ISC/14/BILLWG-1/5

Catch Rate Standardization for Swordfish *Xiphias gladius* in the Shallow-Set Sector of the Hawaii Longline Fishery, 1995−2012

William A. Walsh[1] and Jon Brodziak[2]

[1]Joint Institute for Marine and Atmospheric Research, University of Hawaii
Pacific Islands Fisheries Science Center, 2570 Dole St., Honolulu, Hawaii, 96822 USA

[2]NOAA Fisheries, National Marine Fisheries Service
Pacific Islands Fisheries Science Center, 2570 Dole St., Honolulu, Hawaii, 96822 USA

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Abstract

This working paper presents an analysis of swordfish *Xiphias gladius* catch rates in the shallow-set sector of the Hawaii-based pelagic longline fishery in 1995−2012 using catch and operational data collected by fishery observers. Swordfish is the target species in this sector, which underwent a closure between 2001 and 2004 due to excessive interactions with protected sea turtles. Because of this temporal gap, the analysis used data from 1995−2000 and 2005−2012. The swordfish catch per set was standardized with a generalized linear model (GLM) with a negative binomial error structure. The GLM included three significant factor variables (fishing year, fishing quarter, begin-set time in 4-h intervals) and four significant continuous (linear) variables (hooks per float, latitude, longitude, sea surface temperature). The fitted GLM reduced the null model AIC by 5.2% and the null deviance by 27.8%. The annual index of relative abundance peaked in 2006 because effort in the sector ceased after the first quarter, which is usually the most productive season. The relative abundance index decreased in 2008-2012, but this may have reflected the effects of federally-mandated changes in hook and bait types. We conclude that except for variation attributable to changes in effort patterns and operations in this sector of this fishery, swordfish CPUE has remained stable during the study period. The annual mean standardized catches per set with associated uncertainty are provided in spreadsheet format. Residuals plots are provided in an appendix.

Introduction

This working paper (WP) presents an analysis of swordfish *Xiphias gladius* catch rates in the Hawaii-based pelagic longline fishery in 1995-2012. Courtney et al. (2007) provided the standardized catch per unit effort (CPUE) time series from 1995−2007 used in the 2009 swordfish stock assessment conducted under the auspices of the Billfish Working Group (BILLWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). Because this WP is intended to serve as an update from the work of Courtney et al. (2007), we used the same suite of explanatory variables to standardize CPUE.

The results presented herein are from the shallow-set sector of this fishery, in which swordfish is the target species. This sector was closed from 2001 into 2004 as a consequence of excessive interactions with protected sea turtles. Therefore, we conducted the analysis with data from 1995−2000 and 2005−2012.

This WP presents a standardized CPUE series for the western and central North Pacific Ocean swordfish stock in waters exploited by the Hawaii-based pelagic longline fishery in 1995-2012. The CPUE series is intended for use in a Bayesian production model.

Methods

Data sources

The catch and operational data (e.g., species-specific catch tallies, geographic position, number of hooks deployed, set and haul times) used in this WP were collected by fishery observers from the NOAA Fisheries Pacific Islands Regional Observer Program (PIROP) according to protocols in the field manual from the NOAA Fisheries Pacific Islands Regional Office (2009). Sea surface temperature (SST°C) data were weekly mean values measured by an advanced, very high resolution radiometer borne by a NOAA satellite (Walsh et al. 2007).

The data were prepared for analysis as follows. All observer data were extracted from an ORACLE database at the NOAA Fisheries Pacific Islands Fisheries Science Center (64,435 sets in both sectors). This data set was then truncated to the 1995−2012 study period, leaving 59,813 sets. Three sets lacking identifiers were then deleted (59,810 sets). The data set was again truncated to include only commercial longline trips that had been checked and approved by the PIROP, had departed from and returned to a port in Hawaii, and were not conducted for experimental purposes (56,216 sets). Sets that deployed less than 200 hooks, had unusually long soak times (i.e.,>48 h), lacked unique identifiers, or were deployed in the eastern or southern hemispheres were then deleted. The final set of deletions removed sets lacking hook types and leader material information (55,671 sets). The shallow sets were then extracted, an additional

287 sets from 2001−2004 were deleted because the sector was closed, and two sets were deleted for lack of other fields, leaving an analytical data set of 12,229 observed shallow sets.

Descriptive statistics

Observer effort, operational parameters, and descriptive catch statistics in the shallow-set sector were summarized in tabular form. The annual mean nominal catches per set and nominal CPUE (swordfish/1,000 hooks) are presented together graphically.

CPUE standardization

The GLM was fitted by forward variable selection, using swordfish catch per longline set as the response variable, the haul year, quarter of the year, and begin-set time (six levels of four-hour intervals) as factor variables, and SST, latitude, longitude, and the number of hooks per float as continuous explanatory variables. The logarithm of the number of hooks deployed on a set was used as an offset. The effect of each variable on swordfish catch per set was assessed in terms of the associated reduction of the Akaike Information Criterion (AIC), reduction of the deviance, and the reductions in both per degree of freedom. The significance of each variable was evaluated with a chi-squared test with $P<0.05$ as the significance criterion.

Several plots of deviance residuals were used to assess the GLM fit. These are presented along with a synopsis in Appendix I.

Standardized catch rates

The annual mean standardized catches per set were obtained by using the fitted GLM with the “predict” function in R (Crawley 2007). These results, along with estimates of uncertainty, are presented in a spreadsheet format.

Annual indices of relative abundance

The year effect was extracted from the GLM according to the method in Maunder and Punt (2004). These values are presented graphically as the annual indices of relative abundance. The R “summary” function was used to print out the fitted model, including its coeffficients, standard errors, and *t*-tests; these results are presented as Appendix II. The values for the means and standard errors of the yearly effect in the relative abundance plot were obtained from this table.

Results

PIROP fishery observers recorded catch and operational data at sea during 738 shallow-set trips by 74 Hawaii-based commercial longline vessels that deployed over 11 million hooks in 1995−2012 (Table 1). On average, 909.4 hooks were deployed per shallow set.

Shallow sets were usually deployed in the early evening at relatively high latitudes (ca. 30°N). The target depth was the most variable of the operational parameters, with a standard deviation greater than its mean.

Swordfish were caught on nearly all shallow sets (98.3%). Of these, most were multiple catches (96.1% of all sets). The variance:mean ratio was large (4.52). The annual mean nominal catches per set and nominal CPUE peaked after the re-opening of the sector, but decreased in 2008−2012 so that the initial (1995) and final (2012) nominal catch rates were similar (Figure 1).

CPUE standardization

The forward selection procedures used to fit the GLM are summarized in Table 2. All seven explanatory variables were significant and yielded reductions in the AIC and residual deviance, although the SST effect was much less important than those of all others. The fishing years yielded the largest AIC and deviance reductions in actual and percentage terms, but the begin-set time had the largest reductions per degree of freedom among the three factor variables. The AIC and deviance reductions per degree of freedom for three of the four continuous explanatory variables (hooks per float, latitude, longitude) were greater than those of any of the factors. The fitted model AIC was 5.21% less than that of the null model; the residual deviance was 27.77% less than the null deviance.

Standardized CPUE trends

The annual mean standardized CPUE (swordfish/standard set) values predicted by the GLM are summarized in spreadsheet format in Table 3. These ranged by 36.5% in 1995−2000 (8.203−11.199 swordfish/standard set). After the re-opening of the shallow-set sector in 2005, the annual mean standardized CPUE varied by 22.5% from 13.332−16.331 in 2005−2008, followed by a decrease to lower values (9.233−11.7 swordfish/standard set) in 2009−2012.

Annual estimates of standardized CPUE show different trends before and after the shallow-set fishery closure during 2001-2004 (Figure 2). Swordfish CPUE has an increasing trend before the closure and a decreasing trend after the closure. Average CPUE was about 9.3 swordfish per set during 1995-2000 and increased to average roughly 12.5 swordfish per set during 2005-2012. Variability in CPUE also differed before and after the closure with an average coefficient of variation of swordfish catch per set of about 44% before and 23% after the closure.

Discussion

The shallow-set sector of the Hawaii-based pelagic longline fishery underwent a closure and major changes during between 1995−2012. The latter included federally-mandated changes in hook and bait types to reduce interactions with sea turtles.

The plot of the annual relative abundance index and the variation in the predicted annual mean standardized CPUE values are explicable in light of changes in effort patterns and operations during the study period. Regarding the latter, the annual percentages of shallow sets deployed in the third quarter in 1995−2000 ranged from 5.1−39.0%, but the annual percentages of third quarter shallow sets since 2006 have been 0−5.8%. This is a salient point because the third quarter is usually the least productive season for swordfishing. In contrast, all of the shallow sets in 2006 were deployed in the most productive swordfishing season, the first quarter.

The principal operational changes in the sector involved mandatory switches from squid baits and J-hooks to mackerel bait and circle hooks, but these changes were temporally confounded. These effects should be considered in future attempts to standardize swordfish CPUE.

Conclusions

These analyses did not reveal evidence of inexplicable decreases in swordfish standardized CPUE. Although the data series included a 4-year gap, we conclude that except for variation attributable to unusual effort patterns and operational changes in this sector of this fishery, swordfish CPUE remained approximately stable in 1995−2012. This inference is consistent with findings from Gilman et al. (2012), who reported no significant trends in swordfish CPUE in the deep-set sector of this fishery in March 1994−July 2010. Thus, the best available scientific information suggests that swordfish CPUE in both sectors of this fishery has been approximately stable for almost two decades.

References

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Walsh, W.A., K.A. Bigelow, and R.Y Ito. 2007. Corrected catch histories and logbook accuracy for billfishes (Istiophoridae) in the Hawaii-based longline fishery. NOAA Technical Memorandum NMFS-PIFSC-13.

Table 1. Summary of fishing effort and fishery observer deployments at sea, operational parameters on observed longline trips, and descriptive catch statistics for swordfish in the shallow-set sector of Hawaii-based pelagic longline fishery in 1995–2012. Observer effort is summarized by totals except for mean observer experience. Operational parameters are means and standard deviations (lower parenthetical entries).

Observer effort					
Trips	Sets	Hooks	Vessels	Observers	Mean experience
738	12,229	11,120,961	74	233	3.2
Operational parameters					
Latitude	Longitude	Hooks per set	Hooks per float	Begin-set time	Target depth
30.0°N (3.7°)	158.0°W (8.3°)	909.4 (179.0)	4.5 (0.8)	1911 HST (2.63 h)	47.8 m (48.1 m)
Swordfish catch statistics					
Catch	Catch per set	Nominal CPUE	Sets with positive catches	Sets with multiple catches	Variance: mean (catch per set)
145,166	11.87 (7.33)	13.39 (8.53)	98.3%	96.1%	4.52:1

Table 2. Analysis of deviance table summarizing the negative binomial variable selection procedures for swordfish in the shallow-set sector of the Hawaii-based pelagic longline fishery in 1995-2012. Table entries at each fitting step include the degrees of freedom (Df), significance of the chi-squared test (Pr>|χ2|), reduction in the AIC (ΔAIC), percent reduction of the null model AIC, reduction in the AIC per degree of freedom, the residual deviance reduction, the percent reduction of the null deviance, the deviance reduction per degree of freedom, and the median deviance residual. The null model AIC was 81,632.1.

Parameter	Df	Pr>|χ2|	ΔAIC	% AIC	ΔAIC/Df	ΔDeviance	% Null deviance	ΔDeviance/Df	Median deviance residual
Intercept	1	----	----	----	----	----	----	----	-0.1666
Fishing years	13	<2.2e-16	-1,644.0	2.01%	-126.46	-1,378.95	11.79%	-106.07	-0.1485
Fishing quarters	3	<2.2e-16	-539.65	0.67%	-179.88	-558.62	3.56%	-186.21	-0.1498
Begin-set time	5	<2.2e-16	-1,181.35	1.45%	-236.27	-1,225.46	7.31%	-245.09	-0.1507
Hooks per float	1	<2.2e-16	-304.88	0.37%	-304.88	-310.72	1.78%	-310.72	-0.1478
Latitude	1	<2.2e-16	-315.99	0.39%	-315.99	-320.67	1.81%	-320.67	-0.1503
Longitude	1	<2.2e-16	-257.02	0.31%	-257.02	-261.89	1.45%	-261.89	-0.1467
SST (°C)	1	0.0006	-9.74	0.01%	-9.74	-11.75	0.07%	-11.75	-0.1471

Model AIC = 77,379.47

Model pseudo-R^2 = 27.77%

Reduction of the null model AIC = 5.21%

Table 3. Standardized CPUE (swordfish/standard set) in the shallow-set sector of the Hawaii-based pelagic longline fishery. Results are presented in a spreadsheet format, with the fishing year, annual mean catch per standard set, the variance, standard deviation, sample size, standard error of the mean, and the coefficient of variation of the mean as the table entries. No data are provided for 2001−2004 because the sector was closed.

Year	1995	1996	1997	1998	1999	2000	2005	2006	2007	2008	2009	2010	2011	2012
Mean CPUE	8.334	8.542	9.184	8.203	11.199	10.606	13.332	16.317	13.828	13.535	10.898	9.233	11.700	11.179
Variance	12.806	15.964	14.565	12.285	10.953	39.500	9.409	11.403	10.951	8.976	7.382	5.320	5.613	6.111
Standard deviation	3.578	3.995	3.816	3.505	3.310	6.285	3.067	3.377	3.309	2.996	2.717	2.306	2.369	2.472
CV	0.43	0.47	0.42	0.43	0.30	0.59	0.23	0.21	0.24	0.22	0.25	0.25	0.20	0.22
N	277	334	282	272	176	353	1640	821	1566	1474	1635	1560	928	911
SEM	0.2150	0.2186	0.2273	0.2125	0.2495	0.3345	0.0757	0.1179	0.0836	0.0780	0.0672	0.0584	0.778	0.0819
CV of mean CPUE	3%	3%	2%	3%	2%	3%	1%	1%	1%	1%	1%	1%	1%	1%

Figure 1. Annual mean nominal catch per shallow set and annual mean nominal CPUE in the shallow-set sector of the Hawaii-based pelagic longline fishery in 1995−2012.

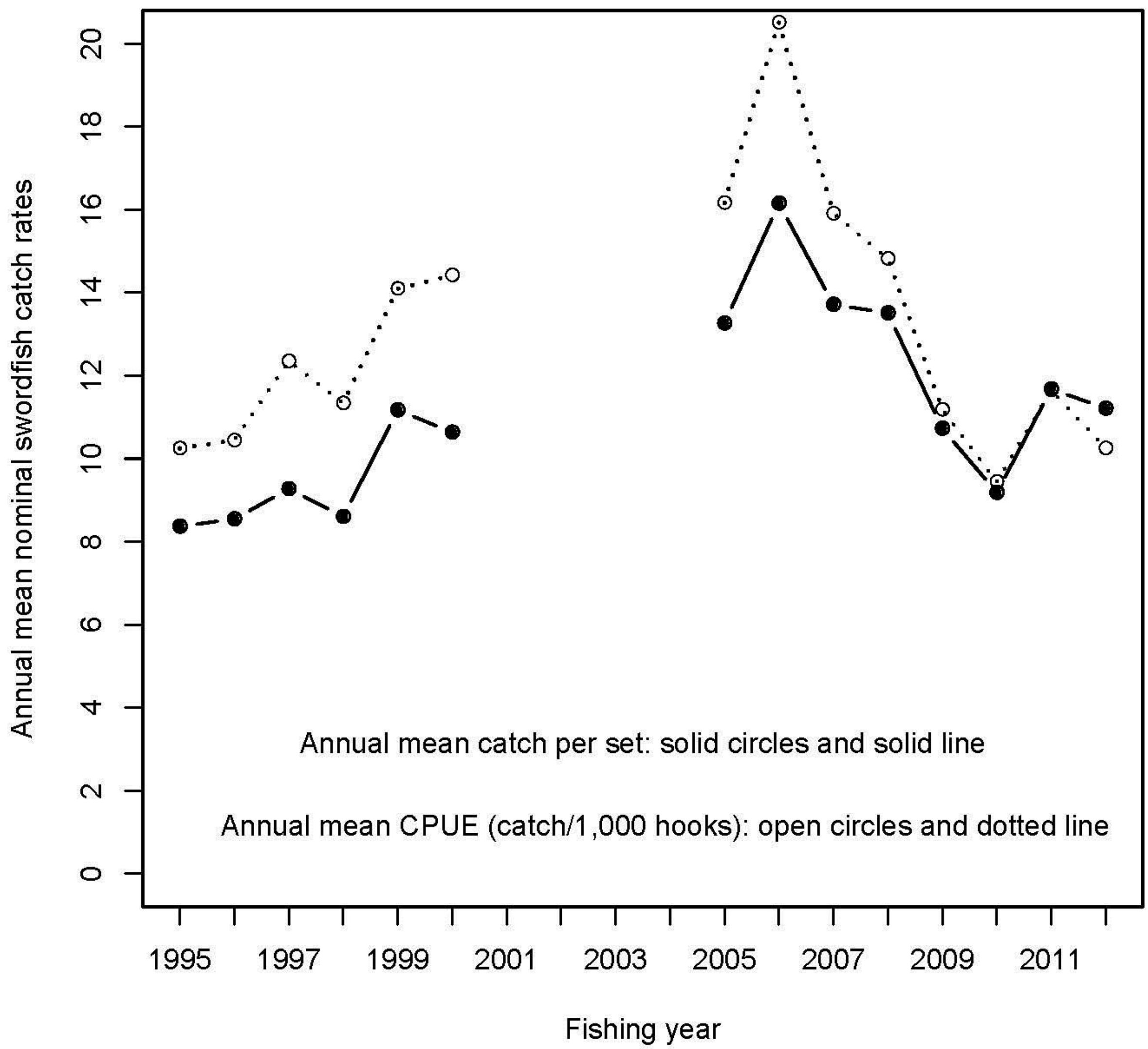
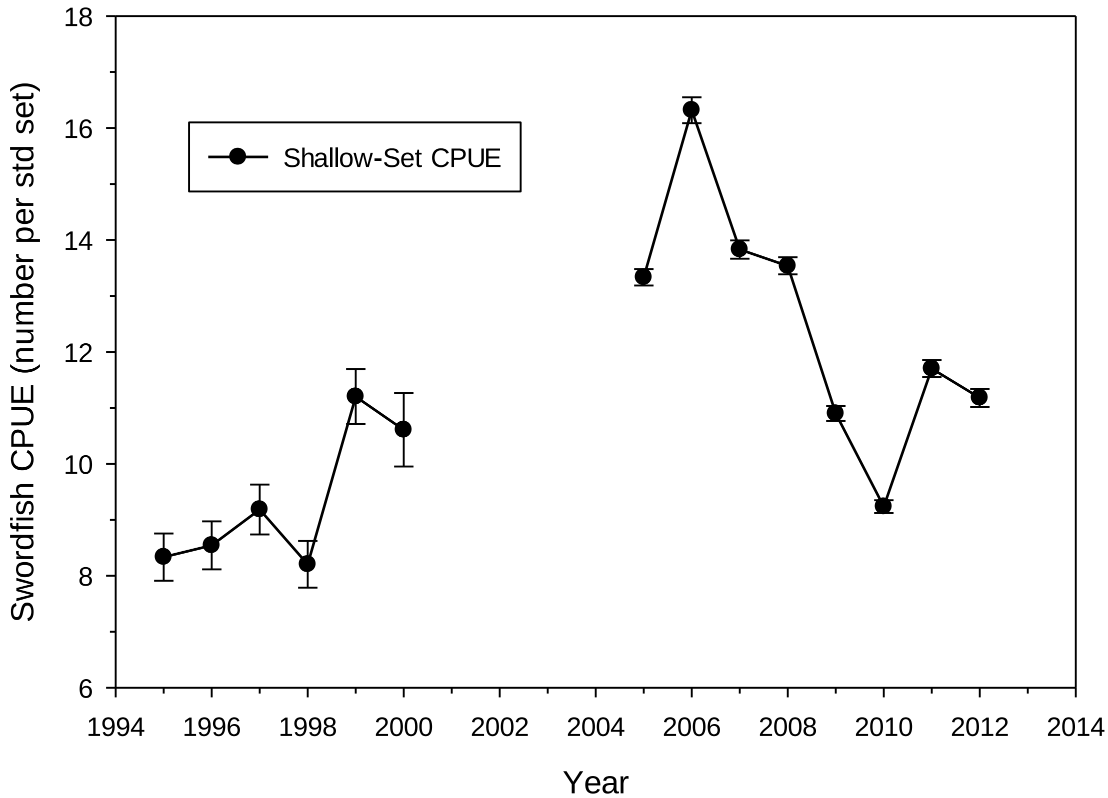


Figure 2. Mean standardized catch-per-unit effort (CPUE, number per standardized set) of swordfish in the shallow-set sector of the Hawaii longline fishery (solid circle) along with 95% confidence intervals. Note that the shallow-set fishery sector was closed during 2001-2004 in order to reduce fishery interactions with protected sea turtle species.



APPENDIX I

Deviance Residuals from the Negative Binomial GLM of Swordfish Catch per set from the Shallow-set Sector of the Hawaii-based Pelagic Longline Fishery

1. Synopsis of deviance residuals

2. Histogram of deviance residuals

3. Normal probability plot of deviance residuals

4. Plots of deviance residuals against the values of explanatory variables

Synopsis of deviance residuals

Several plots of the deviance residuals from the GLM did not reveal serious analytical problems. The histogram of residuals (Figure A1) was approximately symmetrical and normal in appearance. The normal probability plot (Figure A2) was linear except for a few outlying residuals near the tails. The spread of the plot of deviance residuals on the fitted values (Figure A3.1) was greatest near the center, producing a rounded appearance. The boxplots for the residuals from the year (Figure A3.2) and quarter (Figure A3.3) factor variables showed that all means were near zero and the variability was similar at all factor levels. The boxplot for the begin-set intervals (Figure A3.4) indicated that the mean deviance residuals were negative for sets deployed before the afternoon or evening hours. The plot of deviance residuals on the numbers of hooks per float (Figure A3.5) revealed that the residuals were centered about zero, with greatest variation at four and five hooks per float, which was not unexpected because these were used on 90% of the shallow sets. The plots of deviance residuals on latitude (Figure A3.6) and longitude (Figure A3.7) were homogeneously spread and without patterns. The plot of the deviance residuals on SST (Figure A3.8) included two “clusters” of values. These corresponded to swordfishing at high latitudes in winter and early spring, as is currently the practice, or in more temperate waters in spring and early summer months targeting swordfish migrating toward equatorial waters to spawn; this was a relatively common practice in this fishery before the sector closure. Thus, there is a temporal aspect to the SST results, but there is no other pattern in the plot. The plot of the deviance residuals on the number of hooks per set was homogeneous in appearance and without patterns.

Figure A1. Histogram of the deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012.

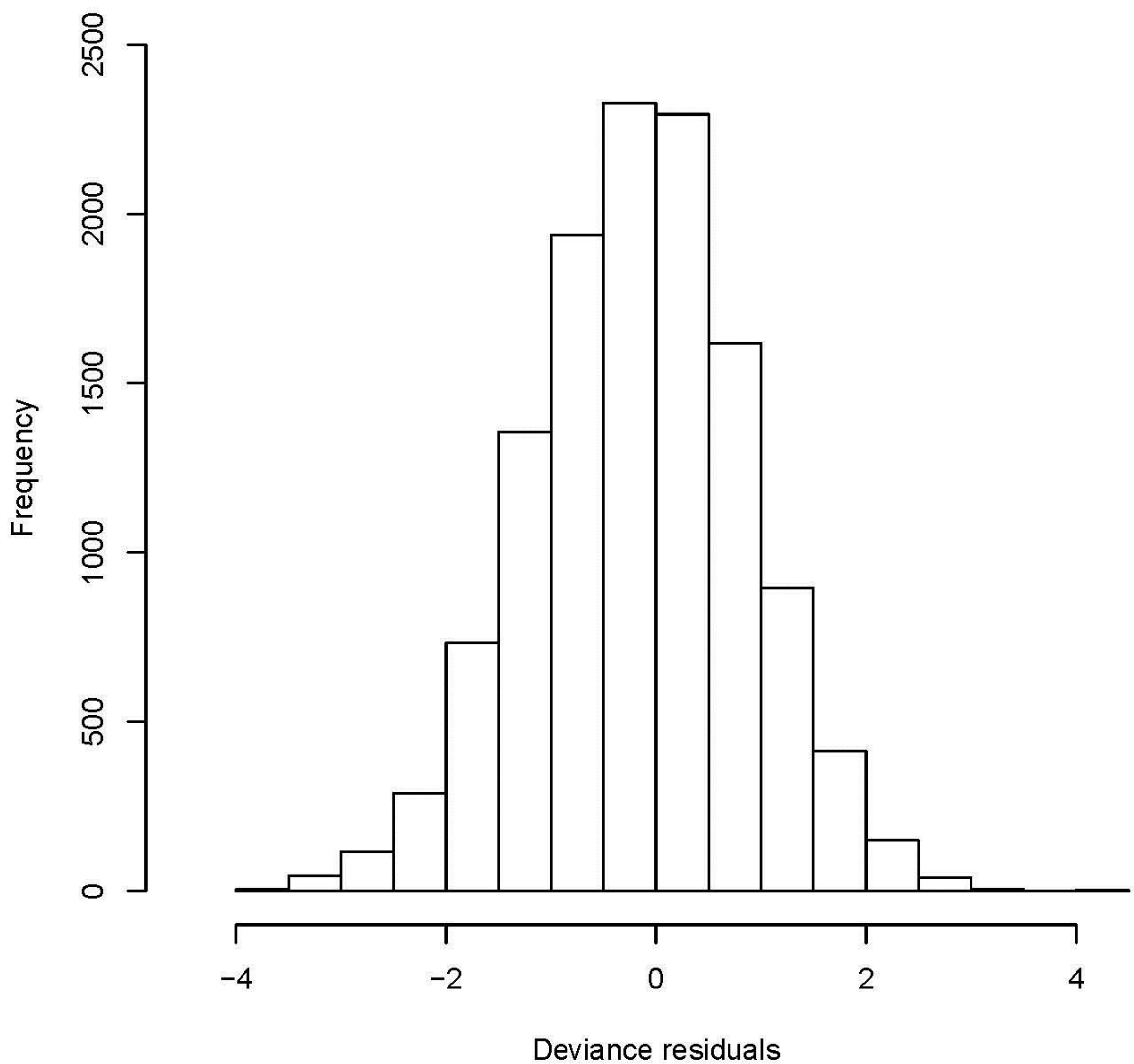


Figure A2. Normal probability plot of the deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012.

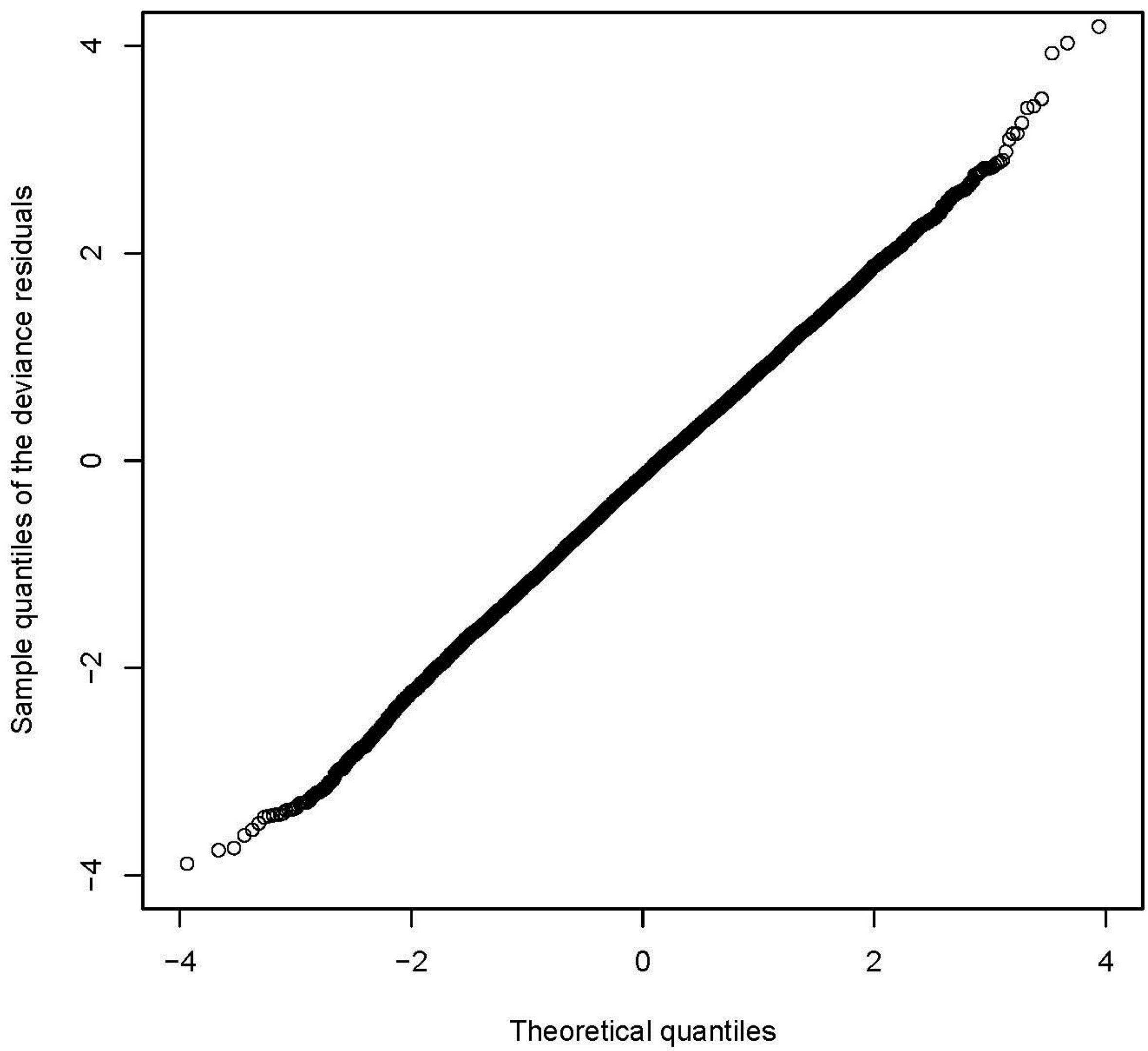


Figure A3.1. Deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012, plotted against the predicted values.

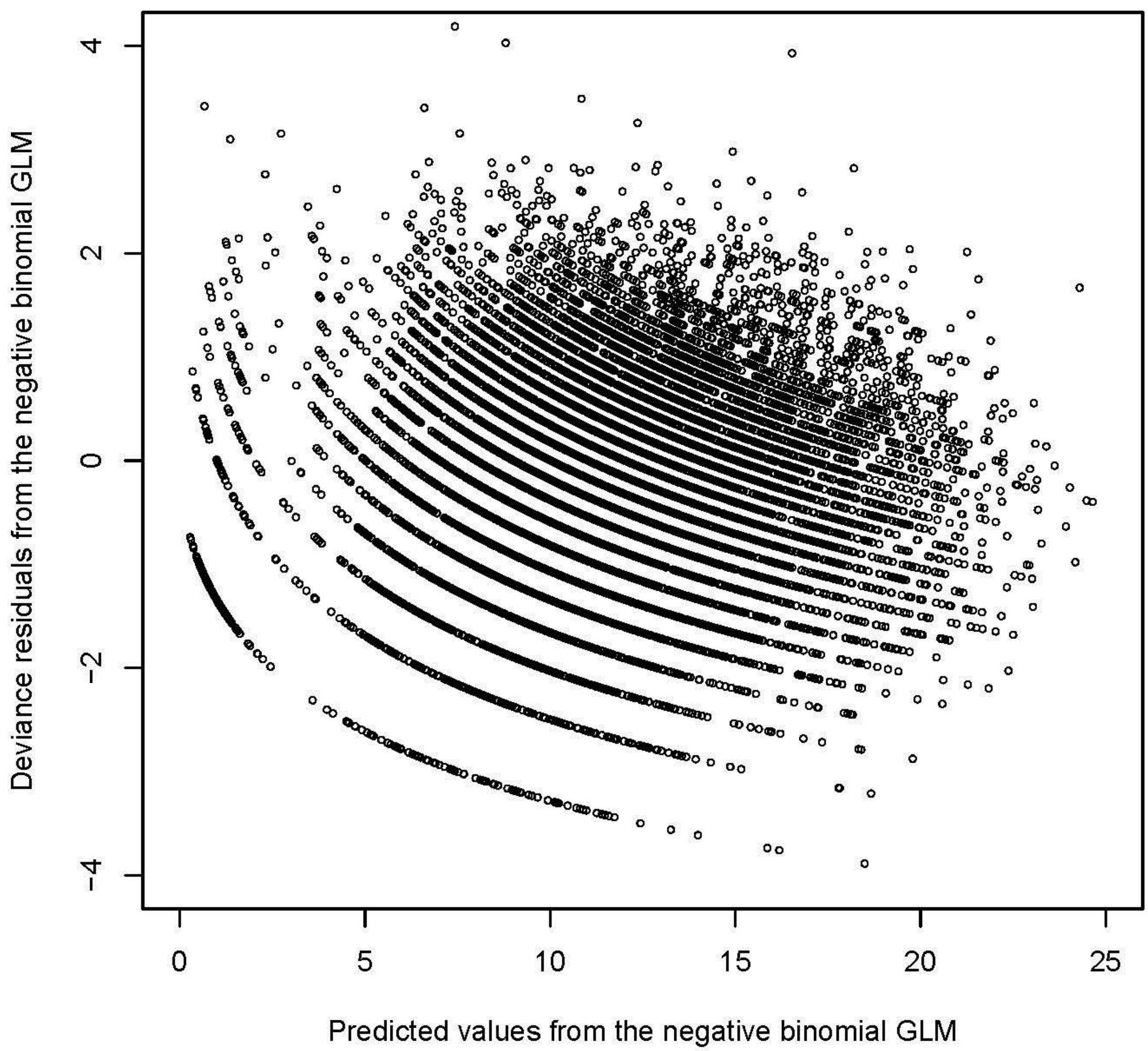


Figure A3.2. Boxplot of deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012. Data are plotted against the fishing year; there are no data for 2001−2004 because the sector was closed.

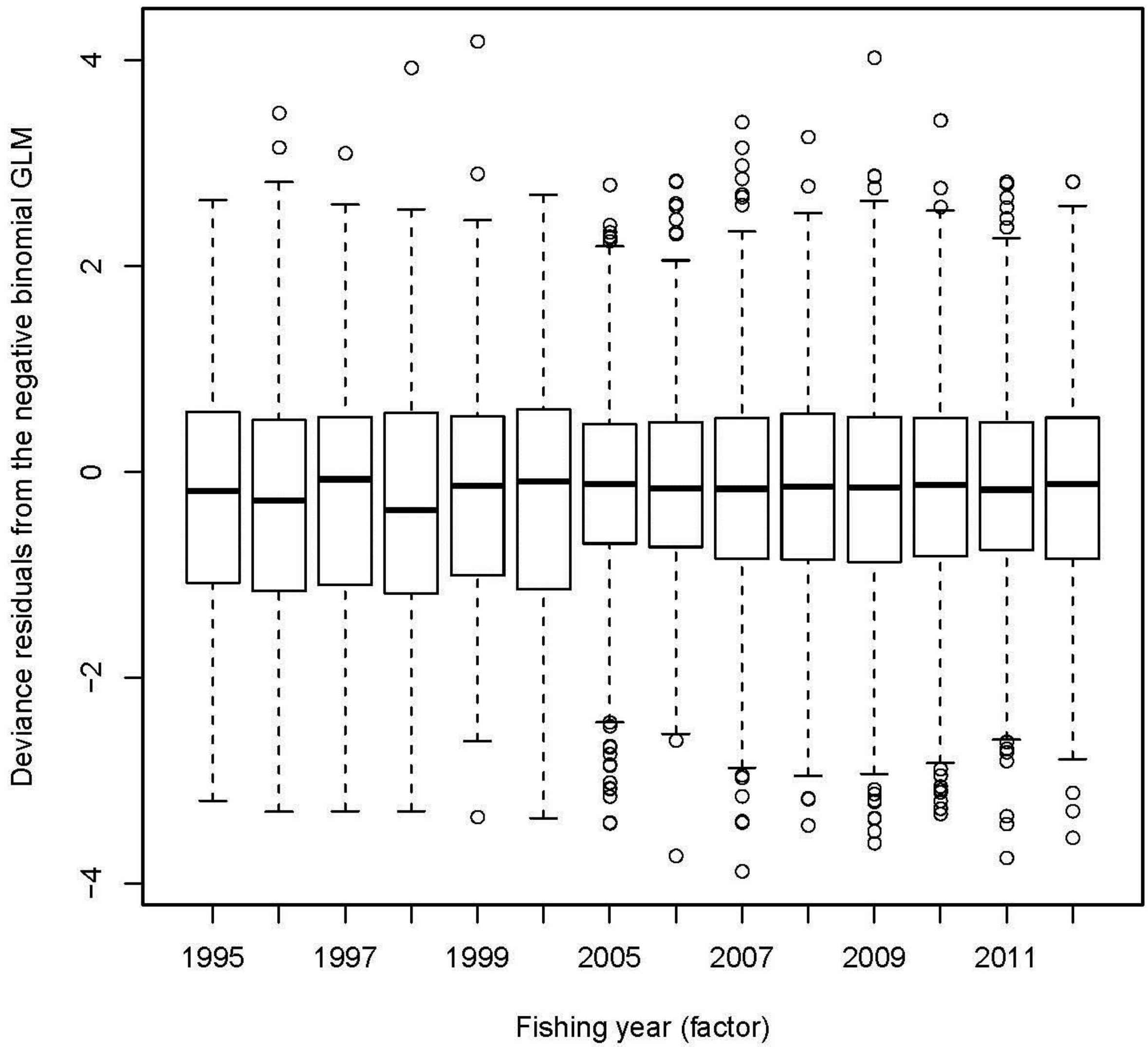


Figure A3.3. Boxplot of deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012. Data are plotted against the fishing quarter (i.e., calendar quarter).

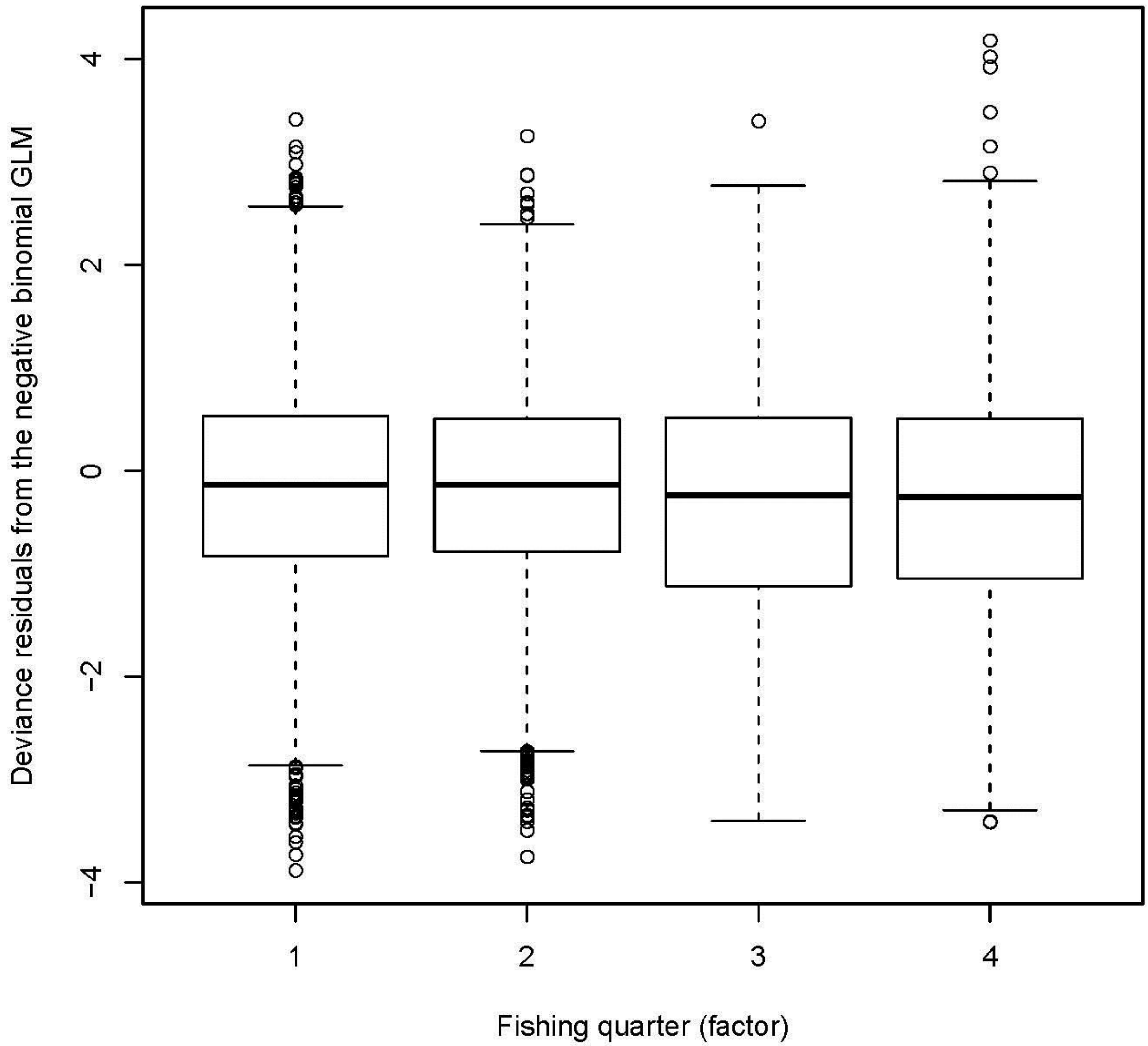


Figure A3.4. Boxplot of deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012. Data are plotted against the begin-set time treated as a factor with six levels defined by four-hour intervals (000−0400h; 0400−0800h; 0800−1200h; 1200−1600h; 1600−2000h; 2000−2400h).

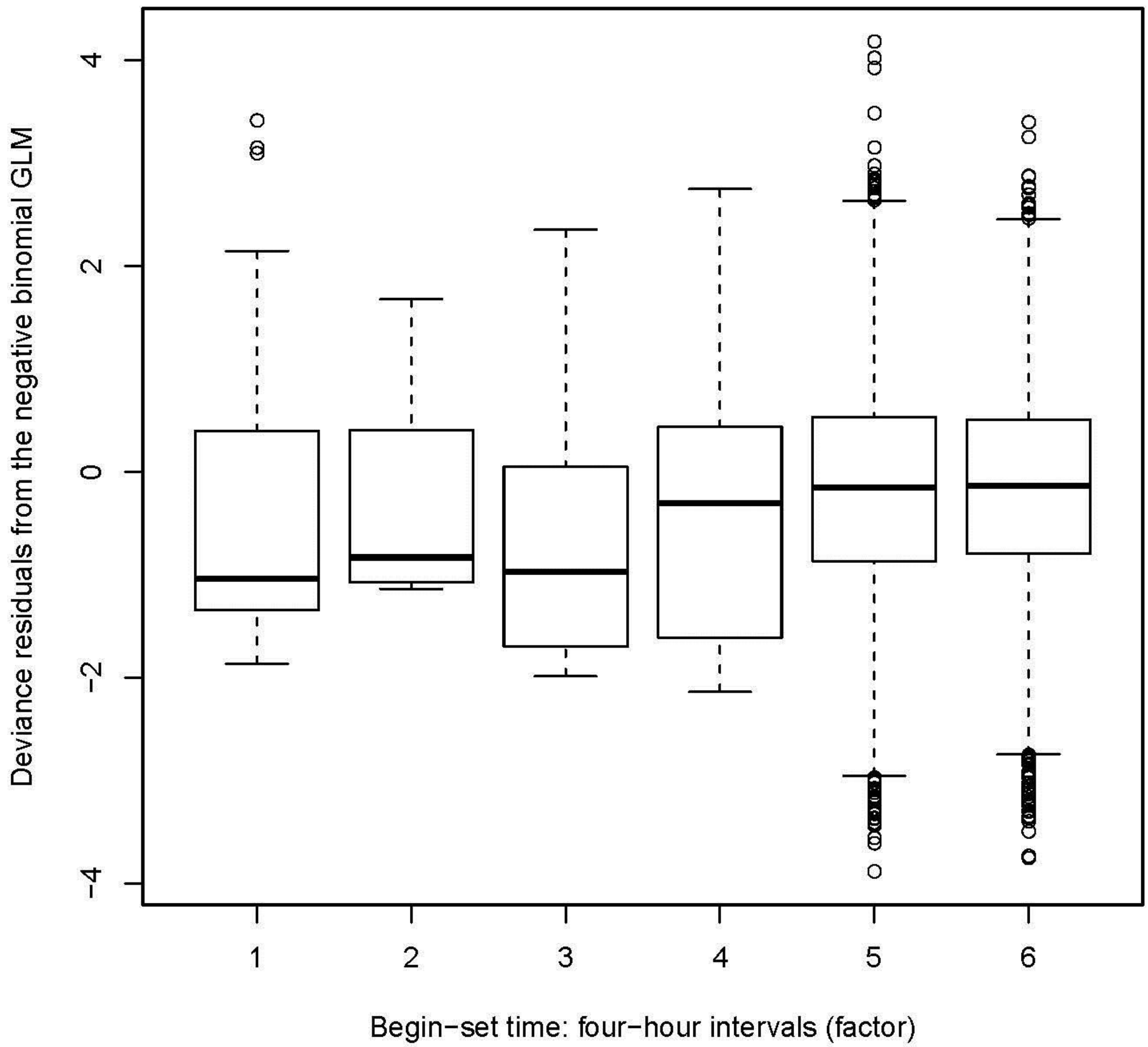


Figure A3.5. Deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012, plotted against the number of hooks per float on the longline gear.

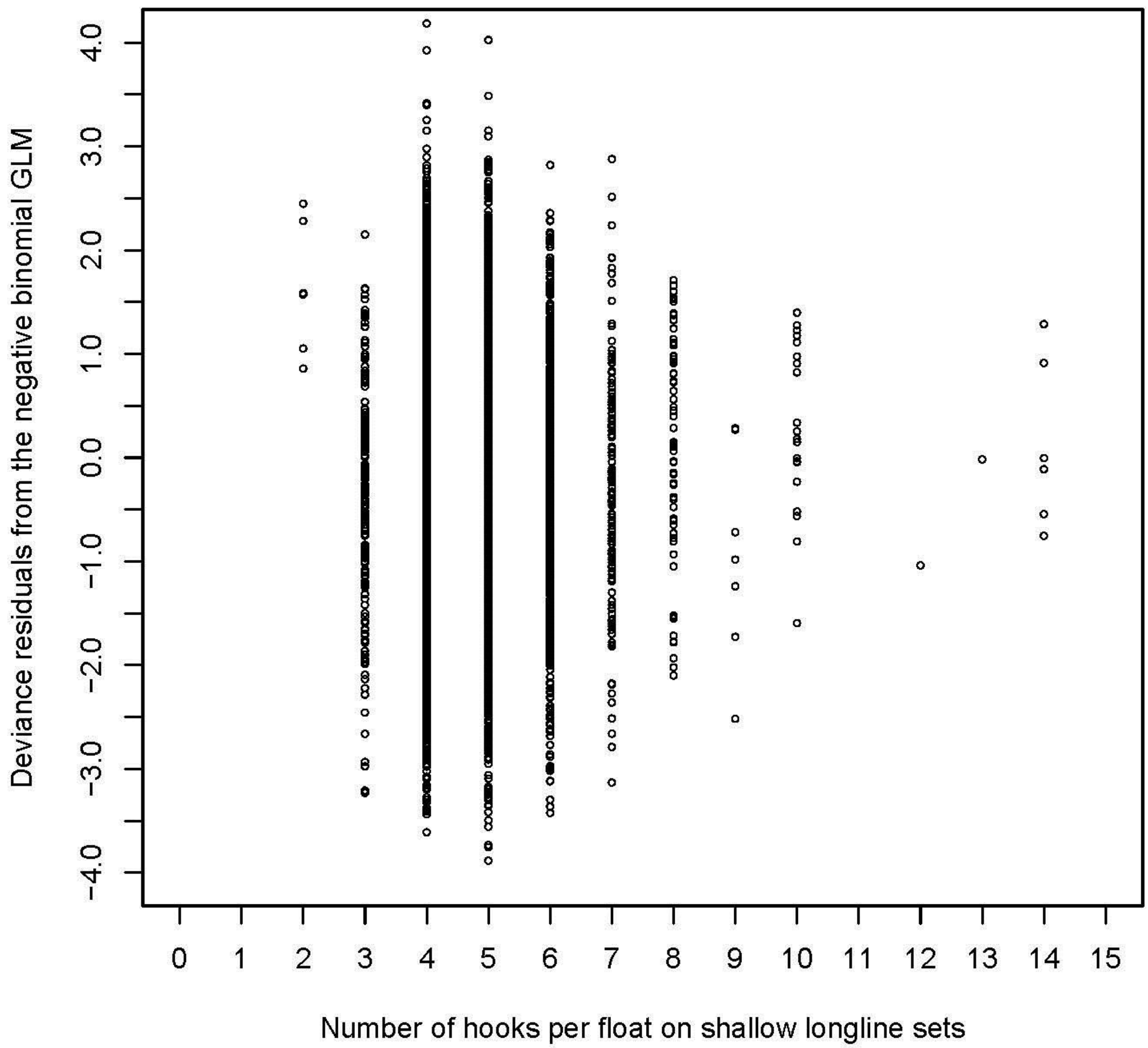


Figure A3.6. Deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012, plotted against latitude.

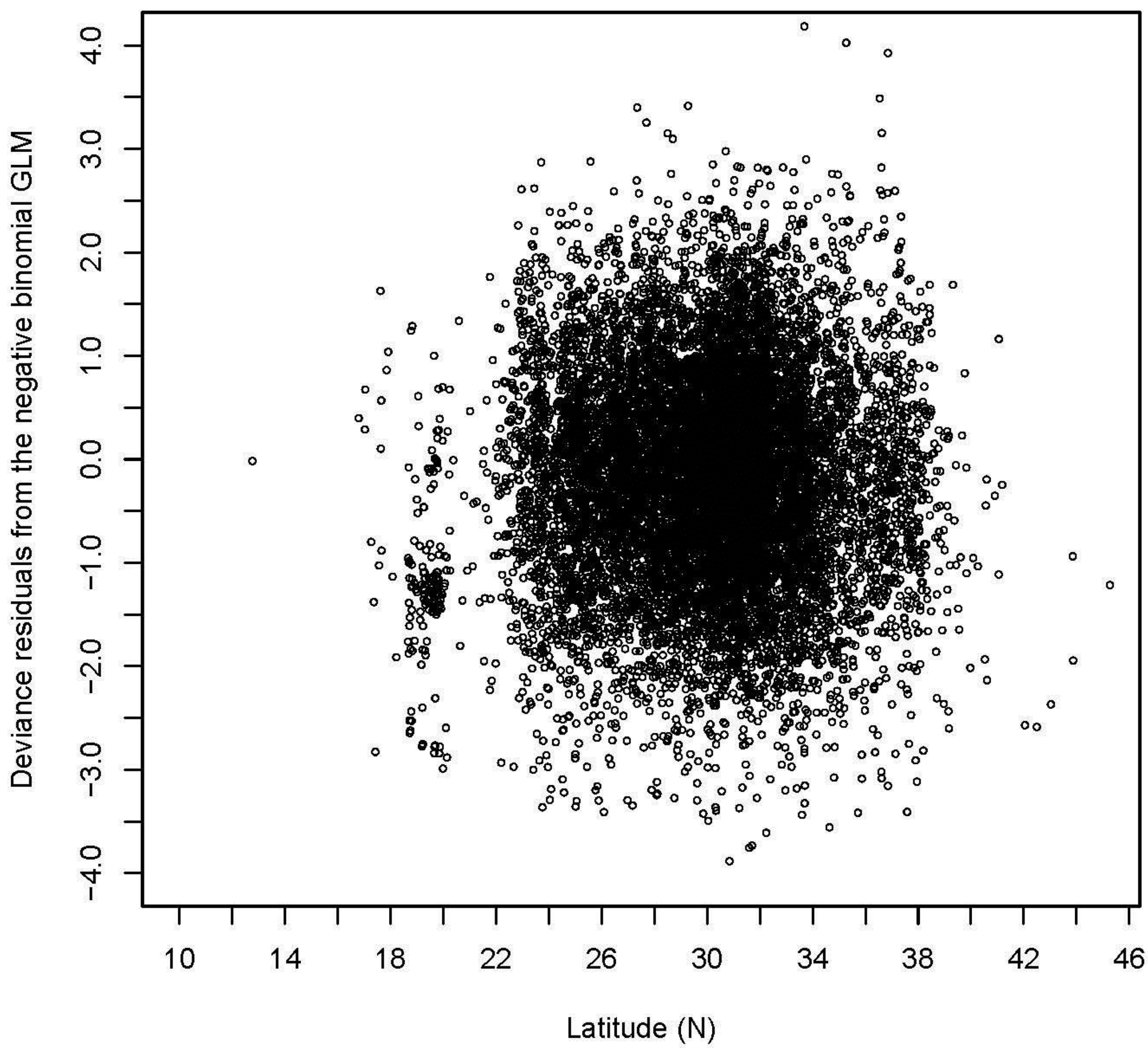


Figure A3.7. Deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012, plotted against longitude.

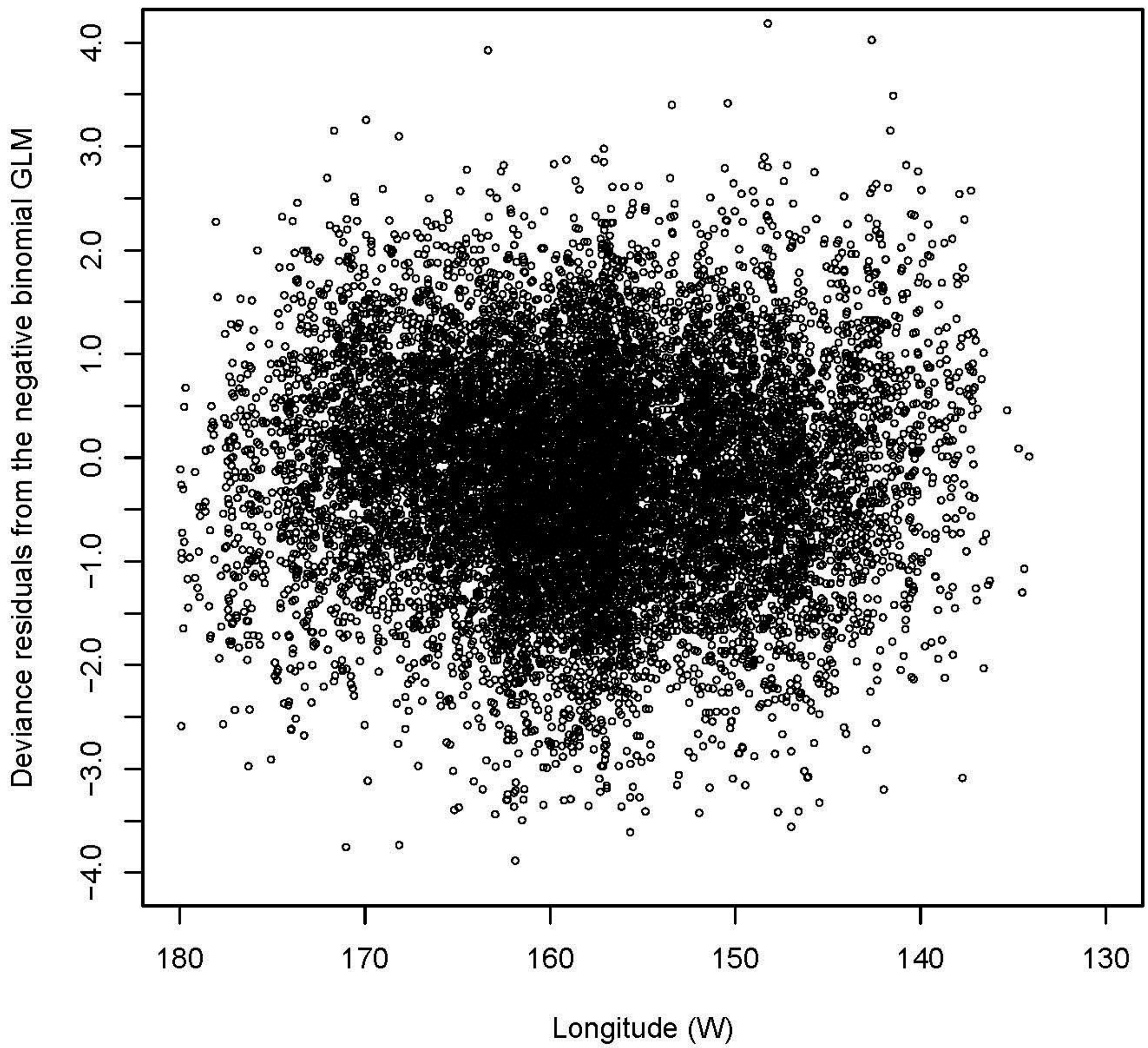


Figure A3.8. Deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012, plotted against the sea surface temperature (SST°C).

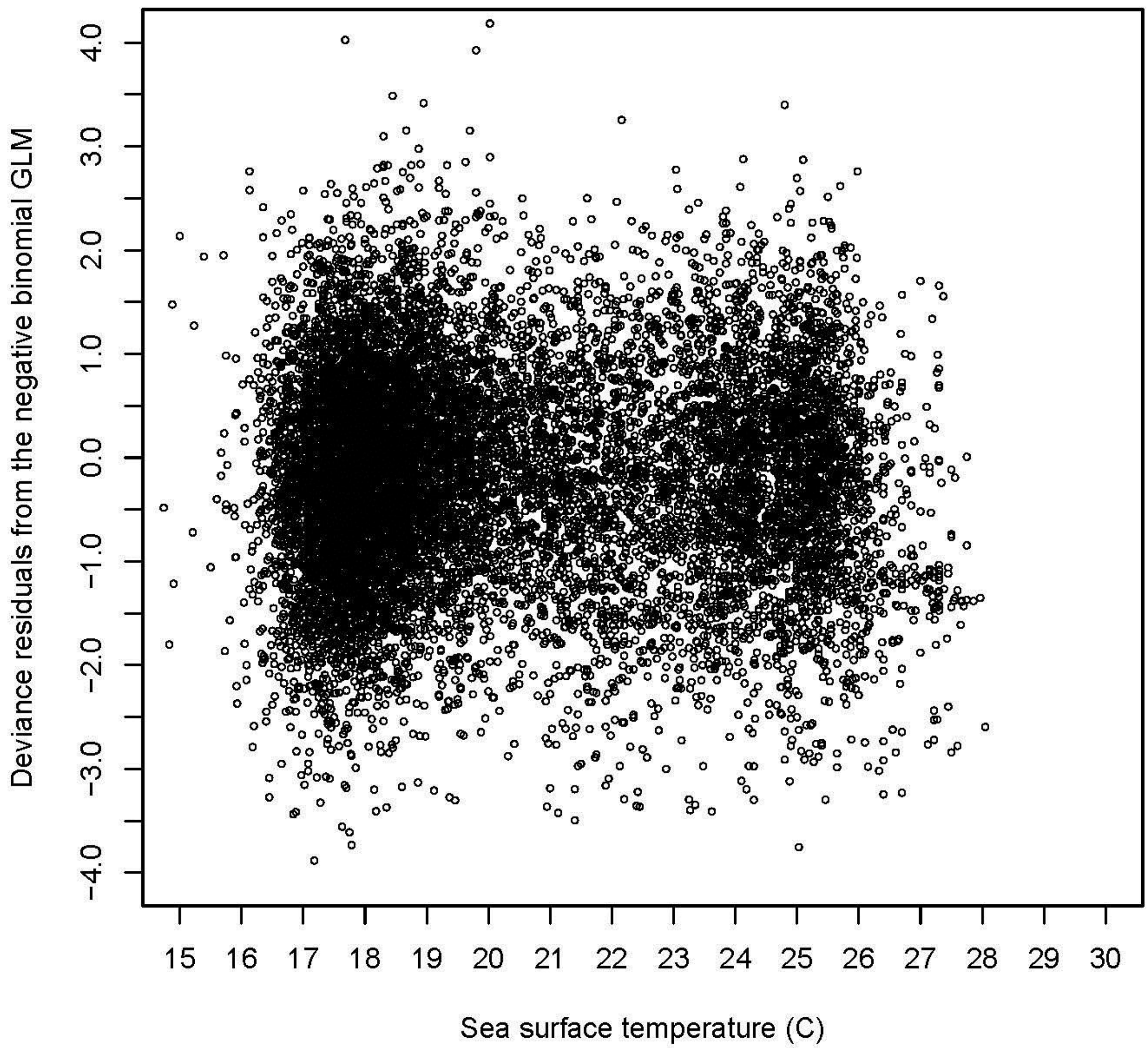
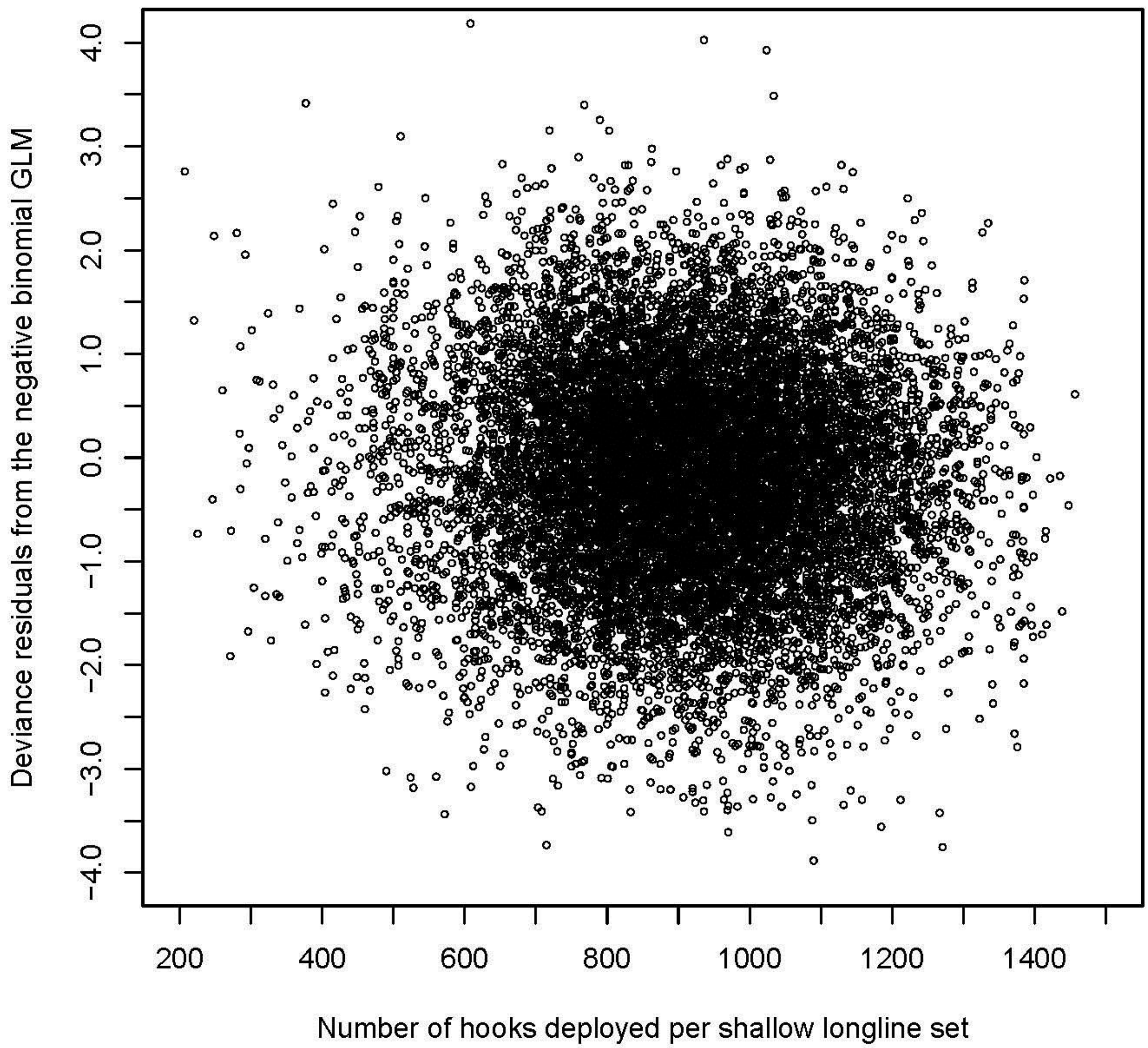


Figure A3.9. Deviance residuals from the negative binomial GLM of swordfish catch per set in the shallow-set sector of the Hawaii-based pelagic longline fishery, 1995−2012, plotted against the number of hooks deployed per longline set.



APPENDIX II

Table AII.1. Negative binomial GLM output from the R summary function.

```
> summary(SF_SS_GLM)

Call: glm.nb(formula = Swordfish~Haulyr1+Quarter1+ BSfactor +Hkpfl +Latitude+Longitude
+SST+offset(log(Hooks)), data = ShalSetStdnData, init.theta = 4.76586034, link = log)

Deviance Residuals:

    Min       1Q     Median      3Q      Max

-3.8872  -0.8480  -0.1471   0.5189   4.1814

Coefficients:

                      Estimate   Std. Error   t value Pr(>|t|)

(Intercept)         -8.6392696  0.2114137 -40.864  < 2e-16 ***

Haulyr11996          0.0476042  0.0488156   0.975 0.329488

Haulyr11997          0.0953622  0.0503790   1.893 0.058395 .

Haulyr11998          0.0682725  0.0515400   1.325 0.185312

Haulyr11999          0.1260594  0.0557352   2.262 0.023730 *

Haulyr12000          0.3200168  0.0486174   6.582 4.82e-11 ***

Haulyr12005          0.2454391  0.0395530   6.205 5.64e-10 ***

Haulyr12006          0.3462524  0.0418690   8.270  < 2e-16 ***

Haulyr12007          0.1995672  0.0394259   5.062 4.21e-07 ***

Haulyr12008          0.1466663  0.0399986   3.667 0.000247 ***

Haulyr12009         -0.0386694  0.0398123  -0.971 0.331422

Haulyr12010         -0.2029869  0.0396556  -5.119 3.12e-07 ***

Haulyr12011         -0.0721569  0.0414183  -1.742 0.081507 .

Haulyr12012         -0.1534487  0.0422012  -3.636 0.000278 ***
```

Table AII.1, continued.

Quarter12	-0.0706928	0.0175267	-4.033	5.53e-05	***
Quarter13	-0.4434931	0.0355927	-12.460	< 2e-16	***
Quarter14	-0.2530610	0.0244302	-10.359	< 2e-16	***
BSfactor[400,800)	-0.7314207	0.2884497	-2.536	0.011235	*
BSfactor[800,1200)	1.1395540	0.2886489	3.948	7.93e-05	***
BSfactor[1.200,1.600)	1.3861788	0.1863002	7.441	1.07e-13	***
BSfactor[1600,2000)	1.7297582	0.0802929	21.543	< 2e-16	***
BSfactor[2000,2400)	1.7397366	0.0802697	21.674	< 2e-16	***
Hkpfl	-0.1150322	0.0072609	-15.843	< 2e-16	***
Latitude	0.0393356	0.0030789	12.776	< 2e-16	***
Longitude	-0.0138116	0.0008489	-16.269	< 2e-16	***
SST	-0.0140149	0.0040526	-3.458	0.000546	***

(Dispersion parameter for Negative Binomial(4.7659) family taken to be 1.012593)

Null deviance: 18194 on 12228 degrees of freedom

Residual deviance: 13142 on 12203 degrees of freedom

AIC: 77379

Number of Fisher Scoring iterations: 1