International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

Standardization of Striped Marlin, *Kajikia audax,* CPUE with Generalized Linear Models fitted to Pelagic Longline Observer Data from the Hawaii-based Fishery: 1995-2009

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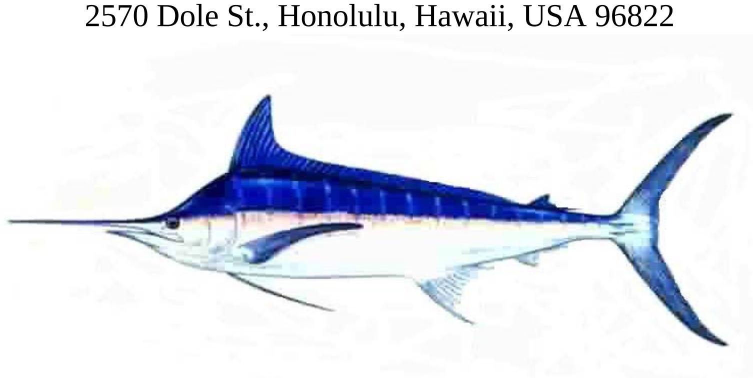

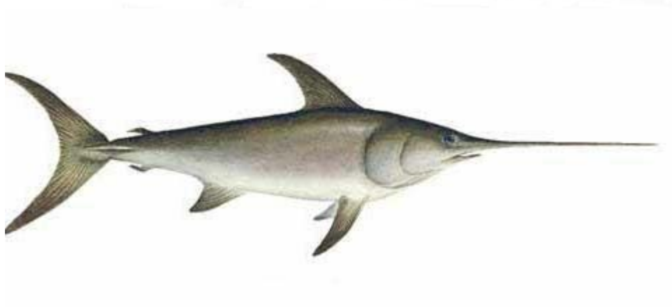

Working document submitted to the ISC Billfish Working Group Workshop, 19-27 January 2011, Honolulu, Hawaii, USA.

Standardization of Striped Marlin *Kajikia audax* CPUE with Generalized Linear Models fitted to Pelagic Longline Observer Data from the Hawaii-based Fishery in 1995–2009

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Abstract

This working paper presents catch-per-unit-effort standardizations for striped marlin *Kajikia audax* in the Hawaii-based pelagic longline fishery from 1995–2009. Catch and operational data were gathered by NOAA Fisheries Pacific Islands Regional Observer Program (PIROP) personnel. The standardizations were conducted by fitting generalized linear models (Poisson GLM; delta-lognormal GLM). Explanatory variables used as factors were the fishing year, quarter of the year, and fishing region. Sea surface temperature, hooks per float, hooks per longline set; the number of shortbill spearfish *Tetrapturus angustirostris* caught per set were used as continuous explanatory variables. Results include descriptive catch statistics, an analysis of deviance for each model with residuals plots and a table summarizing the residuals, and graphical presentations of the nominal and GLM-standardized rates.

Introduction

This working paper presents catch-per-unit-effort (CPUE) standardizations for striped marlin *Kajikia audax* in the Hawaii-based pelagic longline fishery. It complements the corrected catch history presented in WP XYZ (Walsh and Ito 2011). That 62-year corrected catch history included all available catch data, but its accuracy was unverifiable for most of the time series.

The most detailed data from the corrected catch history are the records from the NOAA Fisheries Pacific Islands Regional Observer Program (PIROP), established in February 1994. The observer data are subjected to detailed quality control procedures at the PIROP before being provided to users. In addition, one of us (WAW) has worked extensively with observer data for marlins (Walsh et al. 2005; 2007). For these reasons, the striped marlin CPUE analyses were conducted with observer data from the Hawaii-based pelagic longline fishery from 1995–2009.

Objective

The objective of this WP is to present striped marlin CPUE standardizations for the Hawaii-based pelagic longline fishery to be used as input in the stock assessment. Therefore, we conducted two types of generalized linear model (GLM) analyses, prepared tabular and graphical results summarizing the explanatory power, statistical significance, and residuals of the models, and compared the standardized and nominal catch rates.

Methods

Data Summary

Catch and operational data used as response and explanatory variables in the GLM analyses are summarized in Table 1. Catch (number caught), CPUE, and the presence or absence of catch were each the response variable in a GLM, whereas an identical suite of explanatory variables was used in each model.

The haul year, quarter of the year, and region of fishing were factor variables. The regions were defined as follows: 1) south of 10^{o}N; 2) 10–20^{o}N, east of 160^{o}W; 3) 10–20^{o}N, west of 160^{o}W;

4) north of 20°N, east of 160°W; 5) north of 20°N, west of 160°W. The regions were defined this way because there were insufficient data from south of 10°N for longitudinal separation.

Sea surface temperature (SST), hooks per float, and hooks per set were continuous explanatory variables included in each model[1]. The reason was that a generalized additive model (GAM) analysis revealed highly significant nonlinear effects of these variables on striped marlin catches (Walsh et al 2007). Consequently, these explanatory variables were entered into each GLM as third-order polynomials. The catch of shortbill spearfish *Tetrapturus angustirostris* was entered as a linear term because catch rates for this species tend to follow a seasonal pattern similar to that of striped marlin in this fishery (Walsh et al. 2007).

GLM Analyses

The analyses were conducted by fitting Poisson and delta-lognormal GLMs. The Poisson model with catch as the response variable was computed because this discrete distribution may be appropriate for species where catch is recorded in whole numbers (Maunder and Punt 2004). The delta-lognormal GLM was computed to conform to standard methodology when the intention is to model the catch rate and the data include substantial numbers of zeroes (Stefánsson 1996; Maunder and Punt 2004). Each model is summarized with an analysis of deviance that presents the statistical significance and relative importance of the explanatory variables as well as the overall explanatory power.

The delta-lognormal analysis was conducted in three steps. The first entailed fitting a binomial GLM with the presence or absence of catch as the response variable using the entire data set. The second entailed fitting a lognormal GLM to the subset of the data with positive catch. The third entailed computing annual estimates by multiplying the back-transformed coefficients from the two models and computing jackknife estimates of the standard errors (Dick 2004).

Standardized residuals from the Poisson and binomial models were plotted on the scales of the linear predictors. The residuals from the lognormal GLM were plotted against the predicted values, the values of the explanatory variables, and as a quantile-quantile normal probability plot.

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[1] SST: 24.4±2.8°C; 15.0–30.5°C. Hooks per set: 1812±608, 202–4110. Hooks per float: 22.0±9.6; 2-53. Spearfish catch per set: 0.7±1.4; 0–25. Values are the means, standard deviations, and ranges.

The residuals from all of the models were also tabulated in year/quarter/region combinations in an attempt to identify circumstances associated with systematic lack of fit.

All statistical computations were performed in R (Version 2.4.1). GLM methodology followed Crawley (2007).

Results

Descriptive striped marlin catch statistics and operational information are presented in Table 1. Data were collected aboard 177 longline vessels during 3199 commercial trips. It should be noted that the PIROP developed and then underwent a major expansion during the study period, with a >10-fold increase in the annual number of observed sets between 1995 and 2009.

The nominal catches per set, CPUE, percentage of sets with striped marlin catch, and number of striped marlin caught on sets with positive catch decreased substantially from 1995–2009 (catch per set: -82.5%; nominal CPUE: -87.2%; sets with catch: -61.4%; catch per positive catch set: -55.3%). The relationship among these effects is revealed by the correlation between the frequency of positive catch and the number caught on sets with positive catch (r = 0.904; P = 3.75e-06). In 1995, the catch frequency (63.2%) and the catches on sets with catch (3.51) were the second highest and greatest, respectively, throughout the study period. These variables decreased to their lowest levels in 2007 (20.7%; 1.51 per set) and 2009 (24.6%; 1.57 per set).

Quarterly and regional effects on striped marlin catch rates are summarized in Table 2. In the first quarter of the year, the catches per set and nominal CPUE in Regions 2 and 3 were greater than those in the others. Striped marlin were caught on >50% of the sets in these regions during the first quarter and in Region 5 during the second and fourth quarters. The lowest frequencies of positive catch were those from Region 2 in the first and Regions 1–3 in the second quarter.

Table 3 presents a summary analysis of deviance for the Poisson GLM, which explained 31.6% of the null deviance. Quarterly, annual, and regional effects were highly significant, with deviance explanations per df decreasing in this order. SST effects yielded the greatest deviance reductions per df. The positive relationship between striped marlin and shortbill spearfish catches was also significant and explained 1.2% of the null deviance. The complete R analysis of deviance and supporting documentation are presented in Appendix I.

The Binomial GLM (Table 4) explained 17.2% of the null deviance of the frequency of positive catches. The explanatory variables yielded reductions in the Akaike Information Criterion (AIC) ranging from that of hooks per longline set (-301.38) to that of SST (-3453.37). SST also explained the greatest percentage of the null deviance (6.4%). The complete R analysis of deviance and supporting documentation are presented in Appendix II.

The Lognormal GLM results (Table 5) exhibited a different pattern from the others. Hooks per float was the most important explanatory variable for the log-transformed positive catch rates (11.2% of null deviance; 1258.1 units of deviance per df). This bimodally distributed variable (shallow-set sector: interquartile range = 4–5 hooks per float; deep-set sector: interquartile range = 25–30 hooks per float) is the official criterion defining the two sectors of this fishery (Department of Commerce 2004). It represents the effects of deep- and shallow-set fishing for striped marlin (PIROP nominal mean CPUE, 1995–2009: shallow-set sector = 0.71/1000 hooks; deep-set sector = 0.51/1000 hooks). Regional effects were also more important in this GLM than in the others (5.0% of null deviance; 422.5 units of deviance per df). The mean nominal CPUE in Region 1 (0.85/1000 hooks) was less than all others, while those in Region 2 (10–20^{o}N, east of 160^{o}W; 1.08/1000 hooks) and Region 3 (10–20^{o}N, west of 160^{o}W; 1.09/1000 hooks). Mean nominal CPUE differed significantly (t = 17.331; P <9.9e-16) between Region 4 (north of 20^{o}N, east of 160^{o}W; 1.37/1000 and Region 5 (north of 20^{o}N, west of 160^{o}W; 1.96/1000 hooks).

The annual effect coefficients and plots of the back-transformed catch per set and CPUE trends are presented in Table 6 and Figure 1, respectively. The trends from the Poisson (Figure 1a) and Delta-Lognormal analyses (Figure 1b) were highly correlated (Spearman's correlation: rho=0.929; P<2.2e-16).

Discussion

The descriptive statistics (Table 1) reflect apparent substantial decreases in striped marlin catches and CPUE between 1995 and 2009 associated with decreases in positive catch frequencies and in numbers caught on sets with positive catch. The nominal decrease in CPUE over 15 years was 87.2%; the average annual decrease was 5.8%. The decrease estimates from the two models for the 15-year study period were -82.5% for catch per set (Poisson GLM) and -71.3% for CPUE, equivalent to average annual decreases of 5.5% (catch per set) and 4.8% (CPUE), respectively.

The two obvious differences in the standardization plots can be ascribed to changes in the fishery. In both 1997–1998 and 2004–2005 when the standardized catch per set decreased but the standardized CPUE increased slightly, the number of hooks per longline set increased (1997–1998: +12%; 2004–2005: +16%).

One aspect of the temporal changes requiring evaluation is the extent to which data from 1995 may have proven highly influential in the analyses. The uncorrected nominal landings from 1991–1996 (Walsh and Ito 2011; WP XYZ) were examined because the PIROP was founded in 1994. The annual landings in 1995 (557767 kg) were greater than those from 1991–1994 and 1996 (mean: 473288 kg; range: 335874–517760 kg). Walsh et al. (2007) reported that the weights of striped marlin from the fourth quarter of 1995 were not significantly different from those of other quarters, but the quarterly mean SST was relatively high (25.9°C; all other years except 2003: 24.5–25.2°C). Thus, although possibly influential, the results from 1995 appear to be real, with a possible positive effect of oceanographic conditions on catches in the fourth quarter.

The regional effects generally consisted of increasing catches and CPUE in the more northern areas, with a significant longitudinal separation above 20°N. The latter finding, in particular, indicates that the northwestern areas exploited by this fishery should be carefully considered in any relative abundance analysis for striped marlin.

Conclusions

The standardizations of striped marlin catch per set and CPUE confirm the apparent trend in the nominal catch statistics; namely, that striped marlin catches and catch rates have decreased considerably in the last 15 years. The relatively similar estimates of change in catch per set and CPUE, and the finding that the standardized trends were highly correlated with differences that could be ascribed to operational changes in this fishery reinforces this conclusion.

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Figure 1a. Annual trend of observed striped marlin *Kajikia audax* catch per set as standardized with a Poisson GLM.

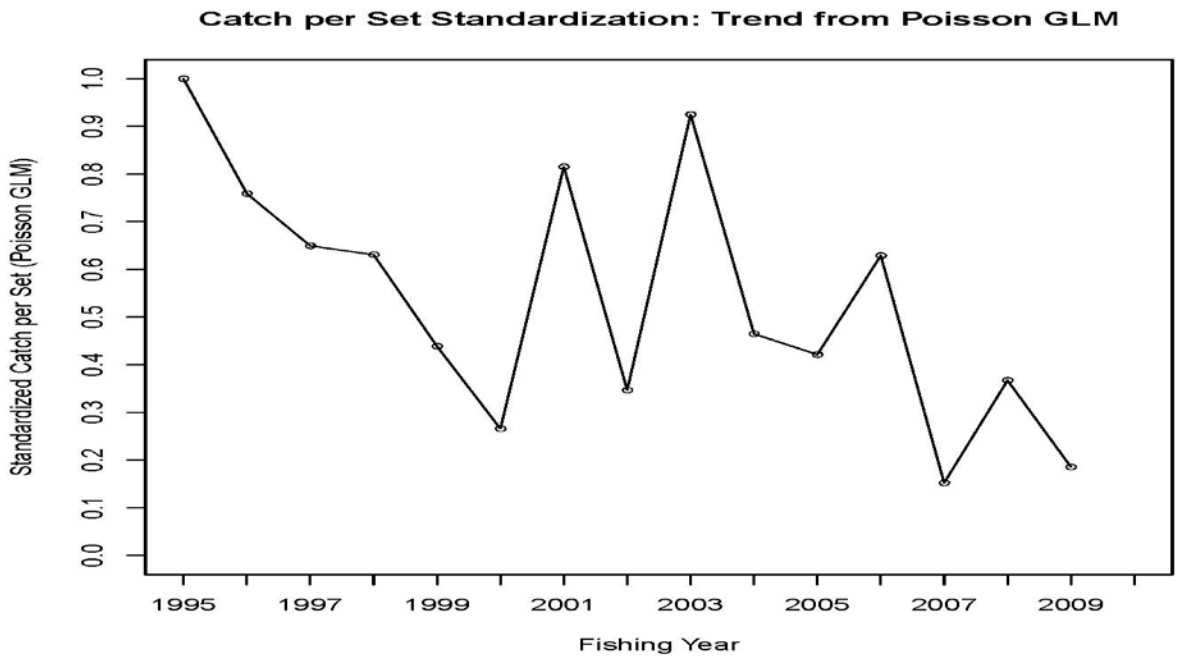


Figure 1b. Annual trend of observed striped marlin *Kajikia audax* CPUE as standardized with a Delta-lognormal GLM.

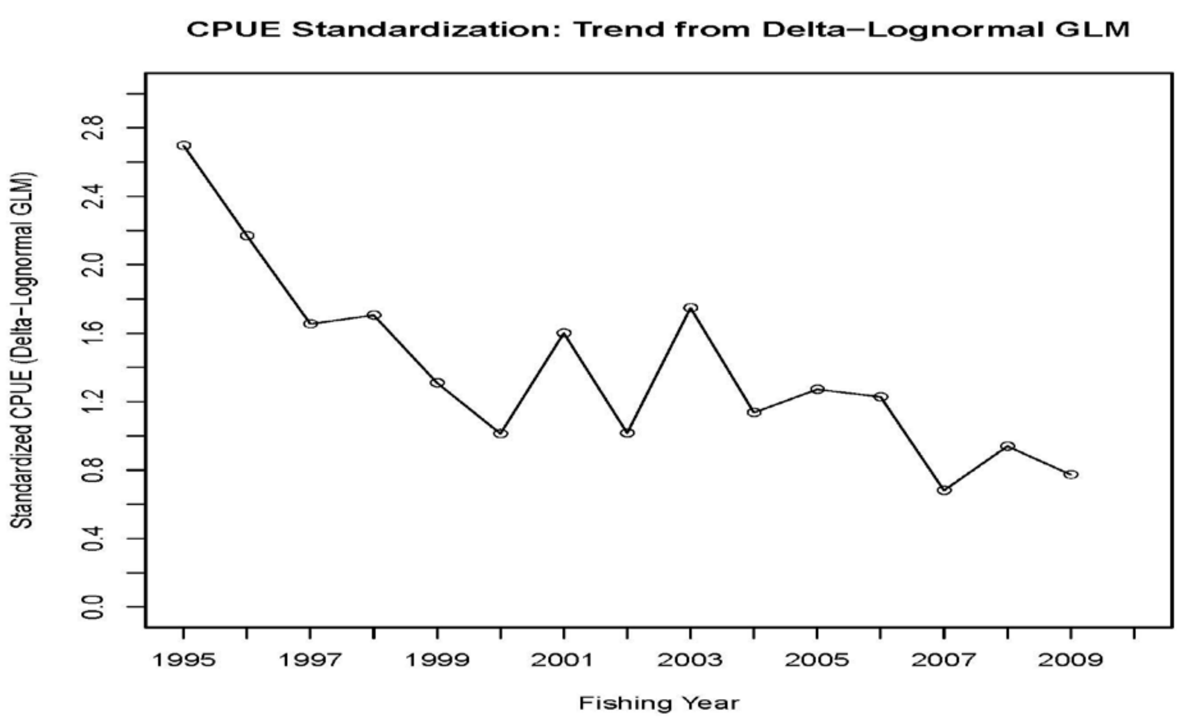


Table 1. Summary of observed striped marlin *Kajikia audax* catch and effort data from the Hawaii-based pelagic longline fishery (January 1995–December 2009). Nominal CPUE is catch per 1000 hooks. Parenthetical entries are standard deviations.

Year	Vessels	Trips	Sets	Catch	Sets with catch (%)	Catch/set	Nominal CPUE	Catch/set: catch > 0
1995–2009	177	3199	39977	37631	39.5%	0.94 (1.79)	0.56 (1.15)	2.38 (2.17)
1995	44	48	466	1041	63.7%	2.23 (3.16)	1.95 (2.89)	3.51 (3.35)
1996	47	52	450	736	53.2%	1.64 (3.10)	1.32 (2.60)	3.17 (3.71)
1997	33	37	361	450	48.8%	1.25 (1.95)	1.02 (1.86)	2.56 (2.12)
1998	40	47	441	555	46.7%	1.26 (2.15)	0.83 (1.32)	2.69 (2.45)
1999	36	39	351	385	55.3%	1.10 (1.51)	0.86 (1.44)	2.15 (1.49)
2000	71	113	1060	599	29.2%	0.57 (1.21)	0.42 (1.03)	1.93 (1.54)
2001	98	243	2404	4253	61.5%	1.77 (2.33)	1.01 (1.40)	2.88 (2.38)
2002	99	282	2699	1873	36.2%	0.69 (1.30)	0.36 (0.67)	1.92 (1.53)
2003	104	261	2958	6619	65.1%	2.24 (2.96)	1.13 (1.51)	3.44 (3.06)

Table 1, continued.

Year	Vessels	Trips	Sets	Catch	Sets with catch (%)	Catch/set	Nominal CPUE	Catch/set: Catch > 0
2004	124	345	4038	3737	42.8%	0.93 (1.65)	0.45 (0.79)	2.16 (1.93)
2005	122	392	5000	4615	41.8%	0.92 (1.55)	0.69 (1.39)	2.21 (1.70)
2006	123	318	4142	4777	45.2%	1.15 (1.55)	0.57 (0.94)	2.55 (2.25)
2007	123	362	5097	1588	20.7%	0.31 (0.76)	0.19 (0.50)	1.51 (0.99)
2008	126	380	5365	4411	37.5%	0.82 (1.53)	0.49 (1.06)	2.19 (1.79)
2009	121	360	5145	1992	24.6%	0.39 (0.85)	0.25 (0.60)	1.57 (1.04)

Table 2. Summary of quarterly and regional effects on striped marlin catch statistics, 1995–2009. Entries are mean values.

Calendar Quarter	Region 1	Region 2	Region 3	Region 4	Region 5
1	Catch/set= 0.39 CPUE = 0.19 Catch>0 = 24.3%	Catch/set= 1.29 CPUE = 0.67 Catch>0 = 59.8%	Catch/set= 1.36 CPUE = 0.67 Catch>0 = 58.8%	Catch/set= 0.45 CPUE = 0.29 Catch>0 = 21.9%	Catch/set= 0.85 CPUE = 0.49 Catch>0 = 35.3%
2	Catch/set= 0.17 CPUE= 0.08 Catch>0 = 12.9%	Catch/set= 0.68 CPUE = 0.36 Catch>0 = 40.4%	Catch/set= 0.95 CPUE = 0.48 Catch>0 = 46.3%	Catch/set= 0.92 CPUE = 0.69 Catch>0 = 45.6%	Catch/set= 1.69 CPUE = 1.51 Catch>0 = 58.4%
3	Catch/set= 0.39 CPUE = 0.19 Catch>0 = 19.6%	Catch/set= 0.26 CPUE = 0.15 Catch>0 = 18.0%	Catch/set= 0.28 CPUE = 0.15 Catch>0 = 19.4%	Catch/set= 0.56 CPUE = 0.29 Catch>0 = 27.8%	Catch/set= 0.85 CPUE = 0.63 Catch>0 = 41.9%
4	Catch/set= 0.41 CPUE = 0.23 Catch>0 = 20.3%	Catch/set= 0.95 CPUE = 0.48 Catch>0 = 35.1%	Catch/set= 0.93 CPUE = 0.47 Catch>0 = 38.1%	Catch/set= 1.20 CPUE = 0.63 Catch>0 = 43.0%	Catch/set= 1.99 CPUE = 1.03 Catch>0 = 60.3%

Table 3. Summary analysis of deviance of a Poisson GLM of observed striped marlin catches from the Hawaii-based longline fishery. Deviance reductions and explanations of the null deviance are pooled for factor variables and polynomial terms.

Parameter	Parameter Estimate	SE	*t*	Pr>|*t*|	Null deviance	*N*
Intercept	0.10512	0.00968	1.086	0.278	92069.7	39977 sets
Parameter	df	Residual deviance reduction	*F*	*P*	Explanation of null deviance	Units of deviance per df
Haul year	14	11769.2	306.54	<2.2e-16	12.8%	840.6
Quarter	3	3440.8	429.63	<2.2e-16	1.2%	1146.9
Region	4	2573.9	246.52	<2.2e-16	2.8%	643.4
SST	3	7960.8	1117.2	<2.2e-16	8.6%	2653.6
Hooks/float	3	1195.6	171.99	<2.2e-16	1.3%	398.7
Hooks/set	3	1063.3	157.63	<2.2e-16	1.2%	354.4
Spearfish/set	1	1108.1	509.72	<2.2e-16	1.2%	1108.1
Dispersion parameter 2.17293	Median residual -0.6174	Mean residual 0.0457	Residual deviance 62958.5	Residual df 39945	Residual mean deviance 1.57613	pseudo-R^2 31.6%

Table 4. Summary analysis of deviance of a Binomial GLM of observed striped marlin catches from the Hawaii-based longline fishery. Deviance reductions and explanations of the null deviance are pooled for factor variables and polynomial terms.

Parameter	Parameter Estimate	SE	*z*	Pr>|*z*|	Null deviance and AIC	*N*
Intercept	-0.42487	0.01023	-41.53	<2e-16	53655.7; 53657.7	39977 sets
Parameter	df	Residual deviance reduction	AIC	ΔAIC	Explanation of null deviance	Deviance per df
Haul year	14	2928.75	50756.95	-2900.75	5.5%	207.2
Quarter	3	1093.26	49669.69	-1087.26	2.0%	364.4
Region	4	762.96	48914.73	-754.96	1.4%	188.7
SST	3	3459.37	45461.36	-3453.37	6.4%	1153.1
Hooks/float	3	329.76	45137.60	-323.76	0.6%	109.9
Hooks/set	3	307.38	44836.22	-301.38	0.6%	102.5
Spearfish/set	1	354.86	44483.36	-352.86	0.7%	354.86
Dispersion parameter (taken as 1.0)	Median residual -0.4810	Mean residual 0.0648	Residual deviance 44419.36	Residual df 39945	Residual mean deviance 1.1120	pseudo-R^2 17.2%

Table 5. Summary analysis of deviance of a lognormal GLM of observed striped marlin catches from the Hawaii-based longline fishery. Deviance reductions and explanations of the null deviance are pooled for factor variables and polynomial terms.

Parameter	Parameter Estimate	SE	*t*	Pr>|*t*|	Null deviance	*N*
Intercept	2.371212	0.127026	18.667	< 2e-16	33803.83	15805 sets
Parameter	df	Residual deviance reduction	AIC	ΔAIC	Explanation of null deviance	Deviance per df
Haul year	14	2550.8	55660.34	NA	7.5%	182.2
Quarter	3	606.4	55356.66	-303.68	1.8%	202.1
Region	4	1690.1	54468.09	-888.57	5.0%	422.5
SST	3	133.7	54400.95	-67.14	0.4%	44.6
Hooks/float	3	3774.3	52188.67	-2212.28	11.2%	1258.1
Hooks/set	3	237.65	52044.01	-144.66	0.7%	79.2
Spearfish/set	1	245.61	51888.77	-155.24	0.7%	245.61
Dispersion parameter (taken as 1.5547250)	Median residual -0.2200	Mean residual 1.520101e-14	Residual deviance 24565.27	Residual df 15773	Residual mean deviance 1.5574	pseudo-R^2 27.3%

Table 6. Annual coefficients and their standard errors from the GLM analyses.

	Poisson GLM		Binomial GLM		Lognormal GLM		Delta- Lognormal GLM	
Haul year	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
1996	-0.275733	0.1184	-0.583091	0.1515	-0.137148	0.005419	2.16918	1.027185
1997	-0.431778	0.1392	-0.484622	0.1627	-0.255942	0.005891	1.65422	1.028182
1998	-0.460992	0.1303	-0.723571	0.1515	-0.271041	0.005627	1.70540	1.026387
1999	-0.824136	0.1476	-0.856061	0.1628	-0.400052	0.005878	1.30959	1.030429
2000	-1.325300	0.1278	-1.65502	0.1315	-0.498589	0.005088	1.01276	1.057904
2001	-0.204252	0.008791	-0.16687	0.1192	-0.125029	0.003996	1.69053	1.013893
2002	-1.059710	0.009846	-1.30061	0.1181	-0.453961	0.004187	1.01615	1.037140
2003	-0.078152	0.008625	-0.197368	0.1176	-0.0355985	0.003955	1.74789	1.013931
2004	-0.766310	0.009084	-0.892052	0.1161	-0.383997	0.004012	1.13586	1.029924
2005	-0.864495	0.008649	-1.02206	0.1143	-0.394997	0.003903	1.27189	1.032605
2006	-0.463885	0.008952	-0.605124	0.1160	-0.250684	0.004009	1.22759	1.026621
2007	-1.882510	0.1012	-2.08216	0.1166	-0.644098	0.004169	0.68107	1.072445
2008	-1.001730	0.008947	-1.33430	0.1156	-0.428667	0.004006	0.93945	1.03947
2009	-1.684770	0.009771	-1.88331	0.1166	-0.637989	0.004127	0.77337	1.059751

Synopsis of Appendices

Three appendices support the results presented in this WP. Analysis of deviance tables are output from R (Version 2.4.1). Standardized residuals for the Poisson and Binomial GLMs were computed according to Crawley (2007).

Most standardized residuals for every explanatory variable were negative, but the ranges of positive standardized residuals were much greater than the ranges that were negative in sign.

Poisson GLM residuals

There were fewer positive than negative mean residuals in all five regions, but none of the totals differed significantly from a 1:1 expectation (five chi-squared tests: all $P>0.25$).

The three largest positive residuals were from Region 1 in the third quarter of 2002, 2006, and 2009.

The largest positive standardized residuals in the plots on fishing year, quarter, region, SST, and shortbill spearfish catch are from the third quarter of 2009 in Region 1. These data require verification because the transition from blue to striped marlin as the most numerous billfish in the catch usually occurs in autumn.

The bimodal appearance of the plots of standardized residuals on hooks per float reflects the two sectors of the fishery.

The plot of standardized residuals on SST is curved and heterogeneous. There was no attempt to plot standardized residuals on the polynomial effect to determine whether the quadratic and cubic terms improved the fit.

Binomial GLM residuals

There were more positive than negative mean residuals in all Regions 3 and 4, but none of the totals differed significantly from a 1:1 expectation (five chi-squared tests: all $P>0.25$).

The plot on SST has a lower belt corresponding to zeroes, and a U-shaped appearance of the positive values.

Lognormal residuals

The Q-Q normal probability plot exhibits some downward curvature near its center.

The plot of residuals on predictions exhibits a ‘flattened’ appearance for negative residuals at low predicted values.

The SST plot is still bimodal but is more homogeneous than those from the other models..

Plots on hooks per float, hooks per set, and shortbill spearfish catch per set look approximately as expected.

APPENDIX I: Poisson GLM Analysis

1). Analysis of deviance (R output)

2). Tabulation of mean residuals

3). Standardized residuals plots

Table AI-1. Analysis of deviance of a Poisson GLM (R output).

> Call: glm(formula = strmar ~ Haulyr1 + Quarter1 + region1 + poly(SST, degree = 3) + poly(hkpfl, degree = 3) + poly(hooks, degree = 3) + spearfish, family = quasipoisson, data = strmar.obs)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-4.9902	-1.0936	-0.6174	0.2793	9.0992

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.051e-01	9.680e-02	1.086	0.277504
Haulyr11996	-2.757e-01	7.127e-02	-3.869	0.000109 ***
Haulyr11997	-4.318e-01	8.379e-02	-5.153	2.57e-07 ***
Haulyr11998	-4.610e-01	7.844e-02	-5.877	4.21e-09 ***
Haulyr11999	-8.241e-01	8.885e-02	-9.276	< 2e-16 ***
Haulyr12000	-1.325e+00	7.692e-02	-17.230	< 2e-16 ***
Haulyr12001	-2.043e-01	5.290e-02	-3.861	0.000113 ***
Haulyr12002	-1.060e+00	5.925e-02	-17.884	< 2e-16 ***
Haulyr12003	-7.815e-02	5.190e-02	-1.506	0.132132
Haulyr12004	-7.663e-01	5.467e-02	-14.017	< 2e-16 ***
Haulyr12005	-8.645e-01	5.205e-02	-16.610	< 2e-16 ***
Haulyr12006	-4.639e-01	5.387e-02	-8.611	< 2e-16 ***
Haulyr12007	-1.883e+00	6.092e-02	-30.900	< 2e-16 ***
Haulyr12008	-1.002e+00	5.384e-02	-18.604	< 2e-16 ***
Haulyr12009	-1.685e+00	5.880e-02	-28.651	< 2e-16 ***
Quarter12	-1.776e-01	2.411e-02	-7.366	1.79e-13 ***
Quarter13	-1.009e+00	3.320e-02	-30.397	< 2e-16 ***
Quarter14	-9.607e-02	2.688e-02	-3.574	0.000352 ***

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
region12	1.070e-01	8.874e-02	1.206	0.227824
region13	2.702e-01	8.618e-02	3.135	0.001718 **
region14	6.593e-01	8.994e-02	7.330	2.34e-13 ***
region15	9.637e-01	8.872e-02	10.862	< 2e-16 ***
poly(SST, degree = 3)1	1.811e+02	4.878e+00	37.118	< 2e-16 ***
poly(SST, degree = 3)2	-8.610e+01	3.141e+00	-27.415	< 2e-16 ***
poly(SST, degree = 3)3	-2.976e+01	3.061e+00	-9.722	< 2e-16 ***
poly(hkpfl, degree = 3)1	-1.237e+02	4.792e+00	-25.807	< 2e-16 ***
poly(hkpfl, degree = 3)2	8.329e+00	1.924e+00	4.328	1.51e-05 ***
poly(hkpfl, degree = 3)3	3.597e+00	1.925e+00	1.869	0.061691 .
poly(hooks, degree = 3)1	8.195e+01	4.526e+00	18.105	< 2e-16 ***
poly(hooks, degree = 3)2	-2.800e+01	2.727e+00	-10.267	< 2e-16 ***
poly(hooks, degree = 3)3	4.079e+00	1.834e+00	2.225	0.026112 *
spearfish	9.212e-02	3.732e-03	24.684	< 2e-16 ***

(Dispersion parameter for quasipoisson family taken to be 2.172926)

Null deviance: 92070 on 39976 degrees of freedom

Residual deviance: 62958 on 39945 degrees of freedom

AIC: NA

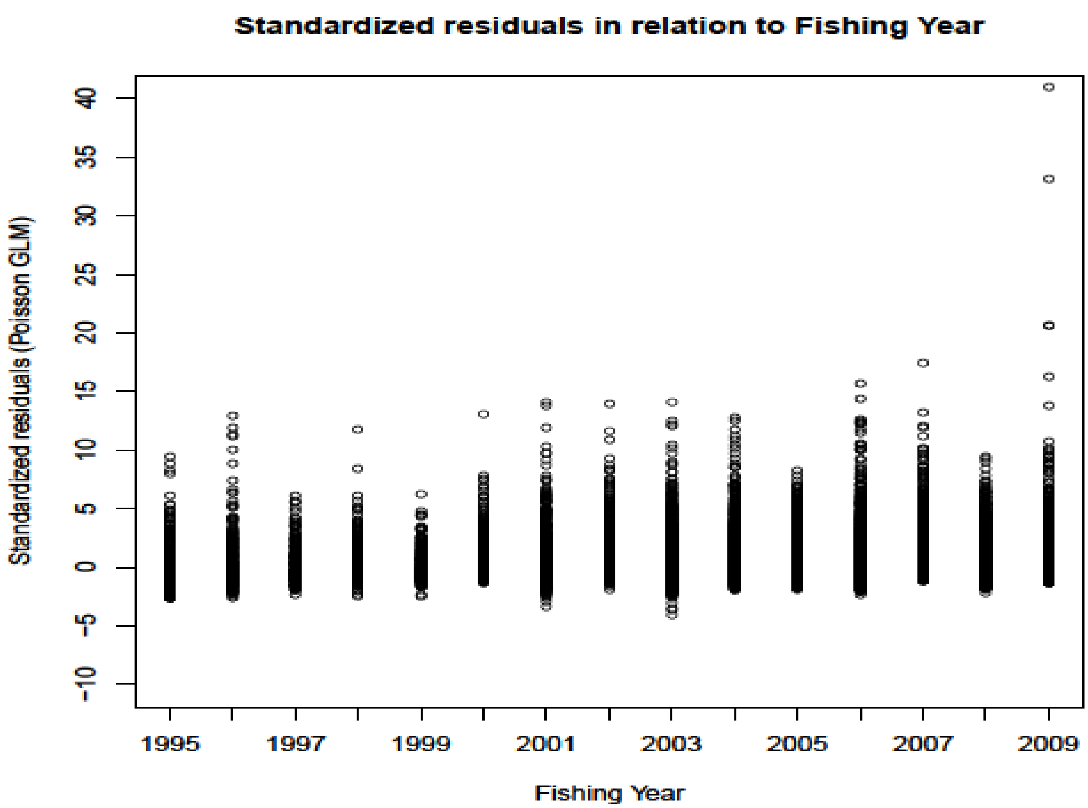
Number of Fisher Scoring iterations: 6

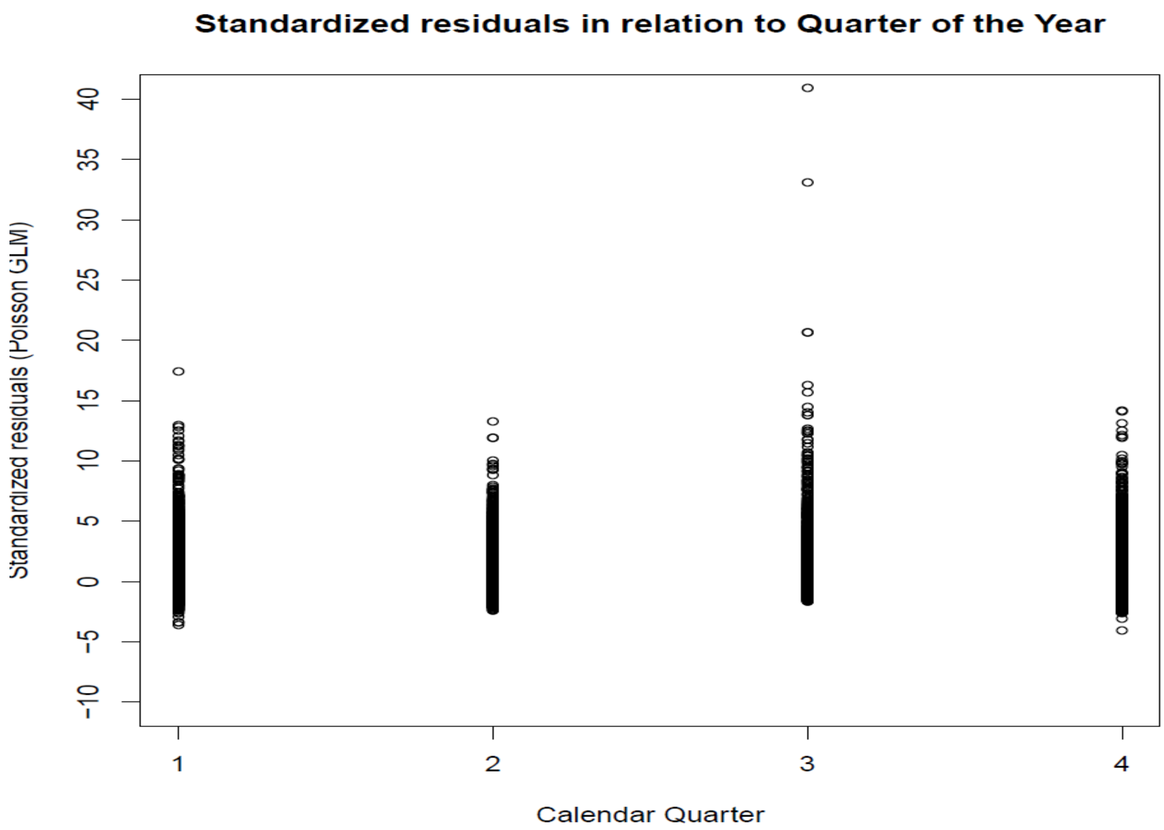
Table AI-2. Mean residuals from the Poisson GLM by year, quarter, and fishing region. Positive values are in red, negative values are in black, and missing cells are in blue (‘NA”). Potential outliers are in bold-face type or large bold-face type.

Haul year	Quarter	Region				
		1	2	3	4	5
1995	1	NA	0.9441	-0.1514	0.7282	-0.1584
	2	NA	0.02689	1.6652	-0.1600	-0.3354
	3	NA	-0.7603	-1.0000	-0.3318	0.1637
	4	NA	0.6472	**3.7128**	0.3792	0.4009
1996	1	NA	**4.5590**	2.1303	-.7156	-0.1765
	2	NA	0.0269	0.2911	-.1791	-0.0768
	3	NA	-0.7603	-0.4585	-.0926	-0.6175
	4	NA	0.6472	0.0384	0.5112	-0.8859
1997	1	NA	-0.1005	0.1010	0.5140	-0.0414
	2	-0.6356	-0.7305	0.0890	0.5037	-0.3406
	3	NA	-0.8413	-1.0000	0.2038	0.2848
	4	NA	-0.6691	-0.2404	-0.4244	-0.6836
1998	1	-0.8695	0.1011	-0.4590	0.5896	0.8154
	2	-0.6711	NA	-0.8765	-0.1990	-0.8311
	3	-1.0000	-0.4154	-0.7583	-0.8867	-0.1479
	4	NA	0.4544	0.2830	0.6413	0.0722
1999	1	NA	-0.6883	-0.3925	0.2252	-0.2174
	2	-0.1615	-0.7061	-0.6085	0.1088	0.1976
	3	NA	-0.4334	NA	-0.1389	1.7515
	4	2.4293	0.0231	NA	0.3067	0.7531
2000	1	-0.7307	0.7209	**3.4987**	-0.2113	-0.2638
	2	0.9250	0.1907	-0.6118	-0.2829	0.7984
	3	-1.0000	-1.0000	-0.4444	-0.4809	1.2126
	4	-0.6573	-0.4082	-0.2073	-0.1604	-0.1683

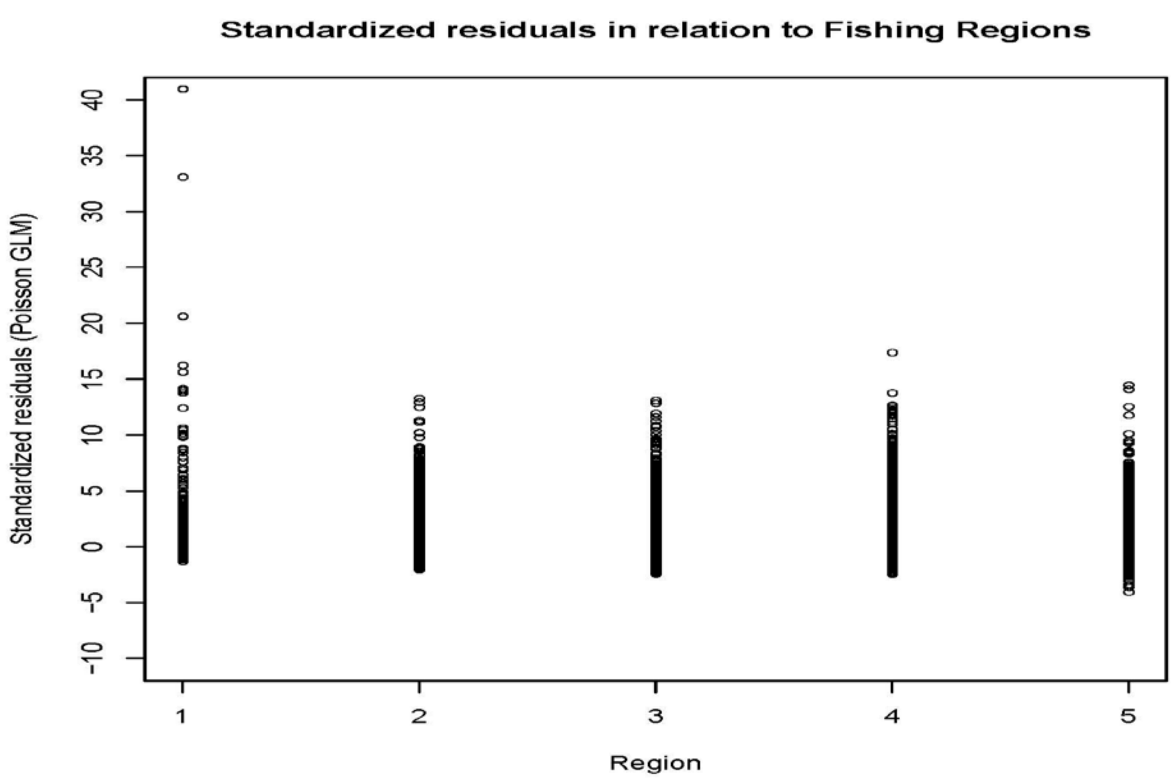
Haul year	Quarter	Region				
2001	1	-0.3947	-0.0397	-0.0425	-0.3723	-0.3191
	2	-0.7685	-0.3061	0.2677	0.1708	0.2994
	3	0.0736	-0.3645	-0.2806	0.8344	-0.5876
	4	0.3480	0.7758	0.3091	0.0617	0.0721
2002	1	0.1061	0.8251	1.3112	-0.3329	-0.2837
	2	0.5423	-0.5764	0.0852	-0.7127	-0.4638
	3	**7.5733**	0.6349	-0.4627	-0.6028	-0.7580
	4	NA	-0.6854	-0.7502	-0.2776	0.4187
2003	1	0.6112	-0.1958	-0.2028	0.0500	-0.4719
	2	-1.0000	-0.4237	-0.3653	-0.4569	-0.3229
	3	NA	-0.4358	-0.3743	-0.3633	-0.2399
	4	NA	0.9512	0.5566	0.3192	0.1911
2004	1	-0.6996	0.3031	0.4092	2.6719	0.1327
	2	-1.0000	-0.0384	-0.3151	-0.1038	-0.4593
	3	2.6086	0.2979	0.3070	-0.0940	-0.3842
	4	0.7099	-0.2684	-0.2197	-0.4500	-0.3437
2005	1	NA	0.0855	0.2017	0.1514	-0.6228
	2	0.1687	0.7604	-0.0003	-0.1241	0.0251
	3	NA	0.2154	-0.2847	-0.2634	-0.3375
	4	NA	-0.1822	-0.1351	0.2982	-0.2216
2006	1	-0.9111	-0.2452	-0.5163	-0.2350	-0.2424
	2	-0.3947	-0.4584	0.0254	-0.0050	-0.1021
	3	**4.7628**	-0.4170	-0.4559	1.4643	0.5169
	4	**3.5621**	-0.0265	-0.3778	0.2222	-0.2691
2007	1	NA	2.1046	2.1859	1.3729	0.2484
	2	-0.5476	0.9901	1.0570	0.2817	0.2560
	3	-1.0000	0.6629	-0.0926	0.0039	0.4787
	4	-1.0000	-0.5381	-0.5516	-0.1098	-0.5657

Haul year	Quarter	Region				
2008	1	-0.6240	-0.4889	-0.6686	0.1136	-0.3714
	2	NA	-0.4552	-0.2199	0.0532	0.6012
	3	NA	-0.3124	-0.1208	-0.3525	0.5722
	4	NA	-0.8309	-0.1675	-0.3611	0.4365
2009	1	0.3284	1.2783	0.6540	0.0229	-0.0013
	2	-0.0975	1.1030	0.2382	-0.1007	0.1864
	3	**11.5246**	-0.3046	0.9845	-0.1150	0.1987
	4	NA	-0.6735	-0.0333	-0.4876	-0.4669
Pattern of quarterly mean residuals		(15: 20:25)	(25: 34 : 1)	(23 : 35: 2)	(27 : 33)	(25 : 35)

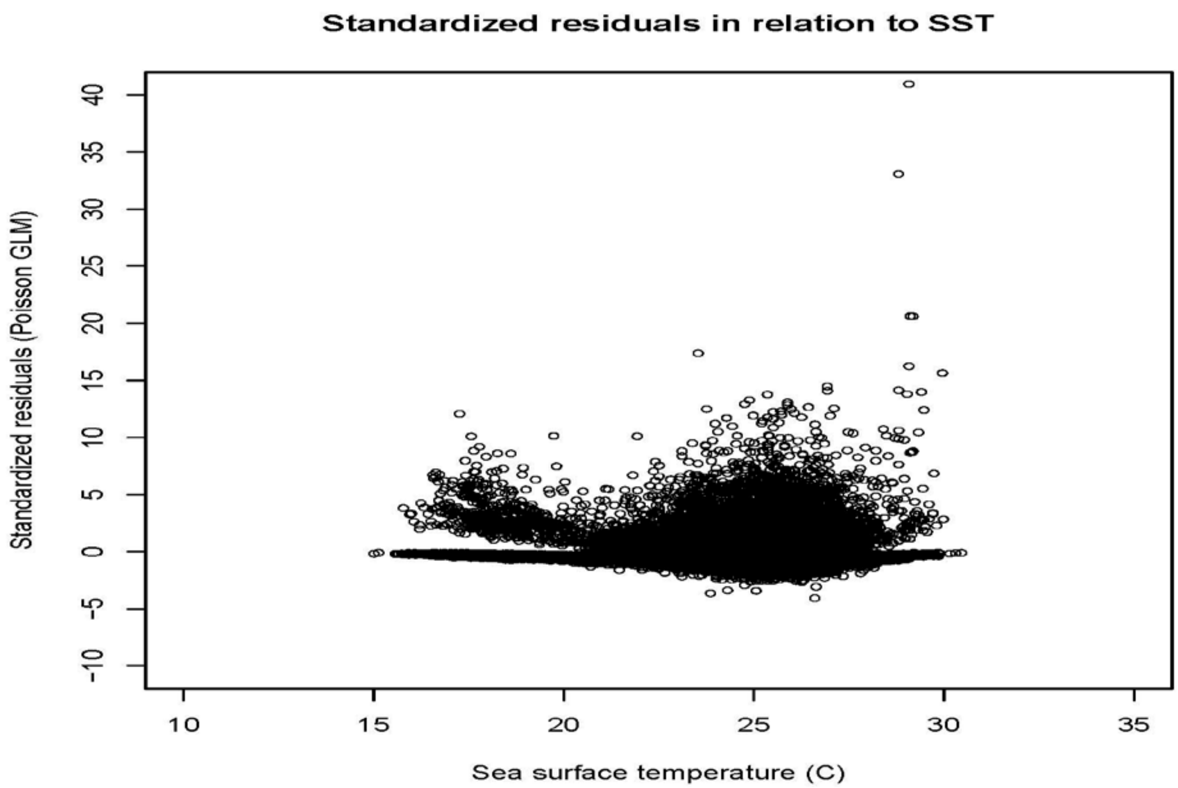


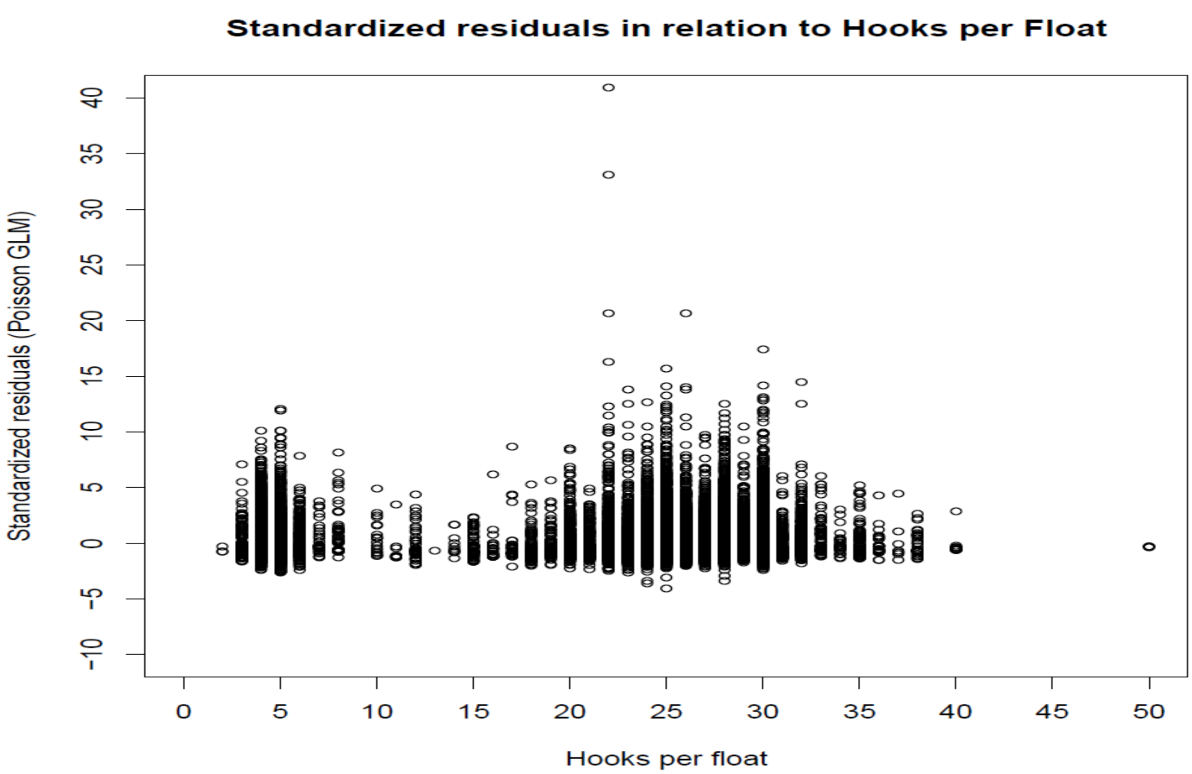


Standardized residuals in relation to Quarter of the Year
Standardized residuals (Poisson GLM)
-10
-5
0
5
10
15
20
25
30
35
40
1
2
3
4
Calendar Quarter

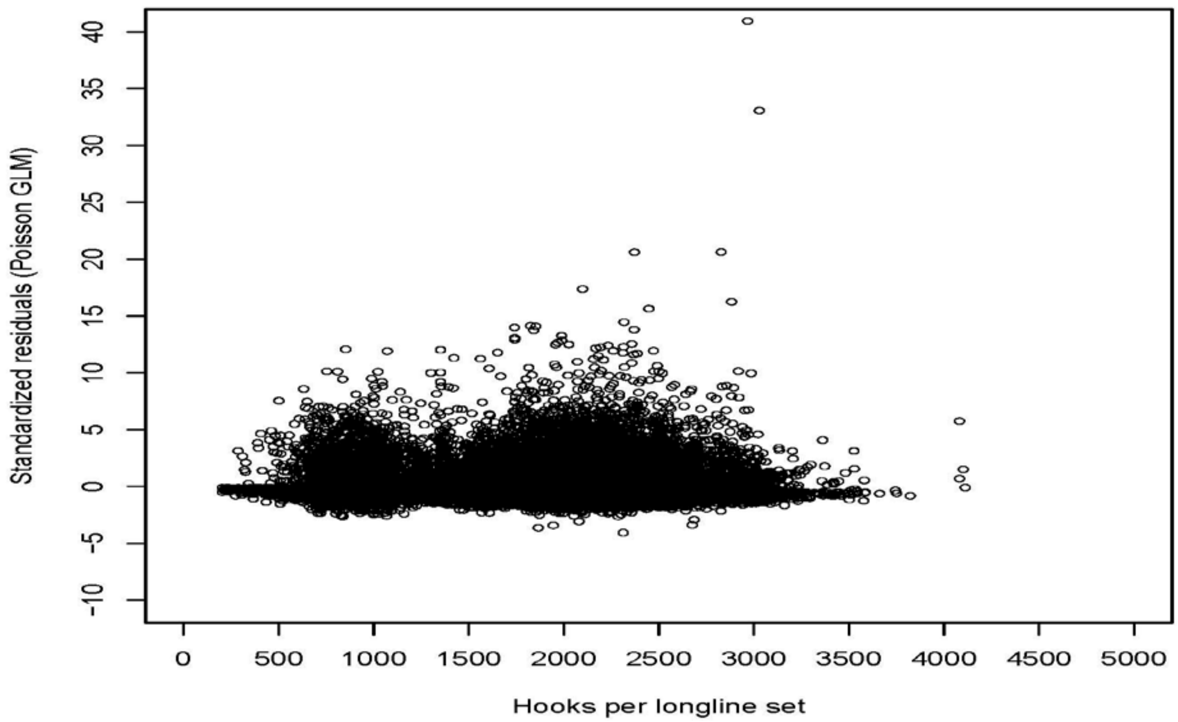


Standardized residuals in relation to Fishing Regions
Standardized residuals (Poisson GLM)
-10
-5
0
5
10
15
20
25
30
35
40
1
2
3
4
5
Region

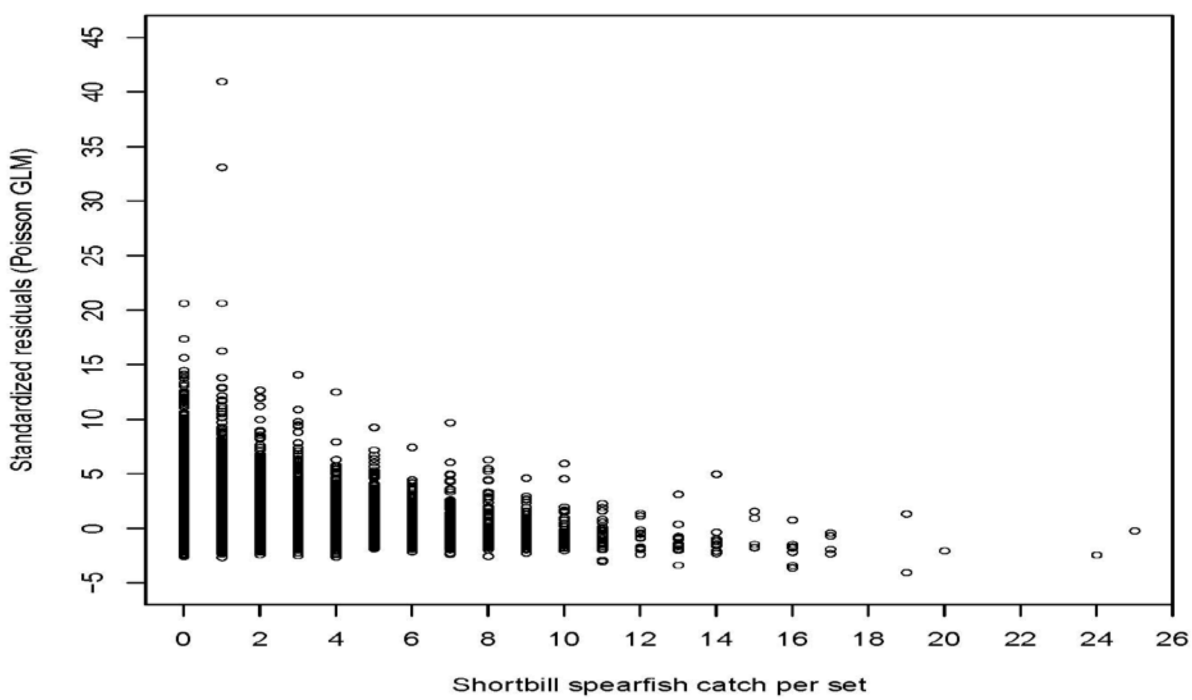

Standardized residuals in relation to SST
Standardized residuals (Poisson GLM)
-10
-5
0
5
10
15
20
25
30
35
40
10
15
20
25
30
35
Sea surface temperature (C)


Standardized residuals in relation to Hooks per Float
Standardized residuals (Poisson GLM)
-10
-5
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
35
40
45
50
Hooks per float

Standardized residuals in relation to Hooks per Longline Set



Standardized residuals in relation to Shortbill Spearfish Catches



APPENDIX II: Binomial GLM Analysis

1). Analysis of deviance (R output)

2). Tabulation of mean residuals

3). Standardized residuals plots

Table AII-1. Analysis of deviance of a Binomial GLM (R output).

Call: glm(formula = catch ~ Haulyr1 + Quarter1 + region1 + poly(SST, degree = 3) + poly(hkpfl, degree = 3) + poly(hooks, degree = 3) + spearfish, family = binomial, data = strmar.obs)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.8158	-0.8954	-0.4810	0.9855	3.1411

Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-3.912e-01	1.455e-01	2.689	0.007167 **
Haulyr11996	-5.831e-01	1.515e-01	-3.850	0.000118 ***
Haulyr11997	-4.846e-01	1.627e-01	-2.978	0.002903 **
Haulyr11998	-7.236e-01	1.515e-01	-4.776	1.79e-06 ***
Haulyr11999	-8.561e-01	1.628e-01	-5.259	1.45e-07 ***
Haulyr12000	-1.655e+00	1.315e-01	-12.583	< 2e-16 ***
Haulyr12001	-1.669e-01	1.192e-01	-1.400	0.161622
Haulyr12002	-1.301e+00	1.181e-01	-11.016	< 2e-16 ***
Haulyr12003	-1.974e-01	1.176e-01	-1.678	0.093317 .
Haulyr12004	-8.921e-01	1.161e-01	-7.682	1.57e-14 ***
Haulyr12005	-1.022e+00	1.143e-01	-8.940	< 2e-16 ***
Haulyr12006	-6.051e-01	1.160e-01	-5.216	1.83e-07 ***
Haulyr12007	-2.082e+00	1.166e-01	-17.853	< 2e-16 ***
Haulyr12008	-1.334e+00	1.156e-01	-11.539	< 2e-16 ***
Haulyr12009	-1.883e+00	1.166e-01	-16.146	< 2e-16 ***
Quarter12	-2.579e-01	3.608e-02	-7.147	8.84e-13 ***
Quarter13	-1.355e+00	4.628e-02	-29.275	< 2e-16 ***
Quarter14	-4.319e-01	4.197e-02	-10.292	< 2e-16 ***

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
region12	7.126e-03	1.030e-01	0.069	0.944867
region13	2.411e-01	9.765e-02	2.469	0.013541 *
region14	6.220e-01	1.073e-01	5.797	6.76e-09 ***
region15	1.102e+00	1.064e-01	10.352	< 2e-16 ***
poly(SST, degree = 3)1	1.917e+02	5.448e+00	35.187	< 2e-16 ***
poly(SST, degree = 3)2	-1.001e+02	3.614e+00	-27.702	< 2e-16 ***
poly(SST, degree = 3)3	-4.565e+01	3.368e+00	-13.554	< 2e-16 ***
poly(hkpfl, degree = 3)1	-1.448e+02	6.842e+00	-21.156	< 2e-16 ***
poly(hkpfl, degree = 3)2	1.320e+01	2.792e+00	4.728	2.27e-06 ***
poly(hkpfl, degree = 3)3	5.015e+00	2.550e+00	1.967	0.049233 *
poly(hooks, degree = 3)1	8.727e+01	5.943e+00	14.685	< 2e-16 ***
poly(hooks, degree = 3)2	-2.737e+01	3.534e+00	-7.745	9.58e-15 ***
poly(hooks, degree = 3)3	8.615e+00	2.529e+00	3.406	0.000658 ***
spearfish	1.684e-01	9.367e-03	17.984	< 2e-16 ***

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 53656 on 39976 degrees of freedom

Residual deviance: 44419 on 39945 degrees of freedom

AIC: 44483

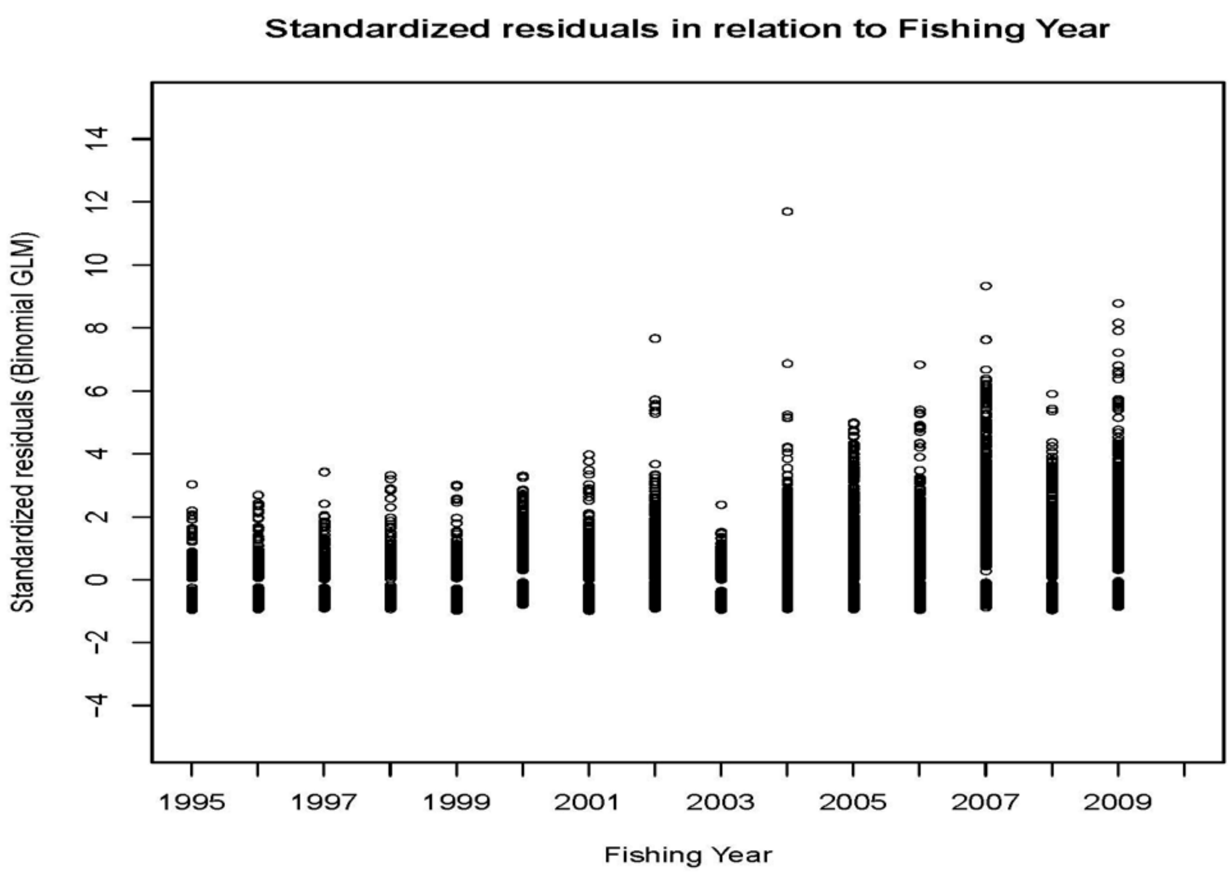
Number of Fisher Scoring iterations: 5

Table AII-2. Mean residuals from the Binomial GLM by year, quarter, and fishing region. Positive values are in red, negative values are in black, and missing cells are in blue ('NA"). Potential outliers are in bold-face type or large bold-face type.

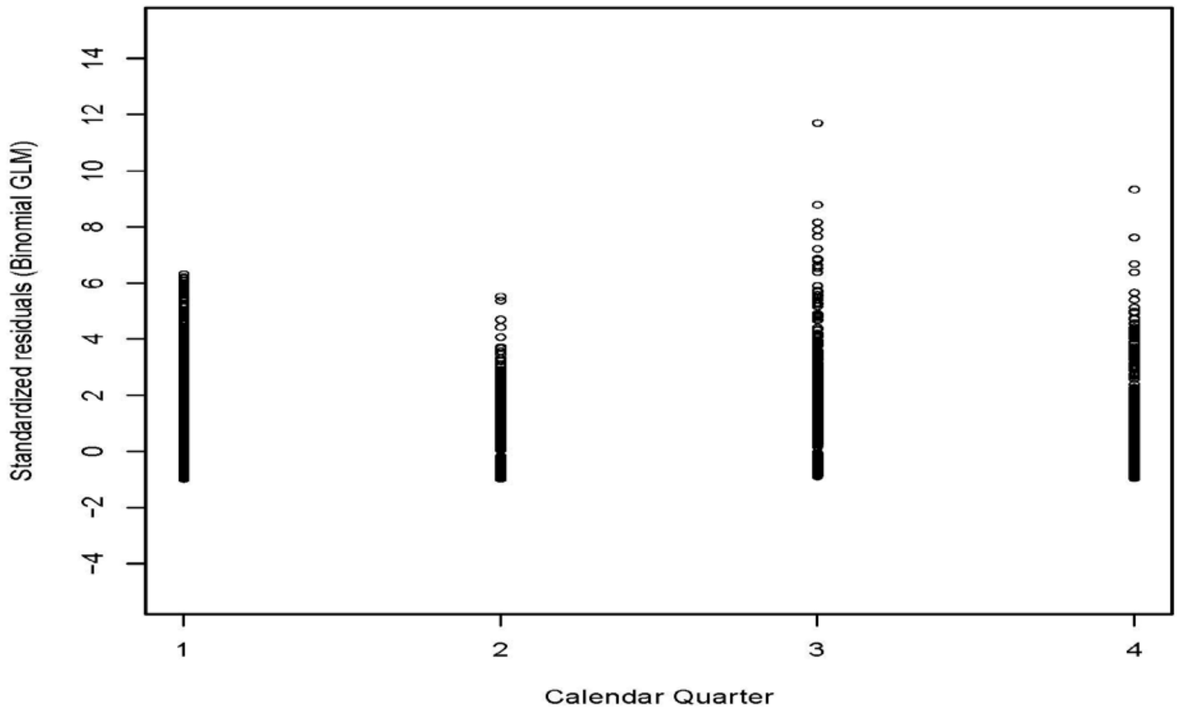
Haul year	Quarter	Region 1	Region 2	Region 3	Region 4	Region5
1995	1	NA	1.0521	0.3743	0.3395	0.2125
	2	NA	-0.0570	1.5613	0.0240	-1.0573
	3	NA	-1.1048	-1.4593	-0.5574	0.5820
	4	NA	1.0189	1.4769	0.1260	-1.0912
1996	1	NA	1.4387	1.4820	-0.9092	-0.2010
	2	NA	-0.0808	0.0222	-0.0934	0.0191
	3	NA	-0.2425	-0.4899	1.0260	-0.7620
	4	NA	-1.0130	0.5476	0.1128	-1.5512
1997	1	NA	0.2526	0.6857	0.2311	0.0389
	2	-0.5736	-0.7448	-0.0485	0.7348	-0.5373
	3	NA	-1.1489	-1.2626	0.4720	-0.3697
	4	NA	-0.7261	-0.0742	0.3173	-1.2634
1998	1	-1.1488	1.6670	0.7924	0.7351	0.9378
	2	-0.5021	NA	-1.4569	0.5538	-1.1955
	3	-1.1838	-0.1925	-0.7066	-1.2405	-0.5755
	4	NA	0.9139	0.8778	0.8484	0.5033
1999	1	NA	-1.3885	-1.1535	0.1227	-1.0584
	2	-0.1526	-2.3168	-6.0761	0.4596	0.0825
	3	NA	-0.3357	NA	-0.0677	1.6149
	4	**3.2082**	0.3783	NA	0.4462	0.3529
2000	1	-0.7921	0.2962	1.6666	-0.3346	-0.4602
	2	1.3020	-0.4375	-0.4724	-0.0685	0.4863
	3	-1.0448	-1.0964	-0.0123	-0.4645	0.6506
	4	-0.5411	-0.1600	-0.0242	0.0302	-0.1546

Haul year	Quarter	Region 1	Region 2	Region 3	Region 4	Region 5
2001	1	-0.6119	-0.1677	0.0214	-0.4808	-1.0224
	2	-1.2470	-0.4025	0.1391	0.1034	0.7865
	3	0.2613	-0.5150	-0.5644	0.5835	-0.7902
	4	-0.0569	0.4218	0.4742	0.3431	0.1965
2002	1	0.1877	0.8007	1.1149	-0.2802	-0.0888
	2	**2.1177**	-0.7117	0.2210	-1.0456	-1.0738
	3	**10.1652**	0.8013	-0.1762	-0.6447	-0.9331
	4	NA	-0.7336	-1.1136	-0.2763	0.7581
2003	1	0.0485	0.0613	-0.0912	0.1739	0.1608
	2	-1.7159	-0.3749	-0.5224	-0.6710	-0.4733
	3	NA	-0.1590	0.2764	-0.5870	-0.2835
	4	NA	0.7718	0.9223	0.5688	0.7310
2004	1	-0.6997	0.2884	0.2898	1.1034	0.2878
	2	-1.2676	-0.1514	-0.4163	-0.1175	-0.6982
	3	**8.1271**	0.4724	0.5914	-0.1184	-0.4414
	4	2.9235	-0.1063	0.2436	-0.3123	-0.2025
2005	1	NA	0.0814	0.3638	0.0948	-0.7480
	2	0.4887	0.9280	-0.0635	-0.0804	0.2320
	3	NA	0.0324	0.1427	-0.1639	-0.6274
	4	NA	0.1391	0.1830	0.5369	-0.1422
2006	1	-1.6157	0.0022	-0.7313	-0.3582	-0.5350
	2	-0.7204	-0.5751	-0.0343	0.2187	-0.3673
	3	**6.7112**	-0.3917	-0.4093	1.0595	0.3487
	4	**12.2097**	0.4333	-0.0494	0.3673	-0.0476
2007	1	NA	1.9000	1.6138	1.1280	-0.1009
	2	-0.5454	0.8461	0.5922	0.2010	0.0990
	3	-1.0258	0.8158	0.1124	0.2070	0.2624
	4	-1.0833	-0.6076	-0.5055	0.0935	-0.7380

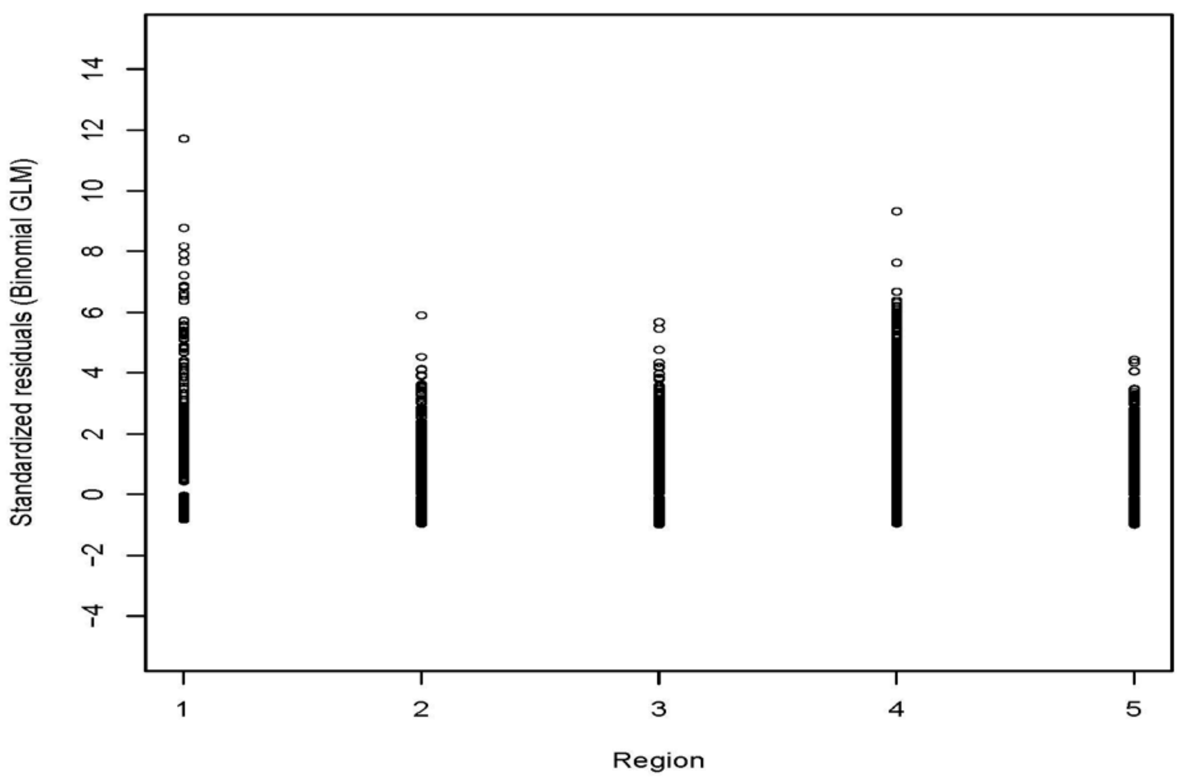
Haul year	Quarter	Region 1	Region 2	Region 3	Region 4	Region 5
2008	1	-0.5431	-0.8256	-1.2610	0.2208	-0.4968
	2	NA	-0.5831	-0.2070	0.2701	0.6357
	3	NA	-0.0019	0.3187	-0.1641	0.8208
	4	NA	-0.9416	-0.5600	-0.0666	0.9700
2009	1	0.9217	1.2930	0.5612	-0.0207	-0.1534
	2	-0.2894	0.8863	0.2289	-0.0911	0.0306
	3	**7.8977**	-0.0836	1.3013	-0.0940	0.3660
	4	NA	-0.8659	0.5312	-0.3790	-0.7196
Pattern of quarterly mean residuals		(14: 21:25)	(26: 33 : 1)	(31 : 27: 2)	(33 : 27)	(26 : 34)

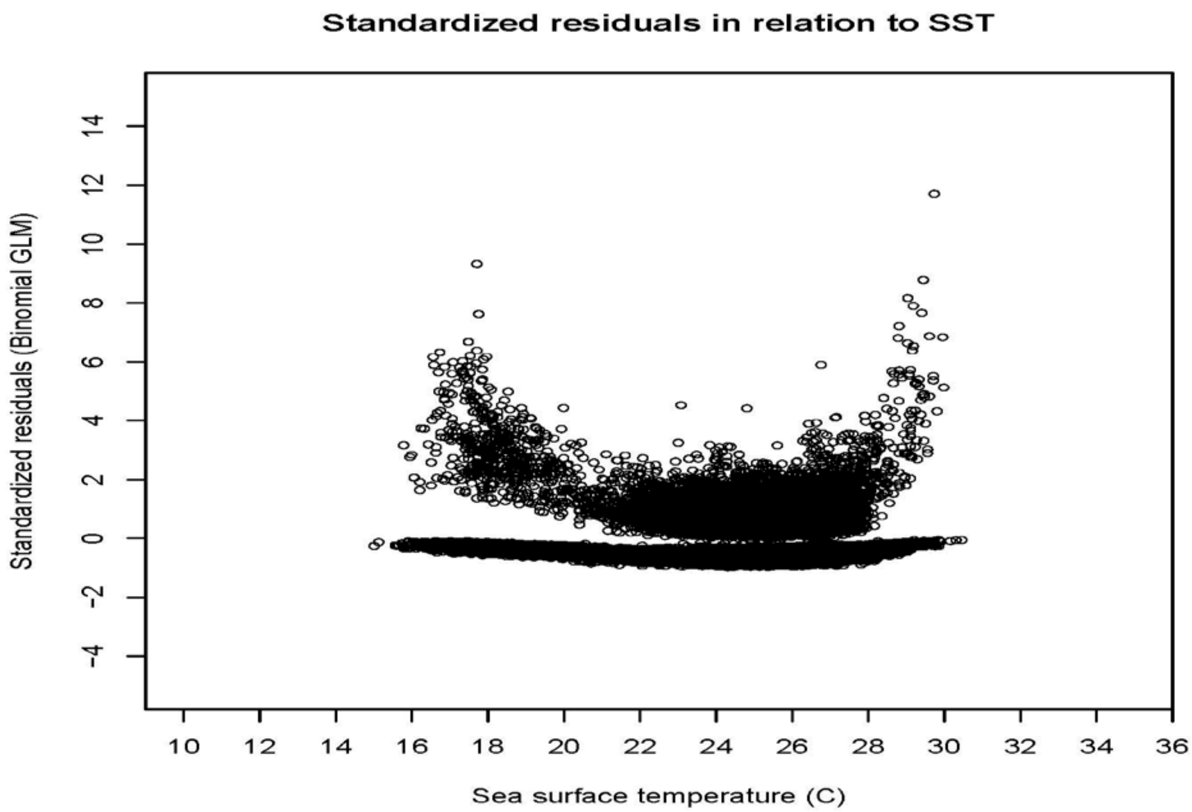


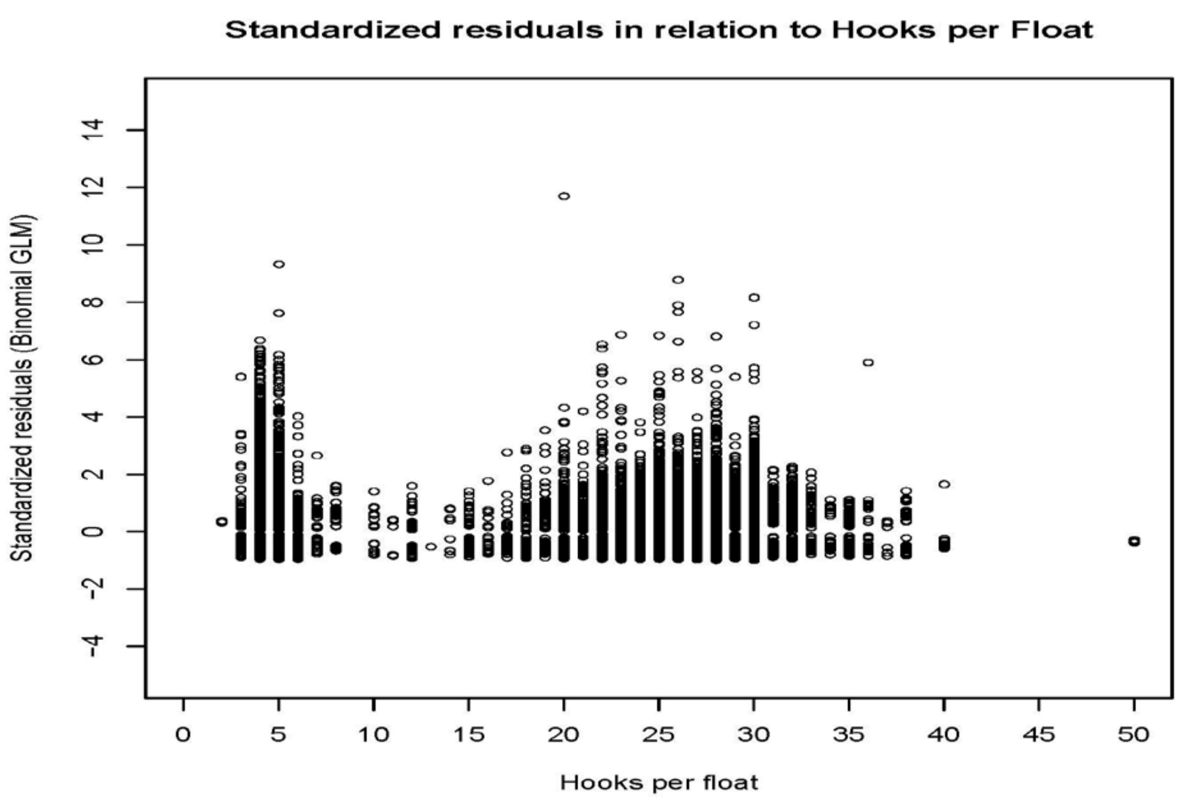
Standardized residuals in relation to Quarter of the Year

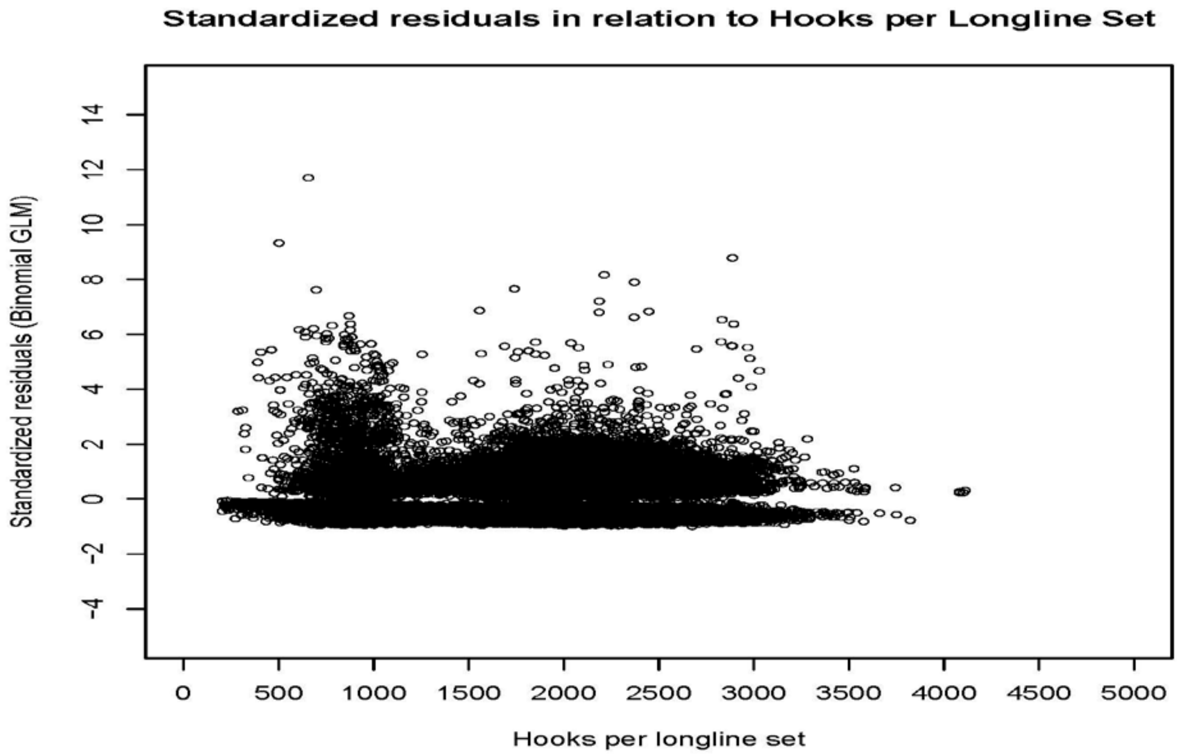


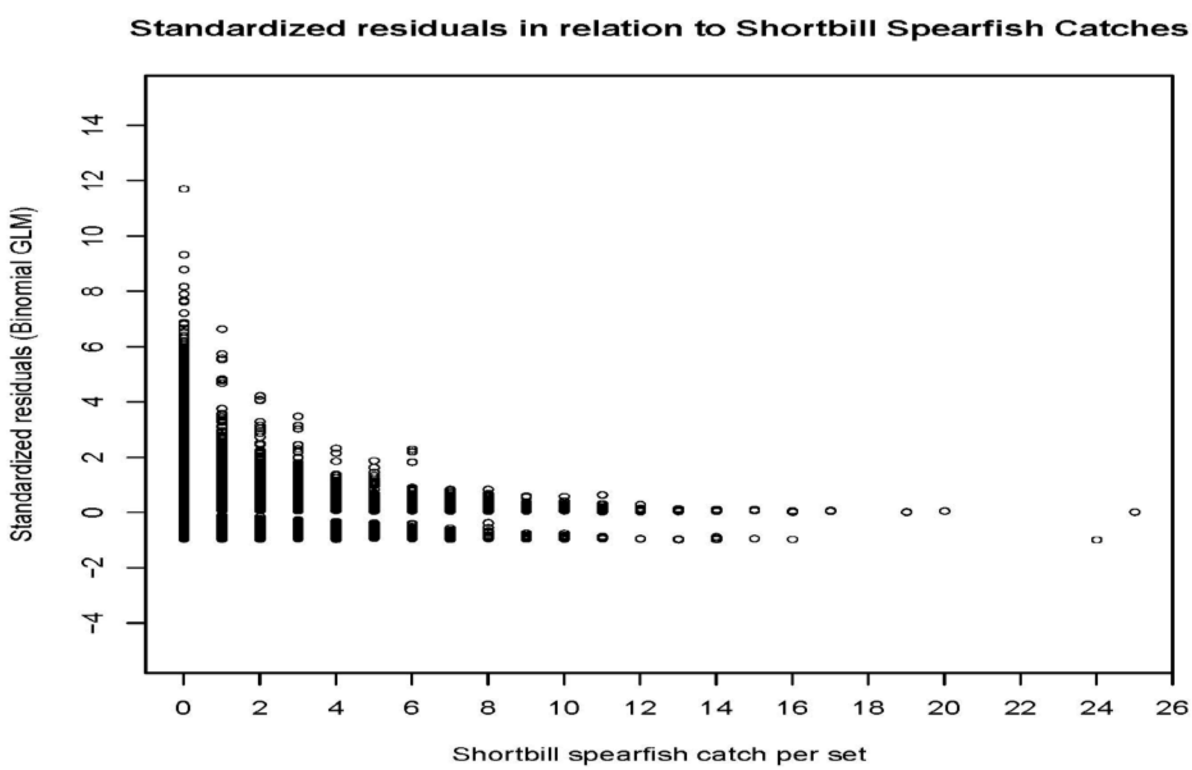
Standardized residuals in relation to Fishing Regions




Standardized residuals in relation to SST
Standardized residuals (Binomial GLM)
Sea surface temperature (C)


Standardized residuals in relation to Hooks per Float
Standardized residuals (Binomial GLM)
Hooks per float


Standardized residuals in relation to Hooks per Longline Set
Standardized residuals (Binomial GLM)
14
12
10
8
6
4
2
0
-2
-4
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Hooks per longline set


Standardized residuals in relation to Shortbill Spearfish Catches
Standardized residuals (Binomial GLM)
14
12
10
8
6
4
2
0
-2
-4
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Shortbill spearfish catch per set

APPENDIX III: Lognormal GLM Analysis

1). Analysis of deviance (R output)

2). Tabulation of mean residuals

3). Residuals plots:

a). Normal probability plot

b). Residuals on predictions

c). Residuals against values of explanatory variables

Table AIII-1. Analysis of deviance of a Lognormal GLM (R output).

Call: glm(formula = log(strmarcpue) ~ Haulyr1 + Quarter1 + region1 +
poly(SST, degree = 3) + poly(hkpfl, degree = 3) + poly(hooks, degree=3)
+ spearfish, family = gaussian, data = strmar1.obs)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.8224	-0.4792	-0.1022	0.4237	2.3480

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.981e-01	6.268e-02	4.755	2.00e-06 ***
Haulyr11996	-1.371e-01	5.419e-02	-2.531	0.011391 *
Haulyr11997	-2.559e-01	5.891e-02	-4.345	1.40e-05 ***
Haulyr11998	-2.710e-01	5.627e-02	-4.816	1.48e-06 ***
Haulyr11999	-4.001e-01	5.878e-02	-6.806	1.04e-11 ***
Haulyr12000	-4.986e-01	5.088e-02	-9.800	< 2e-16 ***
Haulyr12001	-1.250e-01	3.996e-02	-3.129	0.001758 **
Haulyr12002	-4.540e-01	4.187e-02	-10.843	< 2e-16 ***
Haulyr12003	-3.560e-02	3.955e-02	-0.900	0.368139
Haulyr12004	-3.840e-01	4.012e-02	-9.572	< 2e-16 ***
Haulyr12005	-3.950e-01	3.903e-02	-10.120	< 2e-16 ***
Haulyr12006	-2.507e-01	4.009e-02	-6.252	4.15e-10 ***
Haulyr12007	-6.441e-01	4.169e-02	-15.449	< 2e-16 ***
Haulyr12008	-4.287e-01	4.006e-02	-10.701	< 2e-16 ***
Haulyr12009	-6.380e-01	4.127e-02	-15.459	< 2e-16 ***
Quarter12	-5.671e-02	1.503e-02	-3.773	0.000162 ***
Quarter13	-2.668e-01	2.031e-02	-13.136	< 2e-16 ***
Quarter14	-3.705e-04	1.732e-02	-0.021	0.982929
region12	-1.280e-01	5.395e-02	-2.373	0.017655 *
region13	-7.401e-02	5.186e-02	-1.427	0.153594
region14	1.018e-01	5.479e-02	1.858	0.063244 .
region15	2.367e-01	5.413e-02	4.373	1.23e-05 ***
poly(SST, degree = 3)1	1.676e+01	9.608e-01	17.439	< 2e-16 ***

poly(SST, degree = 3)2	-7.302e+00	7.674e-01	-9.515	< 2e-16 ***
poly(SST, degree = 3)3	-5.160e+00	7.025e-01	-7.345	2.16e-13 ***
poly(hkpfl, degree = 3)1	-2.229e+01	1.644e+00	-13.561	< 2e-16 ***
poly(hkpfl, degree = 3)2	9.128e-02	7.721e-01	0.118	0.905892
poly(hkpfl, degree = 3)3	6.826e-01	6.304e-01	1.083	0.278939
poly(hooks, degree = 3)1	-2.941e+01	1.445e+00	-20.351	< 2e-16 ***
poly(hooks, degree = 3)2	3.331e+00	9.663e-01	3.447	0.000568 ***
poly(hooks, degree = 3)3	-3.259e+00	6.443e-01	-5.059	4.27e-07 ***
spearfish	4.892e-02	3.029e-03	16.151	< 2e-16 ***

(Dispersion parameter for gaussian family taken to be 0.3791617)

Null deviance: 8958.3 on 15804 degrees of freedom

Residual deviance: 5980.5 on 15773 degrees of freedom

AIC: 29559

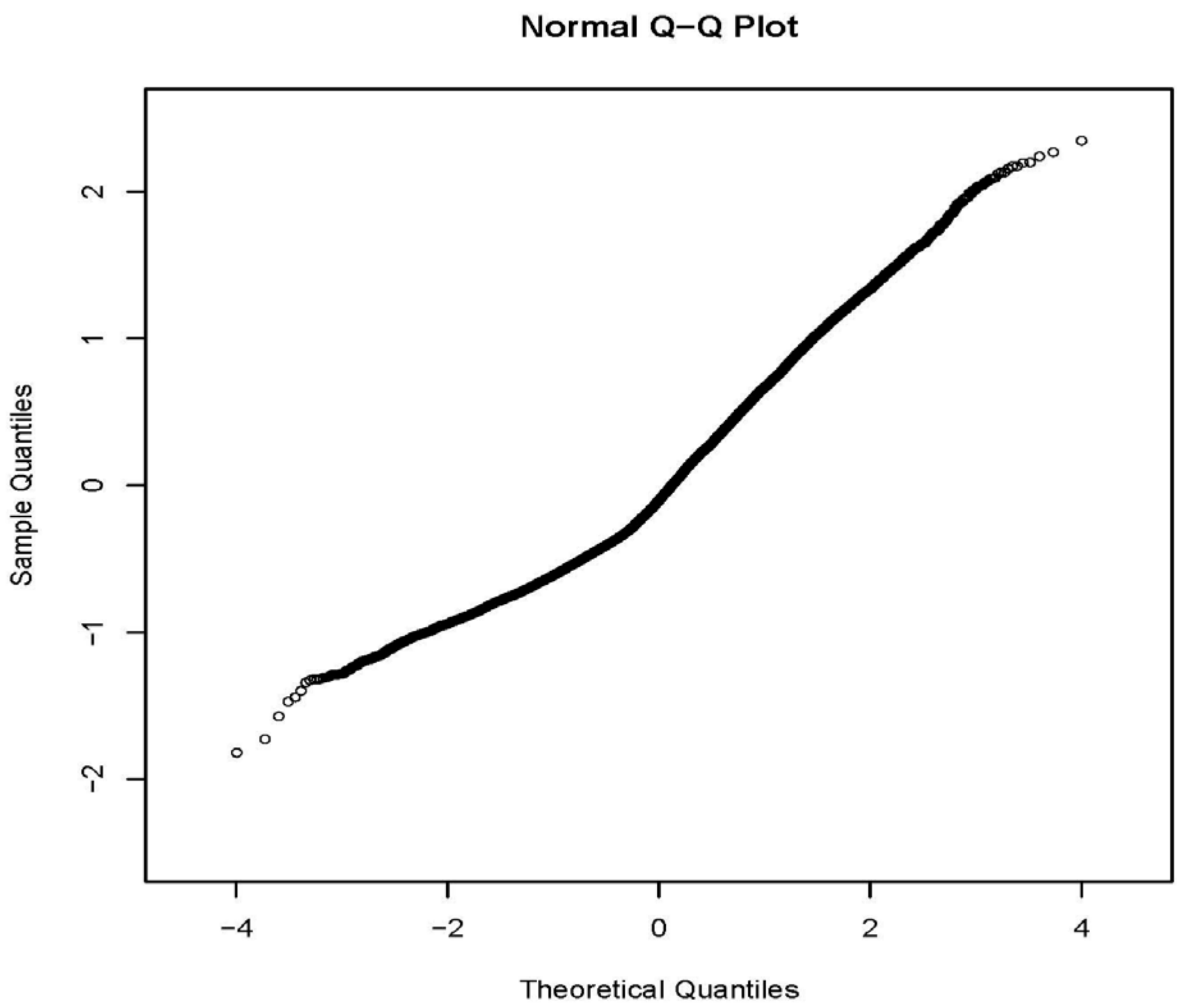
Number of Fisher Scoring iterations: 2

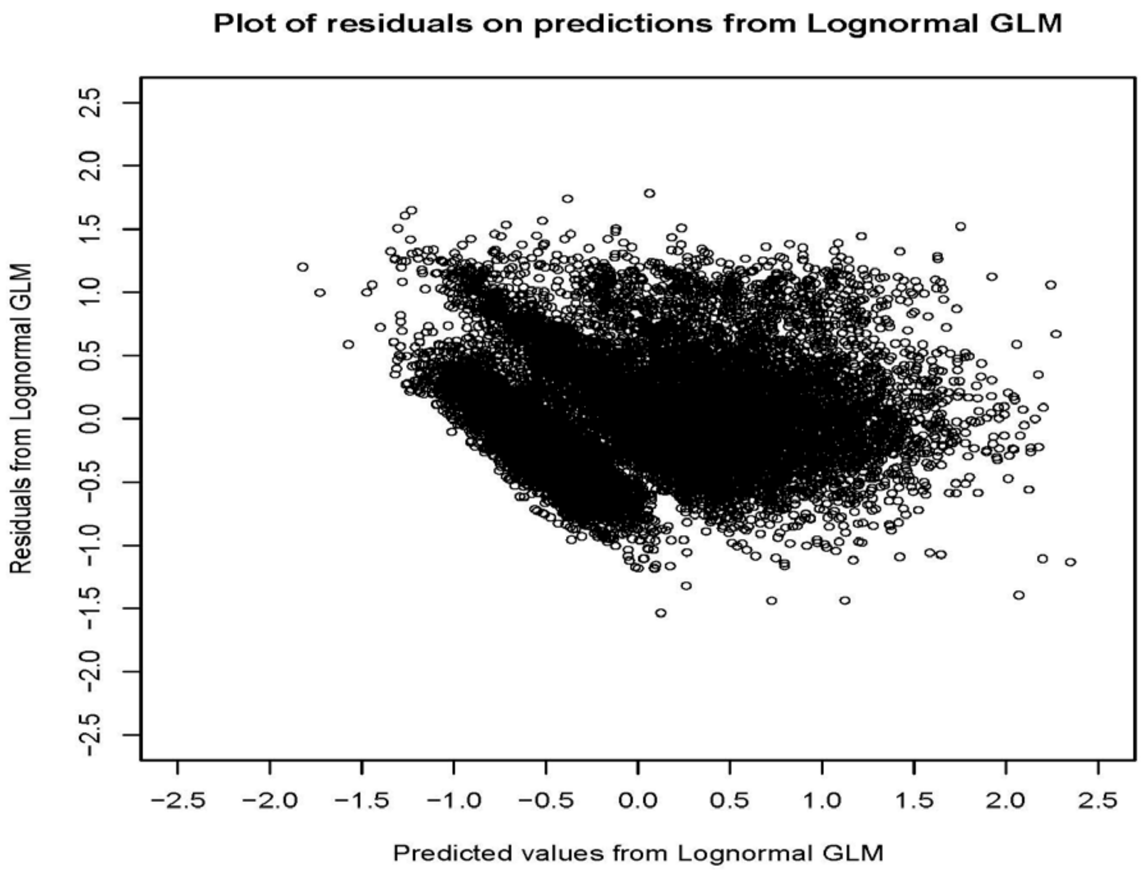
Table AIII-2. Mean residuals from the Lognormal GLM by year, quarter, and fishing region. Positive values are in red, negative values are in black, and missing cells are in blue (‘NA”). Potential outliers are in bold-face type or large bold-face type.

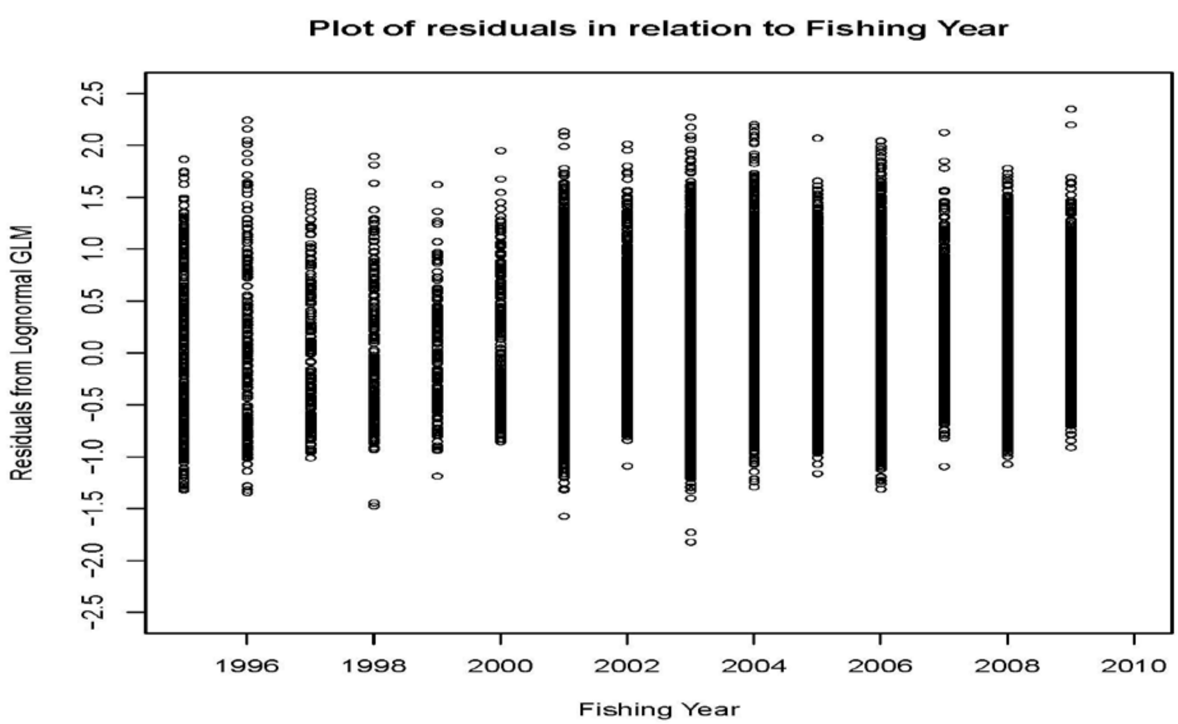
Haul year	Quarter	Region 1	Region 2	Region 3	Region 4	Region5
1995	1	NA	0.1452	-0.1817	-0.3061	-0.0733
	2	NA	-0.0920	0.5879	-0.0810	-0.1435
	3	NA	-0.6100	NA	-0.2660	-0.5742
	4	NA	0.1105	1.2553	0.2309	0.5424
1996	1	NA	1.0872	0.6758	-0.6475	0.2280
	2	NA	-0.1973	0.1829	-0.3742	-0.2371
	3	NA	-0.4284	0.1678	-0.4692	-0.4709
	4	NA	0.0067	-0.0957	0.9259	-0.7539
1997	1	NA	-0.0677	-0.0243	0.0846	0.1422
	2	-0.5405	-0.5985	0.0826	0.2170	0.0851
	3	NA	-0.4951	NA	-0.0158	0.3327
	4	NA	-0.1131	0.0036	-0.3111	-0.5684
1998	1	-0.4837	-0.3525	-0.6126	-0.2147	0.2742
	2	-0.4900	NA	-0.4479	-0.3170	-0.5295
	3	NA	-0.2541	-0.4765	-0.6453	-0.1435
	4	NA	0.1642	0.0300	0.2365	0.1925
1999	1	NA	-0.4098	-0.4137	-0.0605	0.0148
	2	-0.3168	-0.5465	-0.2394	-0.1744	0.0641
	3	NA	-0.3727	NA	-0.1080	0.5020
	4	0.0513	0.0403	NA	0.1793	0.5525
2000	1	-0.4387	0.2829	0.7848	0.1686	0.0991
	2	0.0364	0.7651	-0.4564	-0.3105	0.1385
	3	NA	NA	-0.1130	0.0525	0.3415
	4	0.0015	-0.1569	-0.0668	-0.0892	-0.1020

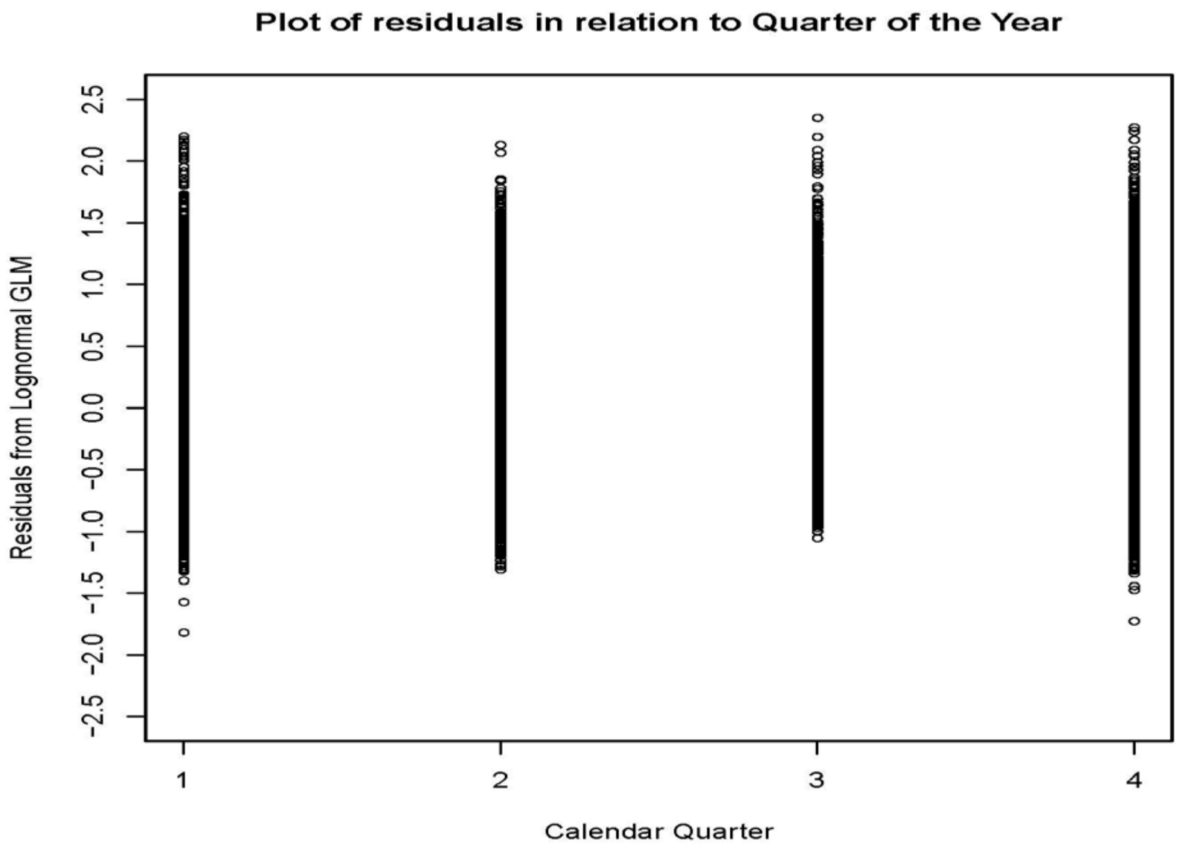
	Quarter	Region 1	Region 2	Region 3	Region 4	Region 5
2001	1	-0.4605	-0.0710	0.0214	-0.4808	-0.2349
	2	-0.5350	-0.1699	0.1391	0.1034	0.1820
	3	-0.0421	-0.1153	-0.5644	0.5835	-0.5386
	4	0.1128	0.4411	0.4742	0.3431	0.1479
2002	1	-0.1033	0.2055	1.1149	-0.2802	-0.3045
	2	-0.1632	-0.1307	0.2210	-1.0456	-0.0026
	3	0.3852	0.3098	-0.1762	-0.6447	-0.3506
	4	NA	-0.1628	-1.1136	-0.2763	0.0577
2003	1	0.3343	-0.2078	-0.0912	0.1739	-0.2576
	2	NA	-0.3680	-0.5224	-0.6710	-0.1221
	3	NA	-0.3409	0.2764	-0.5870	-0.3555
	4	NA	0.4751	0.9223	0.5688	0.1919
2004	1	-0.3987	0.0872	0.2898	1.1034	-0.0092
	2	NA	0.0175	-0.4163	-0.1175	-0.4064
	3	-0.0167	0.1815	0.5914	-0.1184	-0.2198
	4	-0.1537	-0.0744	0.2436	-0.3123	-0.2958
2005	1	NA	0.0130	0.3638	0.0948	0.0740
	2	-0.0543	0.1204	-0.0635	-0.0804	0.0972
	3	NA	0.2709	0.1427	-0.1639	-0.1552
	4	NA	-0.1395	0.1830	0.5369	-0.0842
2006	1	-0.6241	-0.1757	-0.7313	-0.3582	-0.3274
	2	-0.1516	-0.2687	-0.0343	0.2187	0.0081
	3	0.2794	0.0145	-0.4093	1.0595	0.0706
	4	-0.2130	-0.0417	-0.0494	0.3673	-0.1772
2007	1	NA	0.2167	1.6138	1.1280	0.2802
	2	-0.0473	0.1629	0.5922	0.2010	-0.0607
	3	NA	0.3361	0.1124	0.2070	-0.0205
	4	NA	-0.0039	-0.5055	0.0935	-0.3961

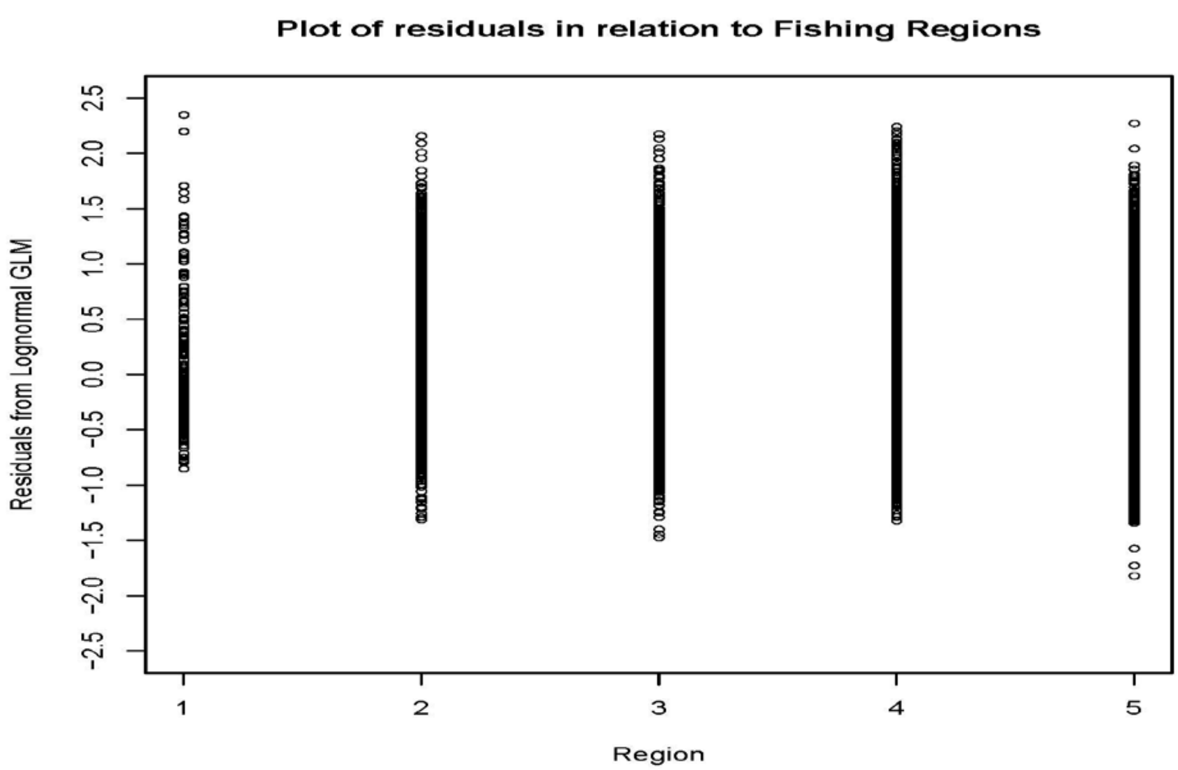
Haul year	Quarter	Region 1	Region 2	Region 3	Region 4	Region 5
2008	1	-0.5085	-0.2387	-0.3501	-0.0309	-0.1676
	2	NA	-0.1520	-0.0683	-0.0035	0.2556
	3	NA	0.0052	-0.1131	-0.0809	0.0033
	4	NA	-0.4258	0.2036	-0.1233	0.0796
2009	1	-0.3137	0.2196	0.0534	0.1332	0.0581
	2	0.0524	0.3120	0.0488	-0.0603	-0.0039
	3	1.0540	0.1491	0.2292	0.0448	-0.1350
	4	NA	0.3026	-0.0407	-0.2455	-0.2683
Pattern of quarterly mean residuals		(9 : 20: 31)	(27: 31 : 2)	(29 : 27: 4)	(25 : 35)	(27 : 33)

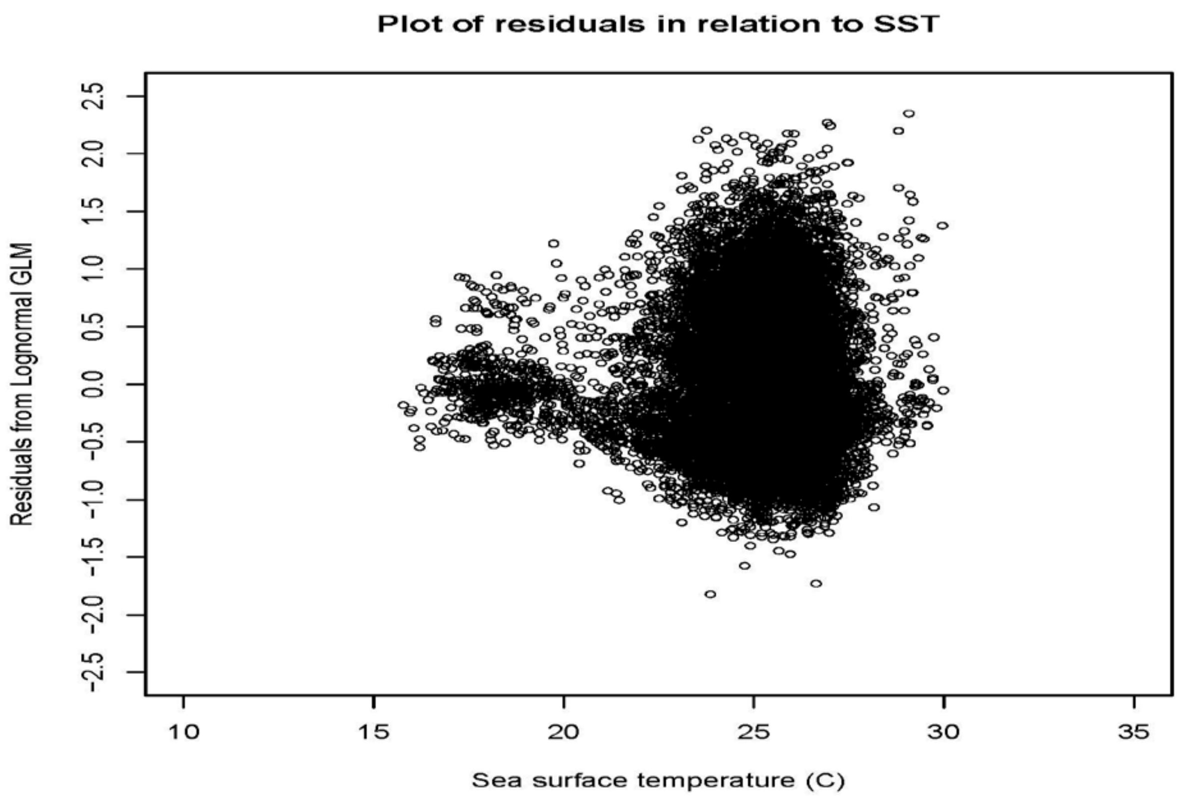


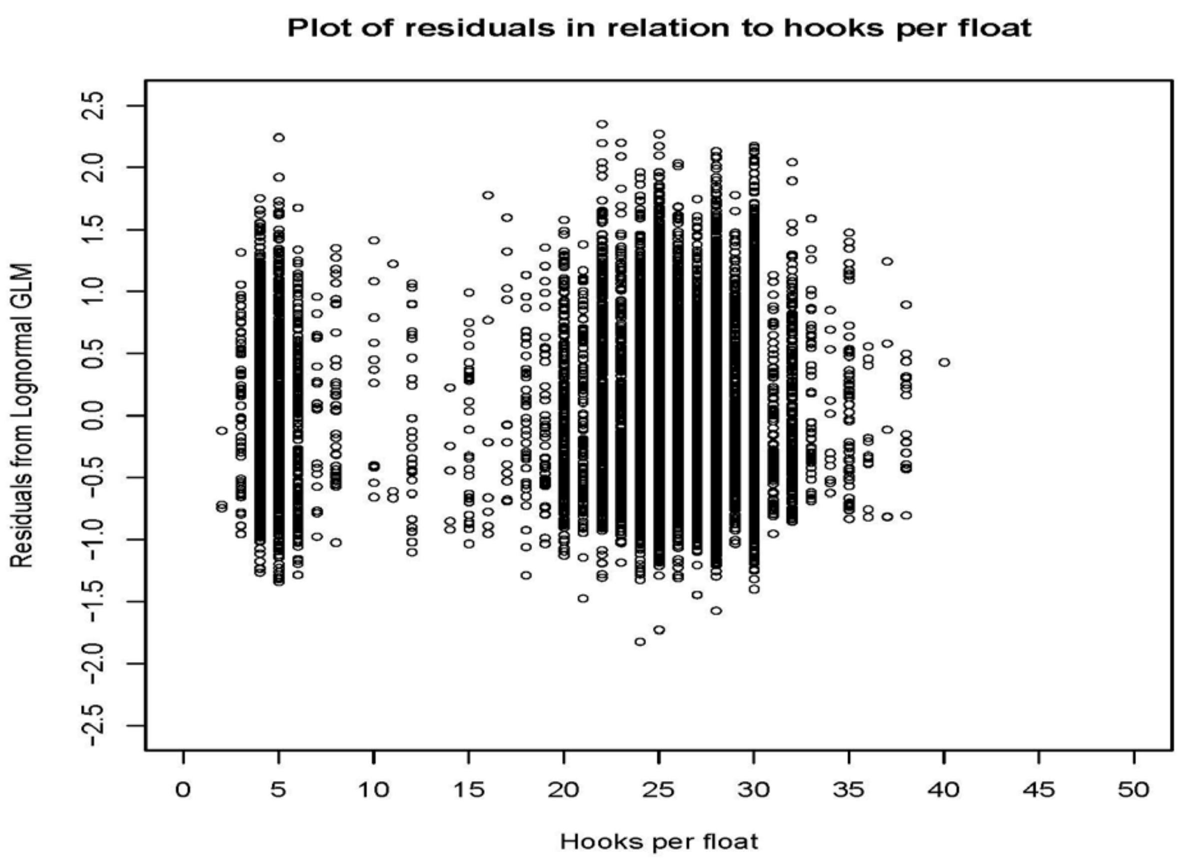

Plot of residuals on predictions from Lognormal GLM
Residuals from Lognormal GLM
Predicted values from Lognormal GLM
−2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 2.5

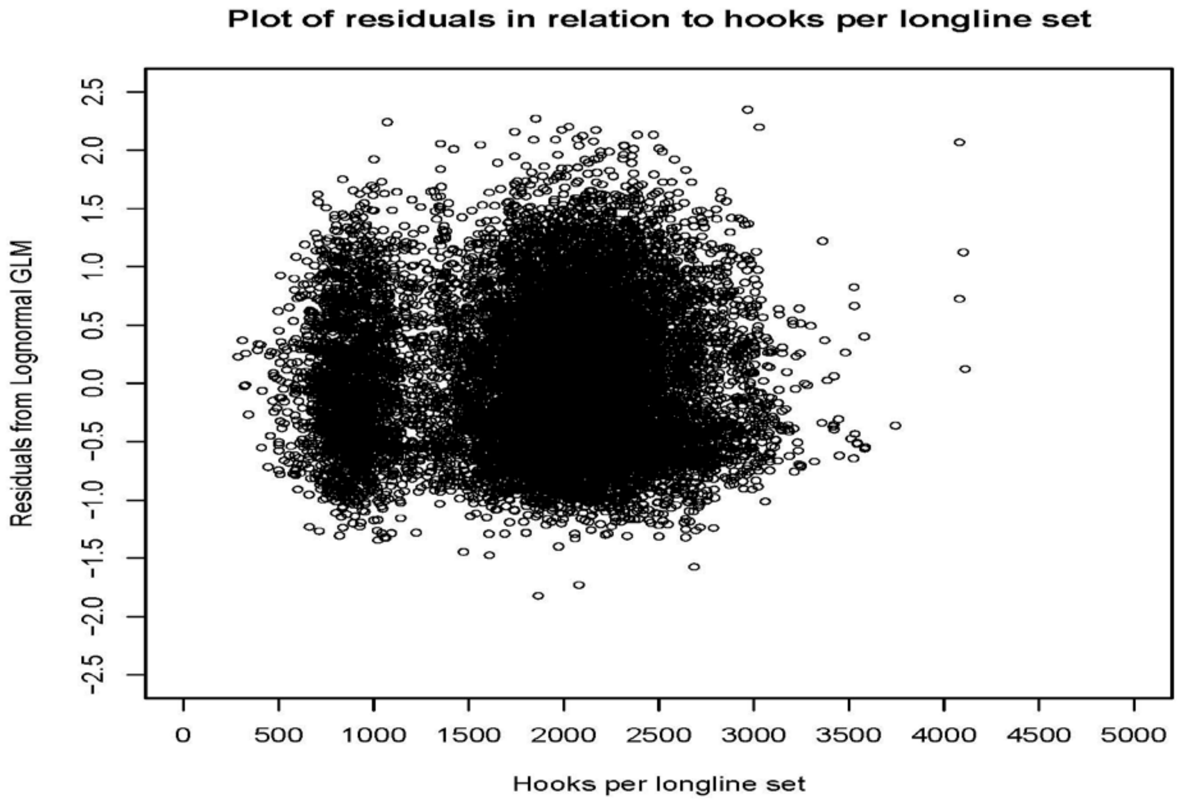

Plot of residuals in relation to Fishing Year
Residuals from Lognormal GLM
Fishing Year
1996 1998 2000 2002 2004 2006 2008 2010

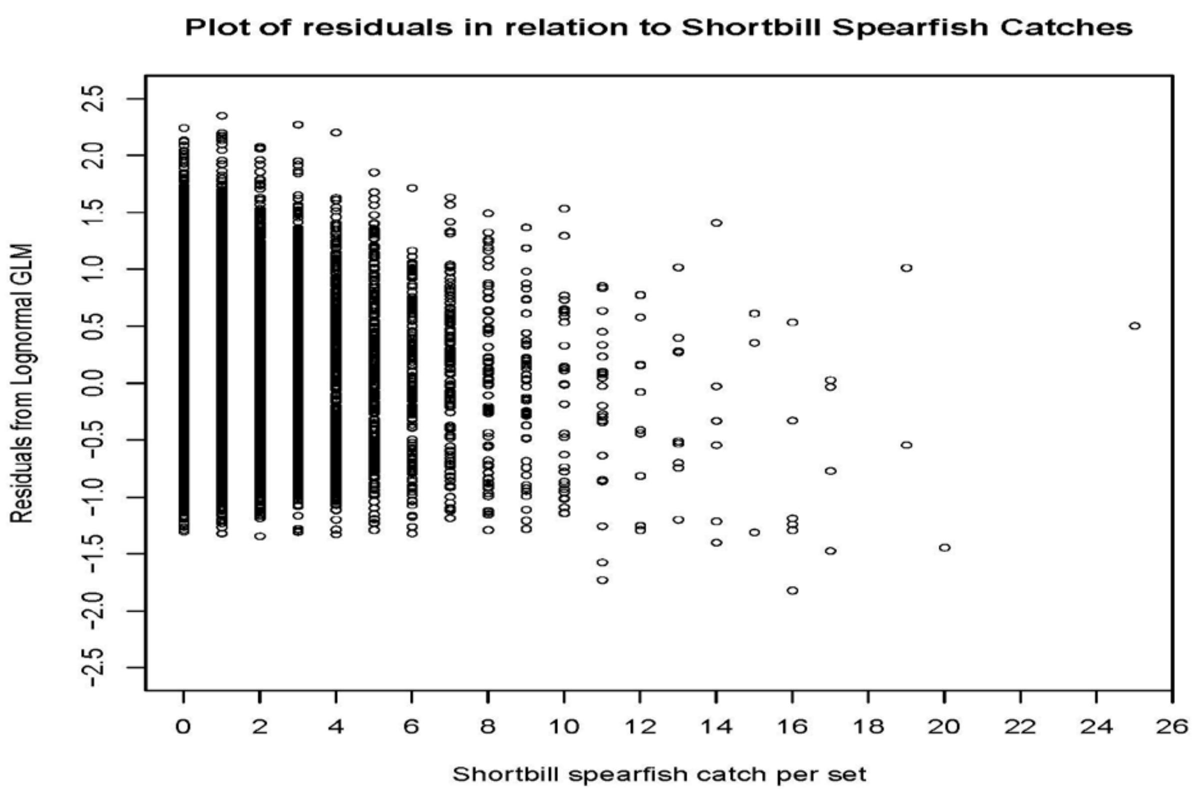

Plot of residuals in relation to Quarter of the Year
Residuals from Lognormal GLM
Calendar Quarter
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
1
2
3
4


Plot of residuals in relation to Fishing Regions
Residuals from Lognormal GLM
Region
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
1
2
3
4
5


Plot of residuals in relation to SST
Residuals from Lognormal GLM
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
10
15
20
25
30
35
Sea surface temperature (C)


Plot of residuals in relation to hooks per float
Residuals from Lognormal GLM
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25
30
35
40
45
50
Hooks per float


Plot of residuals in relation to hooks per longline set
Residuals from Lognormal GLM
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Hooks per longline set


Plot of residuals in relation to Shortbill Spearfish Catches
Residuals from Lognormal GLM
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Shortbill spearfish catch per set