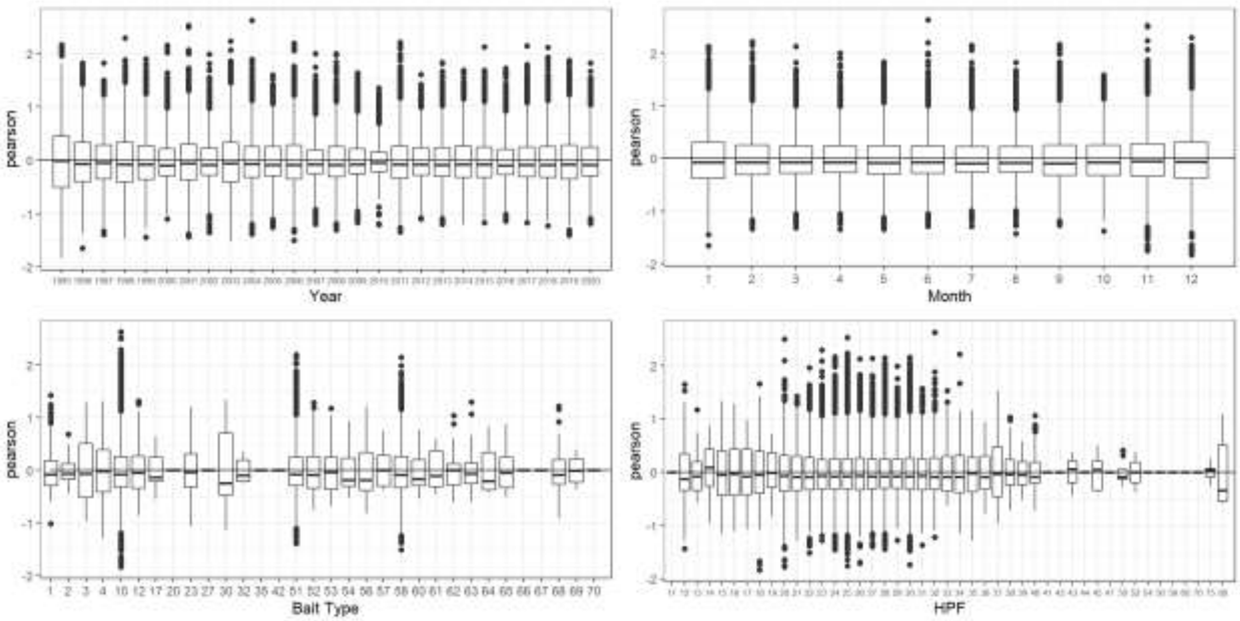

Figure 10. Residuals vs explanatory variables, positive catches in the deep-set dataset: Year (upper left); Month (upper right); Bait type (lower left); and Hooks Per Float (lower right).

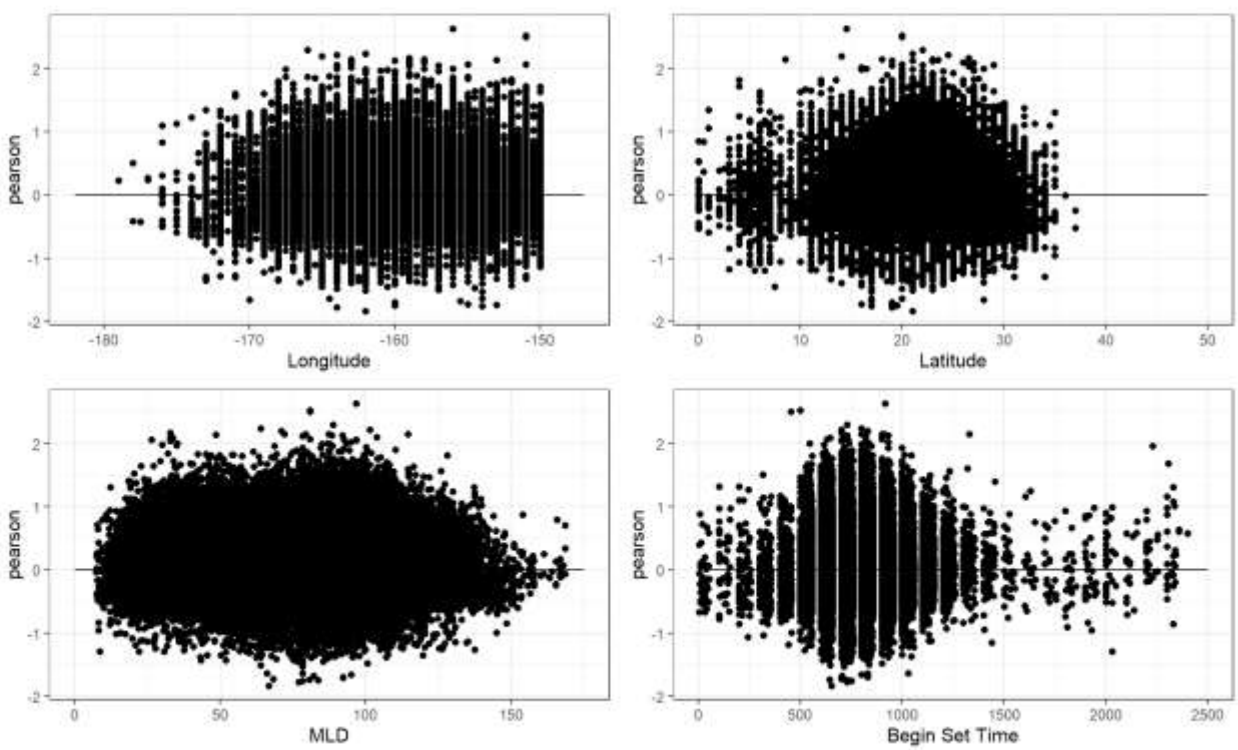

Figure 11. Residuals vs explanatory variables, positive catches in the deep-set dataset: longitude (top left); latitude (top right); mixed layer depth (bottom left); and begin set time (bottom right).

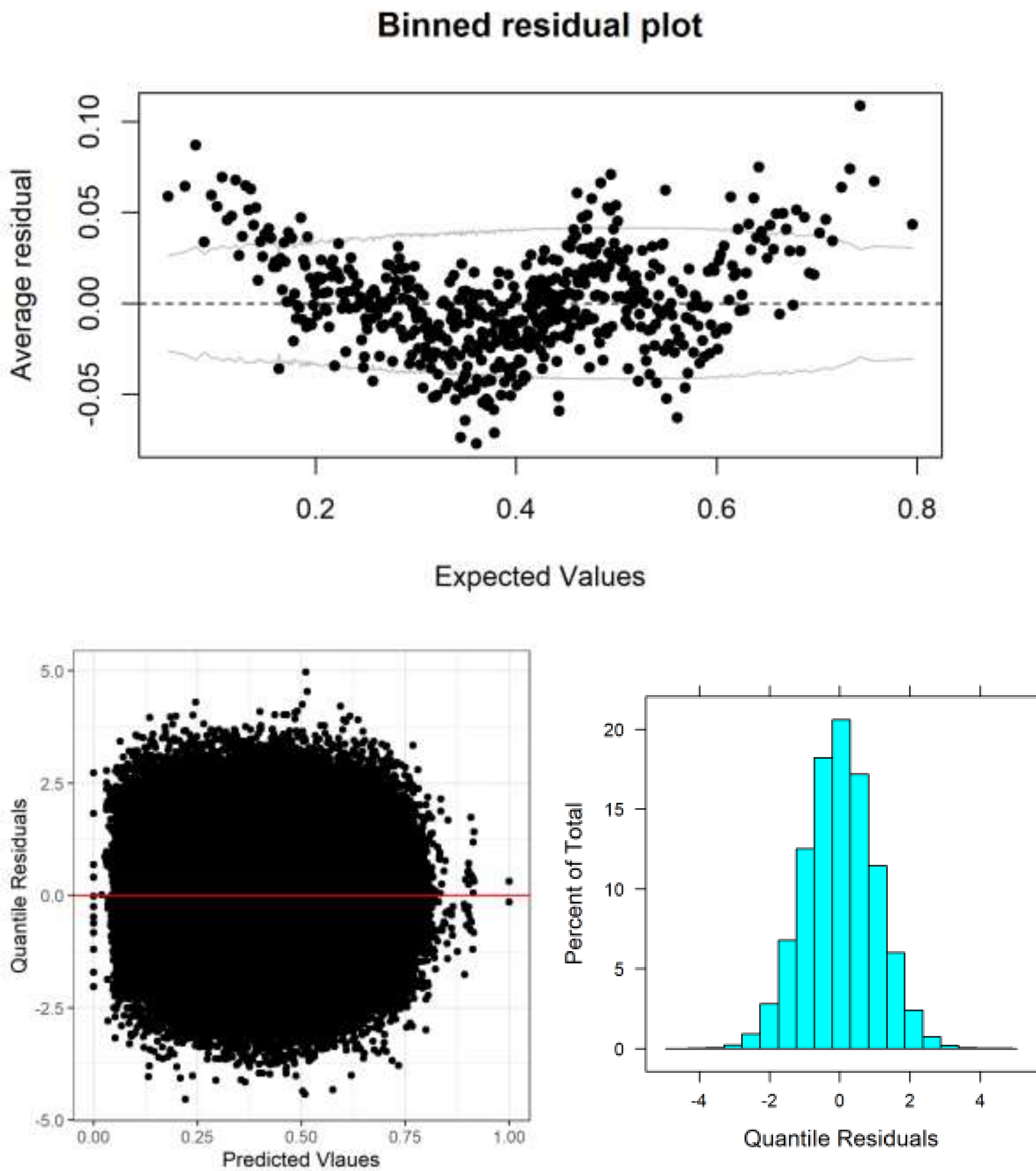

Figure 12. Diagnostics of the encounter probability binomial model for the complete dataset: Binned residual plot (top); expected values vs quantile residuals (bottom left); and histogram of quantile residuals (bottom right).

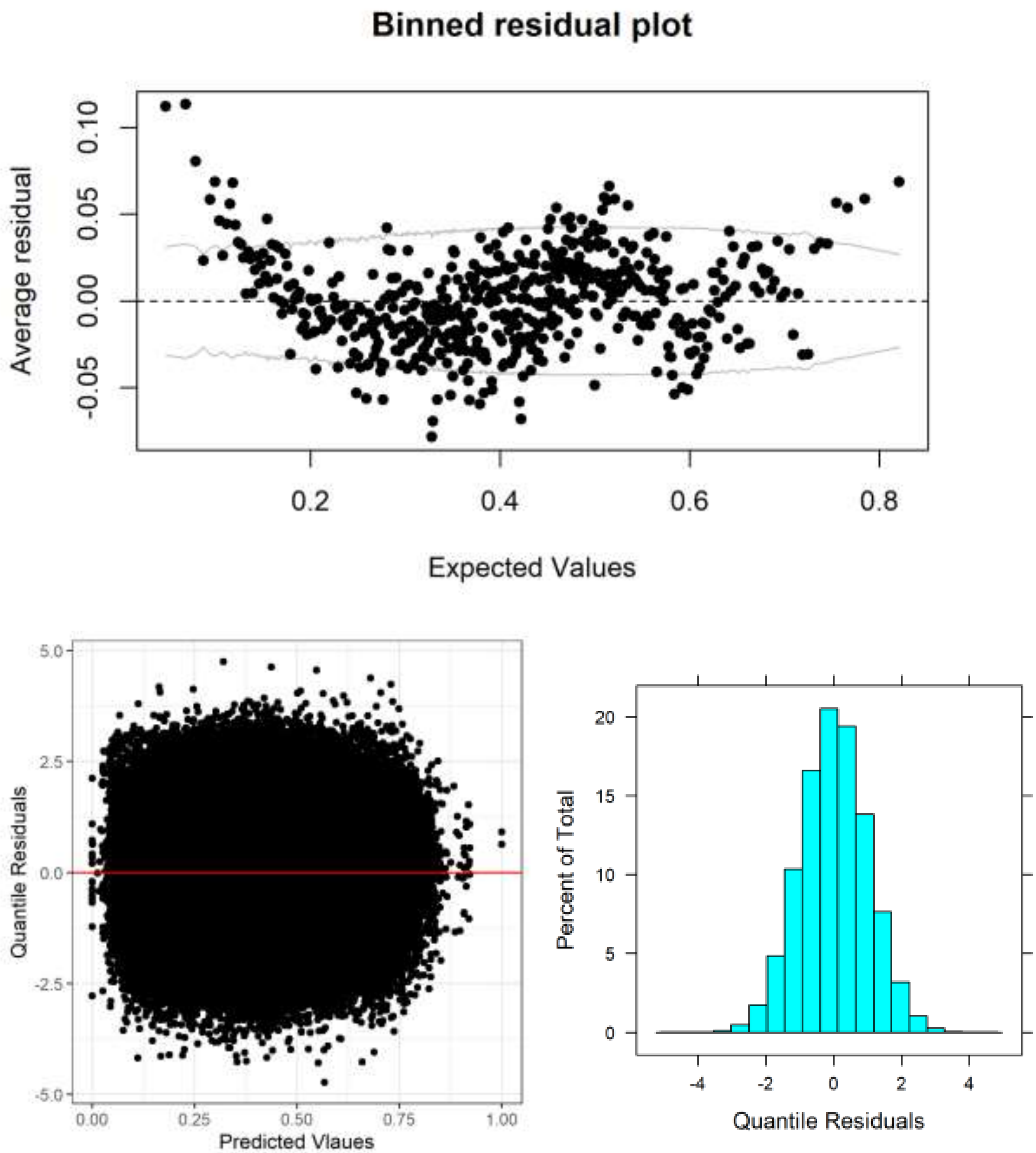

Figure 13. Diagnostics of the encounter probability binomial model for the deep-set dataset: Binned residual plot (top); expected values vs quantile residuals (bottom left); and histogram of quantile residuals (bottom right).

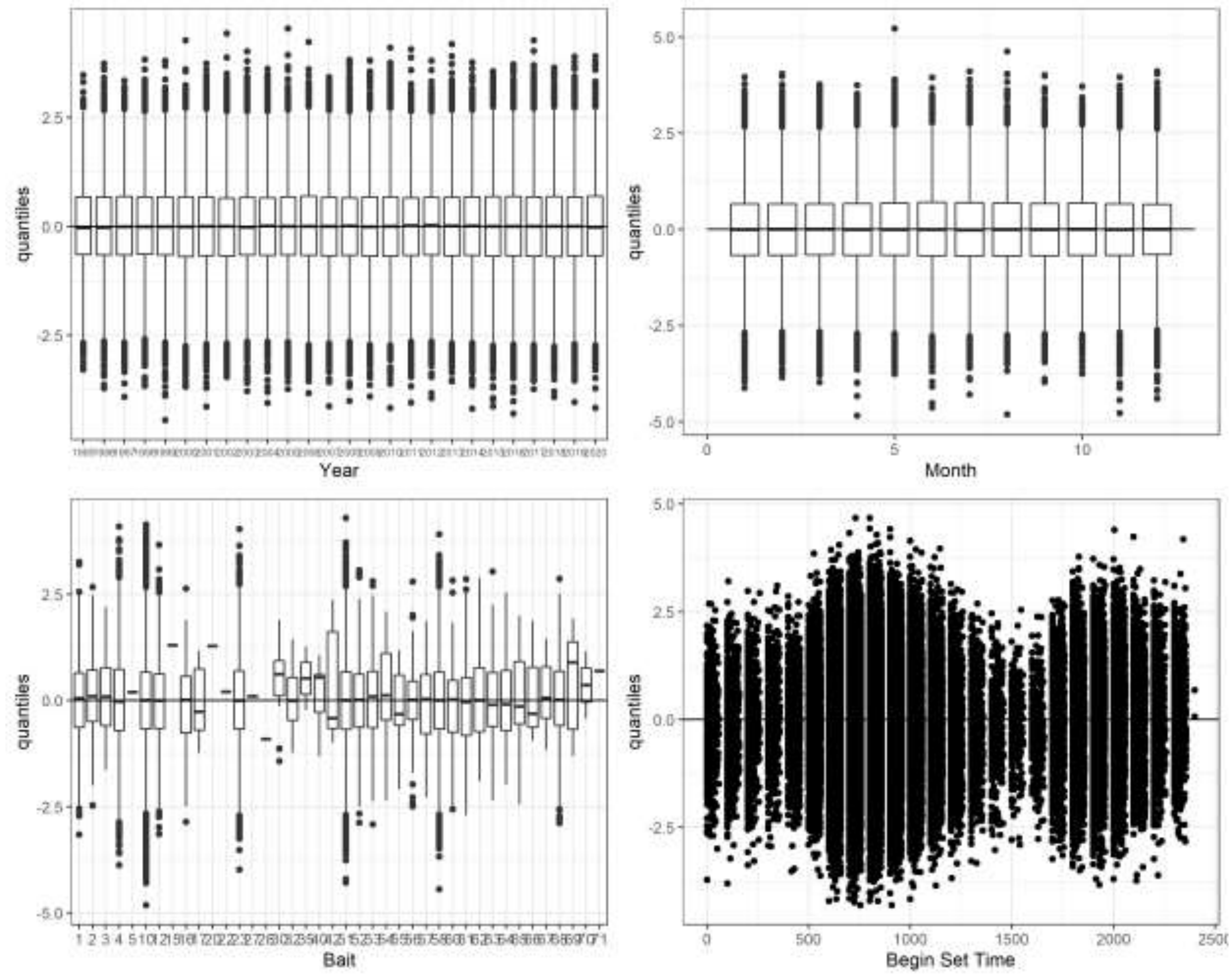

Figure 14. Quantile residuals vs explanatory variables for the encounter probability binomial model for the complete dataset: Year (top left); Month (top right); Hooks per float (bottom left); and Begin set time (bottom right).

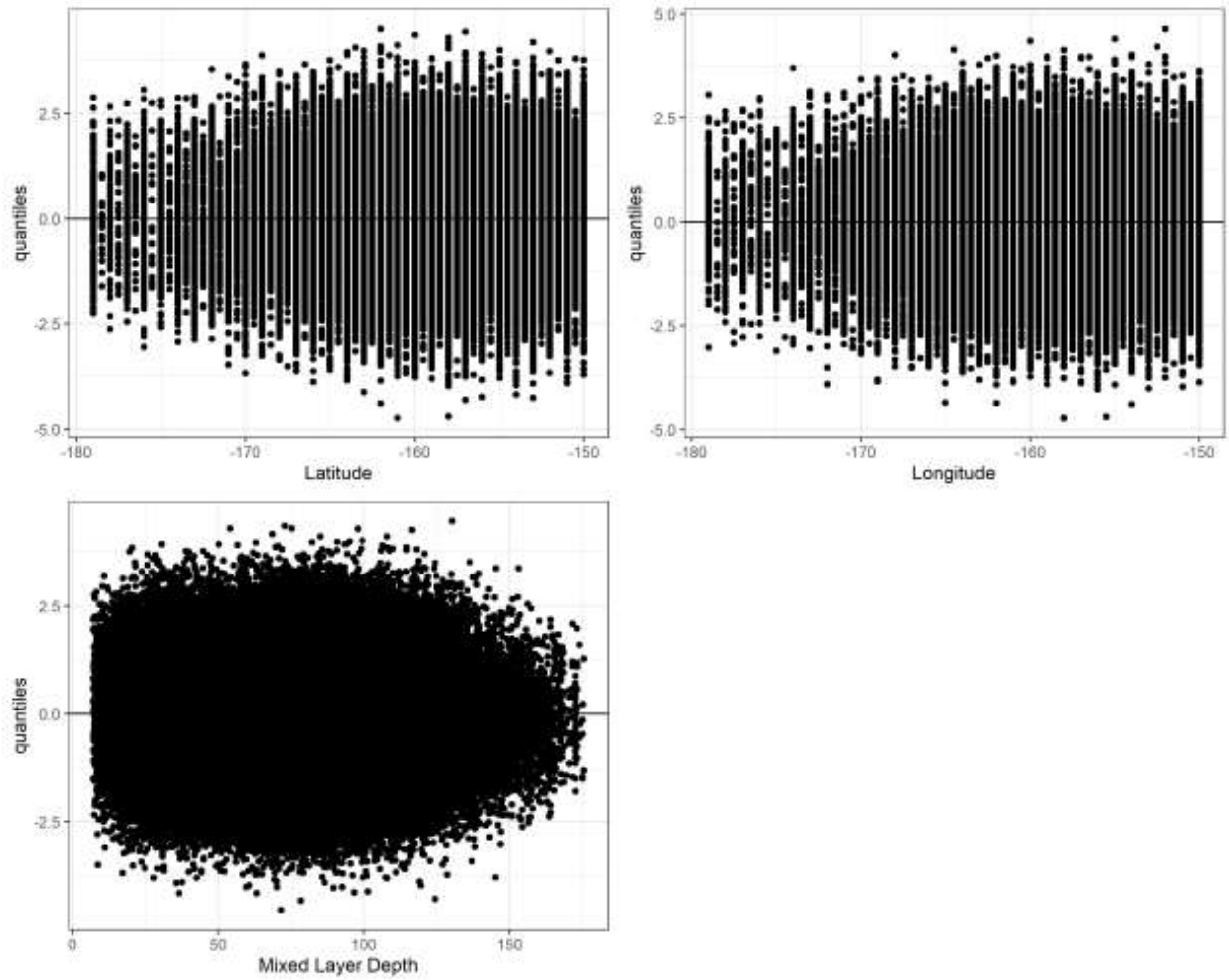

Figure 15. Quantile residuals vs explanatory variables for the encounter probability binomial model for the complete dataset: Latitude (top left); Longitude (top right); and Mixed Layer Depth (bottom left).

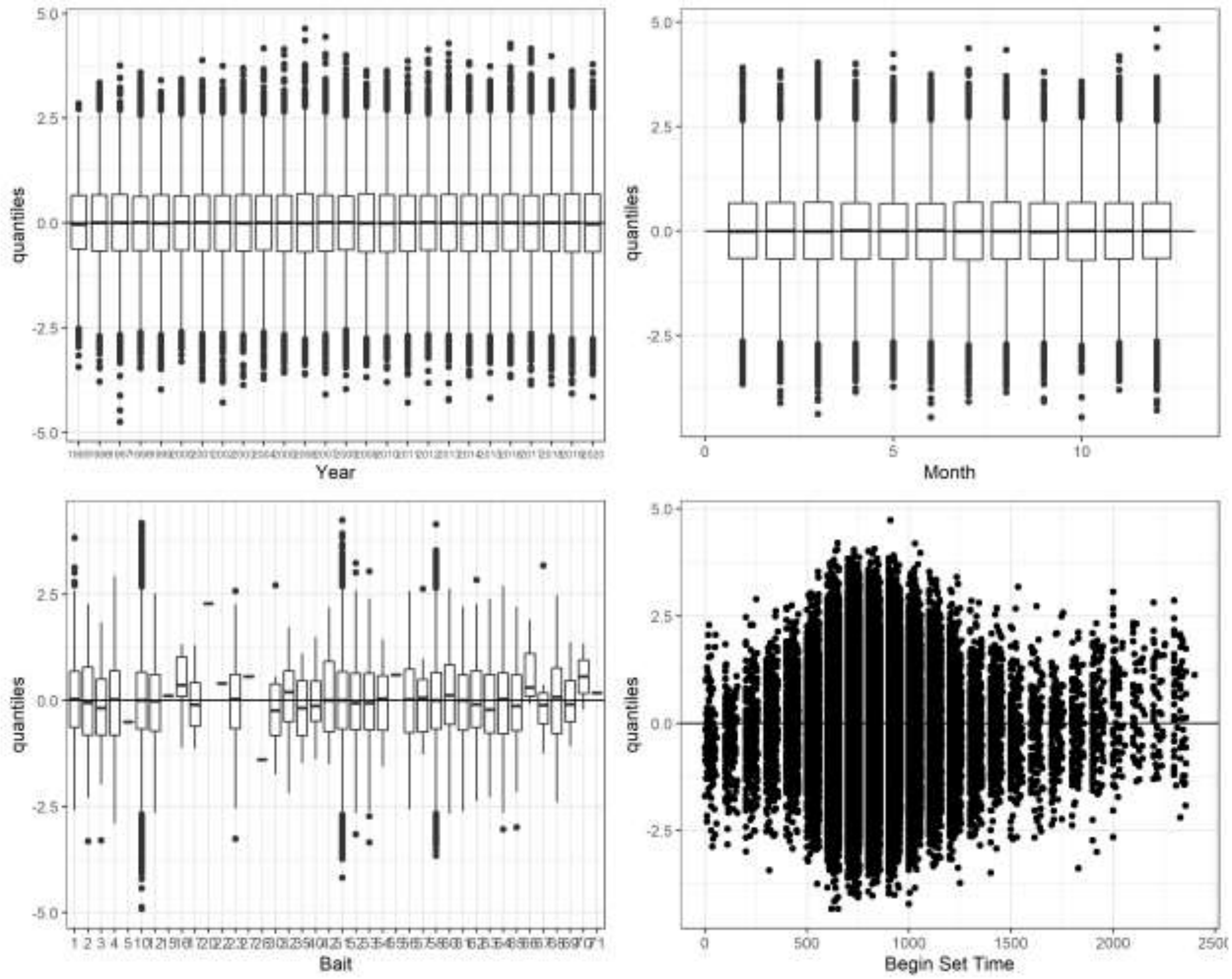

Figure 16. Quantile residuals vs explanatory variables for the encounter probability binomial model for the deep-set dataset: Year (top left); Month (top right); Bait (bottom left); and Begin set time (bottom right).

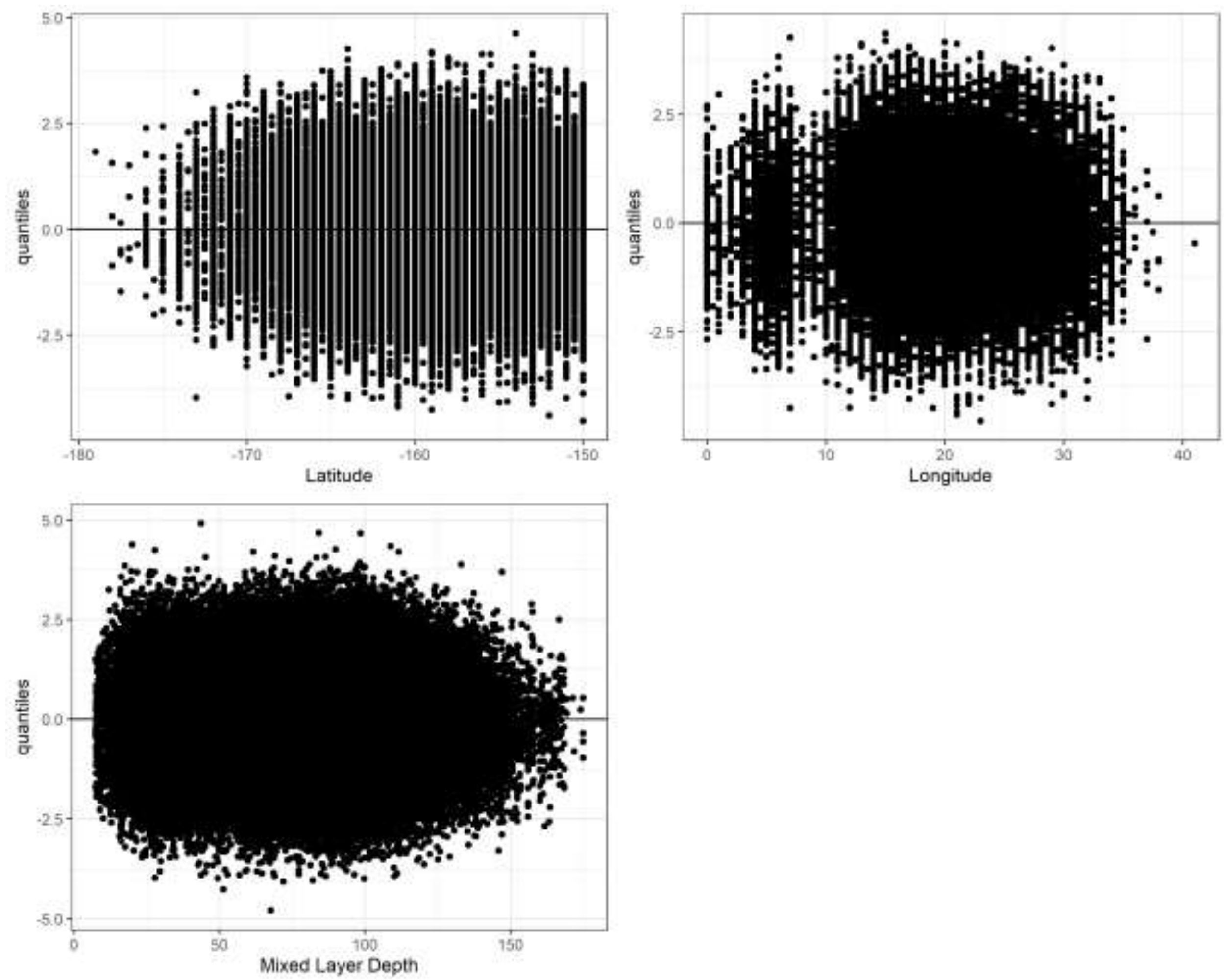

Figure 17. Quantile residuals vs explanatory variables for the encounter probability binomial model for the deep-set dataset: Latitude (top left); Longitude (top right); and Mixed Layer Depth (bottom left).

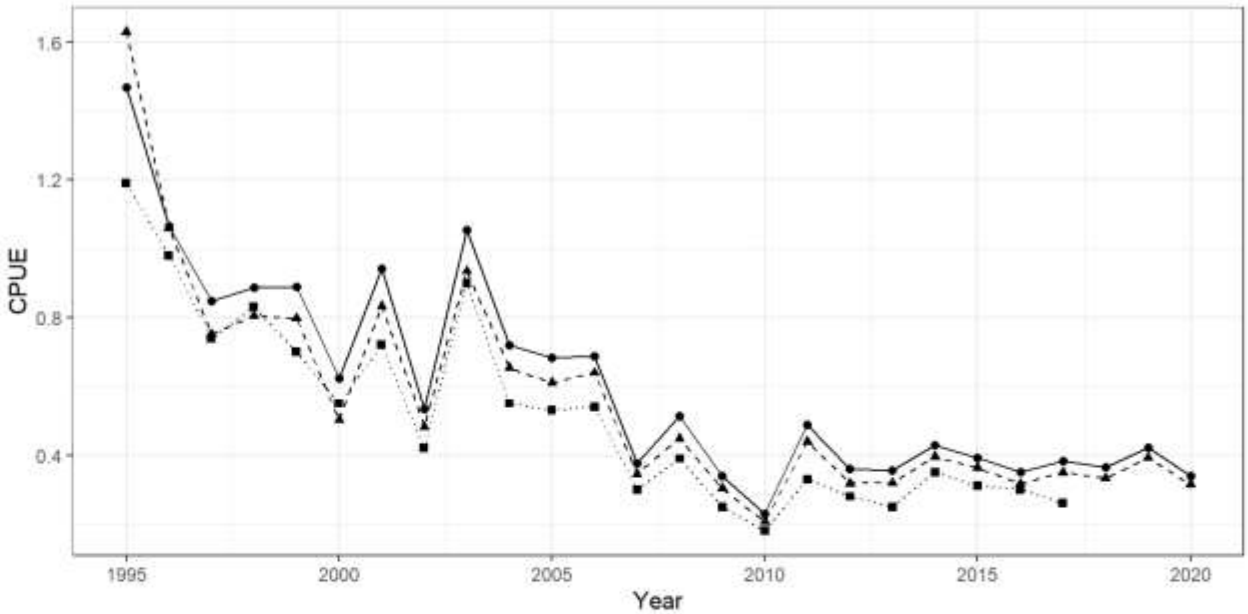

Figure 18. Normalized standardized CPUE from the 2019 assessment (dotted line, squares) and the current 2019 assessment (complete dataset: solid line, circles; deepset data: dashed line, triangles).