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Catch Statistics, Size Compositions, and CPUE Standardizations for Blue Marlin *Makaira nigricans* in the Hawaii-based Pelagic Longline Fishery in 1995-2011[1]

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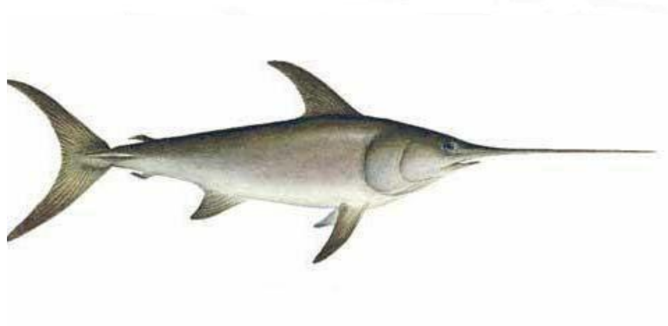

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Catch Statistics, Size Composition, and CPUE Standardizations for Blue Marlin *Makaira nigricans* in the Hawaii-based Pelagic Longline Fishery in 1995–2011

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Abstract

This working paper presents catch statistics, catch maps, catch-per-unit-effort (CPUE) standardizations, and size data for blue marlin *Makaira nigricans* in the Hawaii-based pelagic longline fishery in 1995–2011 using data from the Pacific Islands Regional Observer Program (PIROP) in support of the stock assessment activities of the ISC Billfish Working Group (BILLWG). The largest fraction of the observed blue marlin catch (40.3%) was taken from 10–20°N and 160–180°W. The nominal blue marlin CPUE decreased by 69.9% from 1995 through 2011, reflecting an increase from 69.5% to 85.2% in zero catches and a decrease in positive catches from 30.5% to 14.8%. CPUE was standardized with five generalized linear models (GLMs) in which years, calendar quarters, fishery sectors, fishing regions, and bait types were significant factor variables and sea surface temperature (SST) and vessel length were significant continuous variables. The best fitting model, selected on the basis of its Akaike Information Criterion (AIC), was the zero-inflated negative binomial GLM (ZINB). Annual effect coefficients from all models were plotted as indices of relative abundance; downward trends early in the time series that reflected both a high level of observer effort in the shallow-set sector in 1995 and strong recruitment in 1997 were followed by rough stability since 2002. The ZINB was used to predict standardized CPUE under specified conditions (e.g., quarterly mean SST; mean vessel length; 1000 hooks). Most of these predicted trends appeared relatively constant. We conclude that the nominal fishery-wide decreases in catch rates in 1995–2011 reflect changes in observer coverage and effects of extrinsic factors, and that blue marlin population status in its core area of tropical waters has been roughly stable during that interval.

Introduction

This working paper (WP) presents catch statistics, catch maps, catch-per-unit-effort (CPUE) standardizations, and compilations of size data for blue marlin *Makaira nigricans* in the Hawaii-based pelagic longline fishery in 1995–2011. A stock assessment for striped marlin *Kajikia audax* was recently conducted (Lee et al. 2012) under the auspices of the ISC Billfish Working Group (BILLWG). Blue marlin is the next species scheduled for a BILLWG stock assessment, and the results presented herein are intended as input to it.

The data used for this WP were collected by fishery observers of the Pacific Islands Regional Observer Program (PIROP). The PIROP is now the largest pelagic observer program for longline fisheries in the Pacific Ocean (Walsh et al. 2009).

Blue marlin, the most tropical of the istiophorid billfishes (Nakamura 2001), is believed to comprise a single stock in the Pacific Ocean (Graves and McDowell 2003). This species can attain great size (Heemstra 1986; Nakamura 2001), with the largest females reaching 900 kg. This species is retained for human consumption in many locales (Nakamura 2001) including Hawaii. Blue marlin is an apex predator, but ecological simulations suggest that it could recover relatively quickly after removal of fishing mortality (Kitchill et al. 2005). A brief introduction to blue marlin biology and Pacific Ocean blue marlin fisheries is presented on the BILLWG web page: http://isc.ac.affrc.go.jp.working_groups/billfish_blue_marlin.html.

The CPUE standardizations in this WP are of particular interest. Several generalized linear model analyses (GLMs) were recently conducted using catch and operational data collected by fishery observers for oceanic whitetip shark *Carcharhinus longimanus*. The GLMs were then used to develop multi-model inference techniques for a shark bycatch species caught in low numbers (Brodziak and Walsh, in preparation). This WP presents five CPUE standardization analyses for a large, highly migratory pelagic teleost taken in low numbers, but which is also ecologically important, recreationally prized, and economically valuable as incidental catch.

A companion WP (Walsh 2013; ISC BILLWG WP **#?)** summarizes a corrected catch history for blue marlin in Hawaiian waters in 1948–2011, including some recreational and other catch. These documents in tandem should provide much of the information from the Hawaii-based pelagic longline fishery required for the stock assessment. Our presentation is intended to provide the BILLWG with the requisite descriptive and inferential statistical information for the assessment in a format that should ensure full understanding of the results from this fishery. Therefore, detailed methodology and results, full output of the selected CPUE standardization model, and appendices with analytical diagnostics are included.

Methods

Fishery description

A brief summary of the historical aspects of longline fishing in Hawaii was presented in Walsh and Ito (2011). The document summarizes the means of data acquisition, compilation, and archival of catch data for billfishes from 1948 through 2009. An additional summary is presented in Boggs and Ito (1993).

The data used herein included species-specific catch tallies and operational (e.g., position, number of hooks deployed, set and haul times) descriptors from each longline set (Pacific Islands Regional Office, 2009). Sea surface temperature (SST) data used in the analyses were weekly mean values measured by an advanced, very high resolution radiometer borne by a NOAA satellite. Because the observers receive specialized training at the outset of employment and undergo debriefings after trips, their records were expected to be generally accurate. Nonetheless, the observer data were screened to ensure accuracy by both the observer program and ourselves prior to use in model fitting.

The levels of observer coverage and the pattern of observer allocation changed considerably between March 1994 and February 2004, as described in Walsh et al. (2007). The former increased from 4.7% of fleet-wide effort in 1995, the first full year of the study in which 40.9% of the active vessels carried an observer at least once, to 21.7% in 2003, when 95.5% of the vessels carried an observer at least once and 82.7% twice or more. The initial allocation pattern in 1994 emphasized coverage of swordfishtrips because high interaction rates with sea turtles were expected. As of 1995, however, observer allocation was altered to approximate fleet-wide activity more closely. In 2002−2003, all observed trips targeted bigeye tuna because the shallow-set sector was closed.

A substantial fraction of fishing effort (16.3%) was located north of 30°N in 1994. By 2003, however, only 4.5% of the longline sets were deployed at these latitudes, which reflected a series of management decisions (Walsh et al. 2007). Specifically, swordfish-targeted effort by this fishery was prohibited in April 2001 so as to minimize interactions between longline gear and threatened or endangered sea turtles. This caused a southward shift in effort away from areas where surface waters had previously been fished for swordfish, *Xiphias gladius*, to subsurface depths as the fleet began to target bigeye tuna almost exclusively. In addition to this change in locale, observed trips that targeted bigeye tuna were also characterized by a 60.4% increase in hook numbers per set between March 1994 and February 2004. In general, this fleet moves seasonally to remain near the 26°C SST isotherm to target bigeye tuna (personal communication, W.A.E. Machado, NOAA Fisheries, PIFSC). The shallow-set sector was re-opened in 2004; activity in this sector tends to be concentrated in the first and fourth quarters of the year at relatively high latitudes (Walsh et al. 2009).

Descriptive statistics

Catches, fishing effort (i.e., numbers of longline sets), catches per longline set, and nominal CPUE are tabulated by fishery sectors, calendar quarters, and fishing regions (see Footnote 1, below). Maps of catches and nominal CPUE are presented on 5°×5° squares. This tabulation and these maps use data from all years pooled.

Percentages of released blue marlin from the PIROP observers are also presented. Estimates of mortality from capture stress were calculated from the condition of the fish upon retrieval.

CPUE standardizations

Catch and operational data collected by the PIROP were used to fit GLMs in order to standardize blue marlin CPUE. Five types of GLM analyses (delta lognormal; Poisson; negative; zero-inflated Poisson; zero-inflated negative binomial) were computed and their standardized CPUE trends compared. Because the number of degrees of freedom was large (> 51,000), explanatory variables were required to reduce the null deviance by at least 0.25% and reduce the Akaike Information Criterion (AIC) to be retained in any GLM (Maunder and Punt 2004).

The candidate factor variables included the years, calendar quarters, set types (i.e., deep or shallow, corresponding to the two fishery sectors), eight fishing regions[1], and six bait types[2]. The candidate continuous variables included the sea-surface temperature (SST; °C), the vessel length (ft), and the begin-set time (HST). The SST data were weekly mean values measured by an advanced, very high resolution radiometer borne by a NOAA satellite (Walsh et al. 2007). The vessel length was tested because the smallest vessels in this longline fleet may be unable to reach tropical waters. The begin-set time was tested to indicate whether gear deployment had proceeded normally. Several hook types and leader materials were also tested as factor variables, and bathymetry (average depths at 1°×1° resolution) was tested as a continuous variable, but none was significant, so they were not used in the standardizations.

The delta-lognormal analysis entailed fitting a binomial GLM of the probability of positive catch and a lognormal GLM of CPUE on sets with positive catch. The Poisson and negative binomial GLM analyses were conducted according to procedures in Crawley (2007). The zero-inflated analyses follow procedures in Zuur et al. (2009).

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[1]Region 1: 0–10°N, east of 160°W; Region 2: 0–10°N, west of 160°W; Region 3:10–20°N, east of 160°W; Region 4: 10–20°N, west of 160°W; Region 5:20–30°N, east of 160°W; Region 6:20–30°N, west of 160°W; Region 7: above 30°N, east of 160°W; Region 8: above 30°N, west of 160°W. These correspond to the fishing regions in Brodziak and Walsh (in preparation).

[2] Pacific Islands Regional Office. 2009. Hawaii Longline Observer Program Observer Field Manual. National Oceanic and Atmospheric Administration, Pacific Islands Region, Honolulu, Hawaii. See Chapter 6 of this manual for descriptions of bait types and other gear (e.g., hook types and leader materials).

The models were fitted by forward selection, with results presented in summary analysis of deviance tables. Temporal trends were the principal interest, so yearly and quarterly effects were tested first (and entered if significant). The spatial effects were expected to be important, so the fishing regions were the third entry. The set types were then entered because these represent the basis for management of this fishery. The bait types were then tested as the remaining factor variable, followed by the continuous variables and interactions.

The best fitting model was chosen on the basis of the Akaike Information Criterion (AIC). The full output from the R 'summary' function for the delta lognormal model and the selected model, along with several types of residuals plots, is provided in Appendices I and II.

Annual effect coefficients from the various models are plotted as indices of relative abundance. The precision of the year effect from the delta-log-normal model was estimated by using a bootstrapping approach (Vignaux 1994) and the results are presented in Appendix III. Contrasts of yearly coefficients and the reference year were planned, so the significance criterion used was $P<0.05$. To the extent possible, contrasts of the coefficients of other explanatory variables were based upon *a priori* expectations derived either from knowledge of blue marlin biology or experience in this fishery. However, some contrasts were exploratory in nature, so the Type 1 error probabilities were maintained at $P \leq 0.05$ by application of the Bonferroni principle.

Predictions of standardized CPUE trends

Standardized CPUE trends were predicted by applying model coefficients to new data sets comprised of the fishing years, specific factor levels, and mean values of continuous variables typical of some particular circumstances (e.g., Region 4 in Quarter 4 on deep sets). This entailed applying the coefficients to a matrix, with a first column of 1995–2011 and the other columns consisting of constants repeated 17 times. Several combinations of factor variables, as well as SST within factor levels were used to prepare these new data sets. The mean annual effects were predicted as the standardized CPUE trends and plotted to illustrate the effects of the various explanatory variables. These results were generated with the "predict" function in R, specifying "data=newdata" (see Crawley, 2007, p. 580).

Compilation of size frequencies

Blue marlin size data (eye to fork lengths: EFL) were compiled from observer measurements taken throughout the study period. The data were archived separately for the years until early in 2003 and thereafter. As such, tabulations and size frequency distributions are provided for all data, within periods for both sectors, and within periods by sectors. The measurements were transformed to natural logarithms and evaluated with *t*-tests to determine whether mean sizes differed significantly between periods within sectors or between sectors within periods. The annual mean eye-fork lengths from the entire fishery and in the two sectors were also plotted against time to reveal any possible trend of decreasing sizes.

Results

Descriptive observed catch statistics

The total observed catch was 12,629 blue marlin. These fish were taken on 51,530 observed sets, deployed on 3,825 trips from January 1995 through December 2011. The mean (±SD) nominal catch per set and CPUE were 0.25±0.71 and 0.14±0.50, respectively.

Observed blue marlin catch rates (Figure 1) varied considerably on a quarterly basis, with the highest catches in summer and autumn. The annual mean observed catch per set (Figure 1.1) decreased by 69.8% between 1995 and 2011 (Figure 1), an average of 4.1% per year; the decrease in the annual mean nominal CPUE during this interval was 84.3% (Figure 1.2) or 5.0% per year. These nominal decreases reflected two trends: zero catches increased from 69.5% to 85.2%, while nominal CPUE on sets with positive catches decreased concomitantly from 1.96/1000 hooks to 0.63/1000 hooks (Figure 2).

The large majority (84.5%) of observed sets caught zero blue marlin (Figure 3). Catches of one or two blue marlin comprised 73.7% of the observed blue marlin catch.

Multiple catches per set occurred less frequently over time. In 1995–1997 and again in 2000, 10.9%–13.7% of the observed sets yielded ≥2 blue marlin. By 2002 and thereafter, 2.2%–6.6% of the observed sets yielded ≥2 blue marlin.

Tables 1.1−1.3 present observed set totals and catches, catches per longline set, and nominal CPUE, respectively, sorted by fishery sectors, calendar quarters, and fishing regions. Most (77.4%) observed sets were deployed in the deep-set sector, with 70.3% in Regions 3−6, and most (85.1%) of the observed blue marlin catch was taken by the deep-set sector (Table 1.1). However, the mean nominal CPUE was greater in the shallow-set (0.183/1000 hooks) than in the deep-set sector (0.133/1000 hooks). Most (63.6%) blue marlin were caught in the second and third calendar quarters.

The catch from the deep-set sector in Region 4 comprised 40.3% of the observed total (Table 1.1); the largest quarterly catches in this sector and region exceeded those in all other regions and quarters. The largest catch in the shallow-set sector was taken in Region 5 in the fourth quarter.

The catches per observed longline set (Table 1.2) were highly variable in both fishery sectors. The standard deviation was always greater than the mean catch per set in the deep-set sector and in the shallow-set sector except in Region 3 during the third and fourth quarters and Region 4 during the third quarter.

Nominal CPUE (Table 1.3) was similarly variable. The standard deviation was always greater than the mean in the deep-set sector and in 14 of the 22 region×quarter combinations in the shallow-set sector.

The catch and CPUE spatial patterns are presented as Figures 4.1 and 4.2, respectively. The largest catch (Figure 4.1) was taken in Region 4, particularly from 15–20°N and 160–165°W. There were substantial catches all around the Main Hawaiian Islands. Small catches below 10°N and above 30°N reflected a low level of fishing effort and low SST, respectively.

The general pattern in the CPUE map (Figure 4.2) is increase in a southwesterly direction. The large CPUE from 0–5°N and 150–155°W represents 44 blue marlin taken on 17 sets (Table 1.1).

CPUE standardizations

The blue marlin CPUE standardizations are summarized in Tables 2.1–2.5. The order of presentation is the delta-lognormal analysis (the mixture model), the two counts models (Poisson; negative binomial), and the two zero-inflated models (zero-inflated Poisson; zero-inflated negative binomial).

The binomial model within the delta lognormal analysis (Table 2.1.1) included significant effects of all five factor variables, with quarters, regions, and set types yielding large deviance reductions per degree of freedom, a continuous, positive effect of SST that yielded the largest deviance reduction per degree of freedom, and four interactions. Three interactions between factor variables yielded small deviance reductions per degree of freedom. The other, stronger interactive effect was that between the set types (factor) and hooks per float (continuous). This interaction was tested because a relatively large range of hooks per float is used in the deep-set sector (15–53), and increasing hook numbers weighs down the longline gear. The deep-set sector coefficient was negative (-0.05849) and highly significant (P<2e-16), whereas that for the shallow-set sector, with less than 15 hooks per float, was not significant (P = 0.184). This model with 121 parameters explained 15.7% of the deviance of the probability of a blue marlin catch.

The lognormal model in the delta lognormal analysis (Table 2.1.2) included 119 parameters and explained 65.3% of the deviance of CPUE on sets with positive catches (N=8532). The set types were the preponderant influence, yielding almost half (32.2%) of the deviance explanation. The SST was not retained in the lognormal model because its deviance reduction (0.18%) did not meet the requirements of the stopping rule. This model explained 65.4% of the deviance of blue marlin CPUE on sets with positive catches. Appendix I contains delta lognormal diagnostics.

The Poisson model of blue marlin catch per set included five factor variables, three continuous variables, and three significant interactions (Table 2.2). The set types and SST were strong predictors that yielded large deviance reductions per degree of freedom. The set type effect was associated with greater catch rates in the shallow-set sector, while SST had a direct, continuous effect. Quarters and the fishing regions were the other predictors with strong effects. This model explained 28.1% of the deviance of blue marlin catch per set.

Fitting results with the negative binomial model (Table 2.3), the other counts model, were similar in most respects to those from the Poisson model. The set types and SST again exerted the strongest effects; quarters and regions also had strong effects per degree of freedom. The begin-set time did not reduce the deviance sufficiently to be retained in this model, which differed from the Poisson. The *pseudo*-coefficient of determination for this model was 28.7%.

The zero-inflated Poisson (Table 2.4) was fitted with five factor variables, two continuous variables, and four interactions in the counts model, and four factor variables in the zeros model. All four factors yielded AIC reductions in the counts model. SST and vessel length exerted positive effects as continuous variables. The significance of the set type×hooks per float interaction again reflected the results in the deep-set sector.

The zeros model was fitted with the four factors, and all again yielded AIC reductions. All of these reductions were less than the corresponding values in the counts model.

The zero-inflated negative binomial model (Table 2.5) consisted of a counts model with five factor variables, two continuous variables, and three interactions, and a zeros model with two factor variables, two continuous variables, and an interaction. Several attempts to fit a zeros model with additional factor variables did not converge. Appendix II presents diagnostics for this model.

In the counts model (Table A1), the 1996 annual effect coefficient was significantly greater than the reference year 1995 (P=2.18e-08), while the 1997 (P=0.051) and 1998 (P=0.063) coefficients were marginally greater and the 2010 (P=0.078) and 2011 (P=0.041) were marginally less than the reference year. The AIC reductions (Table 2.5) demonstrated that the quarterly, regional, and set type effects on catches per set were highly significant. The bait types affected catches significantly (Table A1), with all types of fish and "other" baits yielding significantly lower catches than squid baits (all contrasts: $P \leq$1.0e-.04). SST had a significant, positive effect on catch per set. The set type×hooks per float interaction had a significant negative coefficient for the deep-set sector, which indicated that the catch per set would vary inversely with the hooks per float, but had no significant effect in the shallow-set sector.

The zeros model included the fishing years and bait types as factor variables, SST and vessel length as continuous variables, and the set type×hooks per float interaction. All AIC reductions were smaller than the corresponding values in the counts model. The yearly effect coefficients (Table A1) exhibited a pattern: five coefficients from 1996–2001 were significant and positive, whereas five from 2005–2011 were significant and negative, but the 2006 and 2010 values were extremely imprecise. The SST coefficient was significant and negative in this model (-0.44477; P < 2e-16; Table A1), indicating that the probability of false zeros was inversely related to temperature. The set type:hooks per float interaction again had a significant negative coefficient for the deep-set sector, which indicated that the probability of a false zero would vary inversely with hooks per float. In other words, zero catches in the deep set sector associated with large numbers of hooks per float were probably real zeros because the gear was too deep to capture surface-associated fish. The bait type coefficients (Table A1) indicated that the probability of false zeros was not different between large and small squid ($P > 0.10$), but the coefficients for all other baits were positive and very highly significant (five z-tests: all $P < 1.00e\text{-}08$), which meant that use of these baits was associated with greater probabilities of false zeros.

Model selection

A compilation of selection criteria for the CPUE standardization model (Table 3) demonstrated that both zero-inflated models were preferable to the corresponding counts model, and that the zero-inflated negative binomial model yielded a better fit than the zero-inflated Poisson model. The model AIC and the ΔAIC underlay this selection.

Likelihood ratio tests (Table 3) demonstrated that both zero-inflated models fit the catch per set data better than the corresponding models. The test result for the zero-inflated negative binomial model indicated that it was a better fitting model than the zero-inflated Poisson.

Standardized CPUE trends

The mean annual effects from all these models are plotted as indices of relative abundance along with the nominal CPUE in Figure 5. A downward trend in the counts models (Figure 5.1) was apparent early in the time series, stabilizing around 2002. The zero-inflated negative binomial and negative binomial values for 1997 were higher than the Poisson values. The delta lognormal and nominal CPUE traces (Figure 5.2) have been almost identical since 2002.

Plots of standardized CPUE under a variety of conditions are presented in Figure 6. In Figure 6.1, standardized CPUE in the core area (Region 4) at the mean SST (27°C) for the four calendar quarters is presented; since the stabilization of the standardized CPUE trace, the estimated quarterly effect is about a two-fold range.

Appendix III presents standardized CPUE from the delta lognormal model by calendar quarters with 95% confidence intervals. The latter were obtained by a bootstrapping procedure (Figure A3.1). The results are similar to those from the zero-inflated negative binomial model. The greatest uncertainty was observed around 1999 when observer effort was at its minimum. In all quarters, the coefficients of variation (CV) were greater before 2000 (Table A3.1), rather than after, because the expansion of the PIROP only began in 2000.

Figure 6.2 depicts set type and hooks per float effects for Region 6, which was chosen to have both sectors. The traces depicting 15 and 35 hooks per float represent the set type×hooks per float interaction. Reducing the number of hooks per float from 25 to 15 had a greater effect than an increase to 35. The standardized CPUE in the shallow-set sector was often considerably greater than all deep set traces. Figure 6.3 illustrates lower standardized CPUE attained with sardines than with either sauries or mackerel, which did not differ. The effect of variation in SST (10^{th}, mean, 90^{th} percentiles) in the core area was about a 20% increase over the test range.

The pair-wise correlations and angular deviations among the nominal and standardized CPUE vectors (Table 4) demonstrated that the counts models were very similar, with high correlations (0.995–0.999) and small angular deviations (< 3°). The nominal CPUE and delta lognormal vectors were also highly correlated (0.991) with a small angular deviation (5°).

Blue marlin size composition

Eye-fork length (EFL) measurements (cm) from two sampling periods (1995 until early 2003; mid-2003 through 2011) are summarized by fishery sectors, calendar quarters, and fishing regions in Tables 4.1 and 4.2, respectively. The two fishery sectors differ in geographic expanse. Consequently, there are no measurements for the shallow-set sector from Regions 1 and 2 and only 33 blue marlin EFL measurements from Regions 7 and 8 for the deep-set sector.

The largest samples (106–190 blue marlin EFL) for the shallow-set sector from 1995 until early 2003 were obtained during the third quarter in Regions 3, 4, and 6 (Table 4.1). Since mid-2003, the only large sample (398 blue marlin EFL) was obtained during the second quarter in Region 2 (Table 4.2).

Sample sizes were 167–821 and 313–831 blue marlin EFL for the deep-set sector in Region 4 from 1995 until early 2003 (Table 4.1) and from mid-2003 through 2011 (Table 4.2). It was noteworthy that the two largest samples (821; 831) were obtained in Region 4 during the second quarters of the two periods, and the means from the two periods were equal (164.1 cm EFL).

Figure 7 illustrates the temporal pattern in the annual mean eye-fork length measurements. The trend in mean size has been slightly positive.

EFL measurements (Figure 8) are depicted in histograms (Figures 8.1−8.6) for several combinations of fishery sectors and sampling periods. The between-period difference in the deep-set sector was not significant ($P = 0.09$), but it was significant in the shallow-set sector ($P = 2.871e\text{-}07$). The between-sector within periods differences were highly significant (two *t*-tests: both $P < 2.2e\text{-}16$).

Discussion

Data evaluation

This WP summarizes data collected by PIROP fishery observers about blue marlin in the Hawaii-based pelagic longline fishery over a 17-year period for use in the 2013 stock assessment. These data are believed to be accurate and the sample size is large (>51,000 sets).

However, the two fishery sectors do not overlap fully, neither sector exploits the full expanse of the fishery, and the shallow-set sector underwent a closure in the midst of the time series.

The catch, distributional, and size data are presented with the years pooled and relatively large regions defined. Despite this level of organization, there are many data cells with few longline sets or none at all (Table 1.1).

Distribution of blue marlin

The results concerning the distribution of blue marlin in this fishery (Table 1.2; 1.3; Figure 4.2; Figure 4.3), with relatively high catches in tropical and subtropical waters in the warmer seasons, were consistent with expectations for this species, described as the most tropical istiophorid and largely confined to waters above the 24°C surface isotherm (Nakamura 1985). Walsh et al. (2005) fitted a generalized additive model to PIROP data from March 1994–June 2002 (i.e., 6.5 years overlap with this study), with the SST effect expressed by an upward trending smoother trace from 23–30°C.

CPUE standardizations

The CPUE standardizations were conducted by five methods, and in every case, the annual effects were very significant but were not the predominant influences on the probability of a blue marlin catch, blue marlin catch per set, or blue marlin CPUE. The deviance and AIC reductions per degree of freedom in the binomial model, both counts models, and both zero-inflated models indicated that SST and the set types were the stronger influences.

SST yielded the largest deviance reduction per degree of freedom in the binomial model within the delta lognormal analysis. This indicated that the probability of catching a blue marlin varied directly with SST, consistent with the premise that warm, tropical waters are the most suitable habitat for this species. SST did not yield a sufficient deviance reduction to warrant its retention in the lognormal model, which indicated that catch rate was essentially independent of SST within the suitable habitat.

Both zero-inflated models fit the catch per set data than the corresponding models, and the zero-inflated negative binomial fit the data better than the zero-inflated Poisson model. These results indicated that the numbers of zeros were significantly greater than expected with the Poisson or negative binomial distributions, and in the zero-inflated context, the more dispersed negative binomial was the better fitting model. This better fit was attained despite having fewer explanatory variables in its zeros model than the zero-inflated Poisson because more complex models did not converge.

The zero-inflated negative binomial model consisted of the counts model and a zeros model that included annual effects, another manipulable factor variable (i.e., bait types), two easily modeled continuous variables, and a readily comprehensible interaction. As such, the best fit to the catch per set data was explicable in light of operational experience.

The significant negative coefficients for several years between 2005 and 2011 in the zeros model (Table A2.1), representing low probabilities of false zeros, may reflect shallow-set activity and associated observer coverage in Region 7 in the first and fourth quarters after the re-opening of this sector in 2004. Such activity comprised 11.6% all sets, but caught only 1.5% of the blue marlin during these years. These were probably real zeros because the habitat was unsuitable.

The SST coefficients provided insight into both the catches and the probabilities of false zeroes, with significant positive and negative coefficients in the counts and zeros models, respectively (Table A1). Thus, zeros recorded in the suitable, warm tropical habitat were probably real zeros, but those from the northern regions or cooler seasons may have been false zeros. This is important because 58.1% of the observed sets in the shallow-set sector since 2005 were deployed in the first and fourth quarters at a mean SST of 18.8°.

Several bait types also had significant coefficients with opposite signs in the counts and zeros models of the zero-inflated negative binomial model. The fish and other baits had significant negative coefficients in the counts model, representing lower catch rates, and significant positive coefficients in the zeros model, representing increased probabilities of false zeros, perhaps attributable to some unattractive property or properties of these baits.

Vessel length had a significant negative coefficient in the zeros model, but was not significant in the counts model. The latter suggested that larger vessels were able to reach and then fish in the suitable habitat more effectively than smaller vessels in this longline fleet.

The set type×hooks per float interaction had a significant negative coefficient for the deep-set sector in both models. This inverse relationship meant that zero catches in the deep set sector associated with large numbers of hooks per float were probably real zeros because the gear was too deep to capture surface-associated fish.

Brodziak and Walsh (in preparation) have presented a multi-model inference study with oceanic whitetip shark; this study has begun to investigate most of the same types of models with blue marlin. This extension of the previous work is logical because the oceanic whitetip shark, a bycatch species, and blue marlin, an incidental catch species, have similarly large numbers of zeros in the catches (*ca*. 85%). The blue marlin catch data have provided a second opportunity to assess and compare zero-inflated and other models for CPUE standardization, which is expected to prove useful because the models reflect different underlying hypotheses about the capture process (Brodziak and Walsh, in preparation).

Indices of relative abundance

The relative abundance indices were higher in the early years of the time series, and at least two factors contributed thereto. The observer coverage in 1995 was weighted more heavily toward the shallow-set sector than in any other year; also, the catch of blue marlin in 1997 was exceptionally large and dominated by fish that were significantly smaller than blue marlin in the comparable season in all other years (Walsh et al. 2005; 2007). The indices have been approximately stable since 2002.

The standardized CPUE plots also exhibit the effect of recruitment, but most were relatively flat thereafter. The factor variable and the SST effect plots demonstrate that variation in extrinsic factors altered standardized CPUE but usually in parallel.

Sizes of blue marlin

There was no evident decrease in the sizes of blue marlin measured by observers in this fishery between 1995 and 2011. The difference within sectors between periods was statistically but probably not biologically significant. The slight trend in mean size was positive. Because the sampling protocols were revised in 2003, the most appropriate interpretation is probably that the size composition has remained stable.

Management considerations

If present trends continue and shallow-set activity is conducted primarily in the colder months at relatively low SST, it is likely that shallow-set catches of blue marlin will be very low. If reduction of incidental blue marlin catches were defined as an objective, the current activity pattern in the shallow-set sector would comport with it.

Conclusions

The observed catch, nominal CPUE, and size data have been presented in a format that should be appropriate for the stock assessment. Small numbers of longline sets and size measurements in various circumstances will require consideration.

Five standardizations of blue marlin CPUE should permit the BILLWG to make a well-informed decision regarding the choice of indices for the stock assessment.

The standardizations should also prove useful because these analyses were conducted with an incidentally caught, economically valuable teleost, while recent analyses using these models were conducted with a bycatch species, oceanic whitetip shark. Because both species have similarly high percentages of zero catches, and because these models represent different hypotheses about the capture process (Brodziak and Walsh, in preparation), analyses such as these should increase understanding of the capture process for non-target species.

The zero-inflated negative binomial model provided the best fit to the catch per set data. This model is appropriate if overdispersion characterizes both the binomial and counts components.

In the case of blue marlin, overdispersion probably reflects the relatively low abundance expected of an apex predator, its solitary behavior, the distance from Hawaii to the most suitable tropical habitat, and the lack of targeting in this fishery.

The coefficients for the significant explanatory variables in the zero-inflated negative binomial model seemed comprehensible in light of blue marlin biology or experience in this fishery. Therefore, this model is realistic to some extent, albeit unknown.

The plots of standardized CPUE from the core area indicated that blue marlin population status in the Hawaii-based pelagic longline fishery has been approximately stable during 1995–2011.

Diagnostics plots from the delta lognormal and zero-inflated negative binomial analyses did not reveal patterns indicative of serious analytical problems.

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Table 1.1. Summary of observed longline sets (upper cell entries) and blue marlin *Makaira nigricans* catches (lower cell entries) in the Hawaii-based longline fishery in 1995–2011. Entries are the longline set and catch totals sorted by regions, fishery sectors, and calendar quarters. Data from all years are pooled. See text for fishing region and fishery sector definitions.

	Fishing Regions							
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Deep-set Sector								
Quarter 1	35 sets 20 caught	477 sets 158 caught	1888 sets 282 caught	2660 sets 863 caught	2131 sets 99 caught	1253 sets 161 caught	11 sets 0 caught	33 sets 0 caught
Quarter 2	92 sets 24 caught	416 sets 157 caught	2071 sets 541 caught	3671 sets 2370 caught	1872 sets 166 caught	952 sets 387 caught	59 sets 2 caught	93 sets 19 caught
Quarter 3	95 sets 62 caught	292 sets 325 caught	1090 sets 511 caught	1522 sets 1009 caught	4485 sets 517 caught	579 sets 182 caught	1237 sets 105 caught	492 sets 60 caught
Quarter 4	17 sets 44 caught	175 sets 158 caught	1915 sets 351 caught	1758 sets 849 caught	6085 sets 734 caught	2289 sets 553 caught	86 sets 10 caught	67 sets 31 caught
Shallow-set sector								
Quarter 1	0 sets	0 sets	0 sets	0 sets	391 sets 15 caught	705 sets 21 caught	3836 sets 50 caught	654 sets 14 caught
Quarter 2	0 sets	0 sets	22 sets 20 caught	5 sets 6 caught	1453 sets 231 caught	2114 sets 768 caught	248 sets 3 caught	297 sets 5 caught
Quarter 3	0 sets	0 sets	90 sets 165 caught	26 sets 124 caught	107 sets 70 caught	78 sets 115 caught	42 sets 5 caught	426 sets 79 caught
Quarter 4	0 sets	0 sets	7 sets 27 caught	9 sets 13 caught	86 sets 111 caught	39 sets 15 caught	934 sets 20 caught	63 sets 2 caught

Table 1.2. Summary of observed blue marlin *Makaira nigricans* catches per set in the Hawaii-based longline fishery in 1995–2011. Entries are means and standard deviations sorted by regions, fishery sectors, and calendar quarters. Data from all years are pooled. See text for fishing region and fishery sector definitions. “NA” denotes “Not available”.

	Fishing Regions							
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Deep-set Sector								
Quarter 1	0.571 ± 0.739	0.331 ± 0.673	0.149 ± 0.468	0.324 ± 0.686	0.046 ± 0.267	0.128 ± 0.431	0.000	0.000
Quarter 2	0.261 ± 0.466	0.377 ± 0.734	0.261 ± 0.609	0.646 ± 0.988	0.089 ± 0.333	0.407 ± 0.790	0.034 ± 0.182	0.204 ± 0.431
Quarter 3	0.653 ± 1.549	1.113 ± 1.503	0.469 ± 0.950	0.663 ± 0.974	0.115 ± 0.366	0.314 ± 0.684	0.085 ± 0.327	0.122 ± 0.425
Quarter 4	2.588 ± 2.980	0.903 ± 1.276	0.183 ± 0.483	0.483 ± 0.913	0.121 ± 0.476	0.242 ± 1.006	0.116 ± 0.389	0.463 ± 1.385
Shallow-set Sector								
Quarter 1	NA	NA	NA	NA	0.038 ± 0.192	0.030 ± 0.186	0.013 ± 0.126	0.021 ± 0.165
Quarter 2	NA	NA	0.909 ± 1.306	1.200 ± 1.304	0.159 ± 0.478	0.363 ± 0.881	0.012 ± 0.110	0.017 ± 0.129
Quarter 3	NA	NA	1.833 ± 1.750	4.769 ± 3.912	0.654 ± 1.245	1.474 ± 2.516	0.119 ± 0.328	0.185 ± 0.476
Quarter 4	NA	NA	3.857 ± 3.237	1.444 ± 1.667	1.474 ± 1.946	0.119 ± 0.590	0.021 ± 0.159	0.032 ± 0.177

Table 1.3. Summary of observed blue marlin *Makaira nigricans* nominal CPUE from the Hawaii-based longline fishery in 1995–2011. Entries are means and standard deviations sorted by regions, fishery sectors, and calendar quarters. Data from all years are pooled. See text for fishing region and fishery sector definitions. "NA" denotes "Not available".

Fishing Regions								
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Deep-set Sector								
Quarter 1	0.258 ± 0.332	0.155 ± 0.310	0.074 ± 0.231	0.152 ± 0.328	0.023 ± 0.134	0.065 ± 0.265	0.000	0.000
Quarter 2	0.122 ± 0.218	0.172 ± 0.346	0.138 ± 0.345	0.318 ± 0.516	0.041 ± 0.152	0.210 ± 0.464	0.016 ± 0.088	0.089 ± 0.191
Quarter 3	0.381 ± 1.184	0.569 ± 0.791	0.270 ± 0.691	0.324 ± 0.486	0.054 ± 0.172	0.154 ± 0.331	0.037 ± 0.143	0.050 ± 0.174
Quarter 4	2.132 ± 2.463	0.465 ± 0.686	0.095 ± 0.256	0.228 ± 0.451	0.058 ± 0.230	0.117 ± 0.473	0.051 ± 0.174	0.236 ± 0.714
Shallow-set Sector								
Quarter 1	NA	NA	NA	NA	0.045 ± 0.211	0.035 ± 0.187	0.014 ± 0.120	0.025 ± 0.157
Quarter 2	NA	NA	1.168 ± 1.081	1.314 ± 1.146	0.182 ± 0.427	0.400 ± 0.632	0.013 ± 0.113	0.018 ± 0.133
Quarter 3	NA	NA	2.100 ± 1.449	5.616 ± 2.370	0.853 ± 0.924	1.714 ± 1.309	0.107 ± 0.326	0.207 ± 0.454
Quarter 4	NA	NA	4.415 ± 2.101	1.725 ± 1.313	1.452 ± 1.205	0.399 ± 0.632	0.026 ± 0.162	0.042 ± 0.205

Table 2.1. Summary of the delta lognormal GLM variable selection analysis of deviance table. Table 2.1.1 presents the binomial model; Table 2.1.2 presents the lognormal model of positive catches. Table entries include the degrees of freedom associated with each variable (Df), the deviance explained by each variable (ΔDeviance), the deviance explained per degree of freedom (ΔDeviance/Df), the percentage of deviance explained (% Deviance), the *P*-value of the sequential chi-squared test (Pr>|χ2|), the reduction in AIC (ΔAIC), and the median residual at each step of fitting. The null deviance and AIC for the binomial model are 45746.63 and 45748.63, respectively. The null deviance and AIC for the lognormal model are 6068.07 and 21309.21, respectively.

Table 2.1.1: Binomial model

Parameter	Df	ΔDeviance	ΔDeviance/Df	% Deviance	Pr>|χ2|	ΔAIC	Median Deviance Residual
Intercept	1						-0.6055
Years	16	-957.28	-59.83	2.09%	< 2.2e-16	-925.28	-0.5274
Quarters	3	-1227.16	-409.05	2.67%	< 2.2e-16	-1221.16	-0.5169
Regions	7	-3113.44	-444.78	6.81%	< 2.2e-16	-3099.44	-0.4318
Set types	1	-367.52	-367.52	0.80%	< 2.2e-16	-365.52	-0.4321
Bait types	6	-184.47	-30.75	0.40%	< 2.2e-16	-172.47	-0.4247
SST	1	-588.48	-588.48	1.29%	< 2.2e-16	-586.48	-0.4186
Year:Quarter	48	-303.83	-6.33	0.66%	< 2.2e-16	-207.83	-0.4118
Year: Set type	16	-119.51	-7.47	0.26%	< 2.2e-16	-87.51	-0.4111
Quarter:Region	21	-199.71	-9.51	0.44%	< 2.2e-16	-157.71	-0.4100
Set type: Hooks per float	2	-137.98	-68.99	0.30%	< 2.2e-16	-133.98	-0.4090

Table 2.1.2: Lognormal model

Parameter	Df	ΔDeviance	ΔDeviance/Df	% Deviance	Pr>|χ2|	ΔAIC	Median Deviance Residual
Intercept	1						-0.2537
Years	16	-1065.8	-66.61	17.56%	<2.2e-16	-1615.84	-0.1684
Quarters	3	-258.50	-86.17	4.26%	< 2.2e-16	-446.7	-0.1389
Regions	7	-282.71	-40.39	4.66%	< 2.2e-16	-510.25	-0.1119
Set types	1	-1953.72	-1953.72	32.20%	< 2.2e-16	-4913.73	-0.0927
Bait types	6	-81.93	-13.66	1.35%	< 2.2e-16	-271.45	-0.0879
Vessel length	1	-19.40	-19.40	0.32%	< 2.2e-16	-66.53	-0.0932
Year:Quarter	48	-60.92	-1.27	1.00%	< 2.2e-16	-122.82	-0.0907
Year: Set type	16	-83.36	-5.95	1.37%	< 2.2e-16	-280.81	-0.0859
Quarter:Region	21	-56.50	-2.69	0.93%	< 2.2e-16	-173.84	-0.0822
Set type: Hooks per float	2	-104.33	-52.17	1.72%	< 2.2e-16	-409.51	-0.0841

Table 2.2. Summary of the Poisson GLM variable selection analysis of deviance table. Table entries include the degrees of freedom associated with each variable (Df), the deviance explained by each variable (Δ Deviance), the deviance explained per degree of freedom (Δ Deviance/Df), the percentage of deviance explained (% Deviance), the *P*-value of the sequential chi-squared test (Pr>|χ2|), the reduction in AIC (Δ AIC), and the median residual at each step of the fitting process. The null deviance and AIC are 49815.36 and 68860.67, respectively.

Poisson GLM Analysis of Deviance Table

Parameter	Df	Δ Deviance	Δ Deviance/Df	% Deviance	Pr>|χ2|	Δ AIC	Median Pearson Residual
Intercept	1						-0.4934
Years	16	-2610.7	-163.2	5.2%	2.2e-16	-2578.71	-0.4512
Quarters	3	-1873.8	-624.6	3.8%	2.2e-16	-1867.76	-0.4012
Regions	7	-4524.6	-646.4	9.1%	2.2e-16	-4510.61	-0.3352
Set types	1	-1199.0	-1199.0	2.4%	2.2e-16	-1197.02	-0.3327
Bait types	6	-534.2	-89.0	1.1%	2.2e-16	-522.19	-0.3261
SST	1	-1121.9	-1121.9	2.3%	2.2e-16	-1119.88	-0.3175
Begin-set time	1	-168.3	-168.3	0.3%	2.2e-16	-166.31	-0.3187
Vessel length	1	-157.6	-157.6	0.3%	2.2e-16	-155.60	-0.3165
Year:Quarter	48	-694.6	-14.5	1.4%	2.2e-16	-598.56	-0.3085
Year: Set type	16	-373.2	-23.3	0.7%	2.2e-16	-341.16	-0.3073
Quarter:Region	21	-426.2	-20.3	0.9%	2.2e-16	-384.23	-0.3054
Set type: Hooks per float	2	-297.4	-148.7	0.6%	2.2e-16	-293.43	-0.3046

Table 2.3. Summary of the negative binomial GLM variable selection analysis of deviance table. Table entries include the degrees of freedom associated with each variable (Df), the deviance explained by each variable (ΔDeviance), the deviance explained per degree of freedom (ΔDeviance/Df), the percentage of deviance explained (% Deviance), the *P*-value of the sequential chi-squared test (Pr>|χ2|), the reduction in AIC (ΔAIC), the median residual at each step of the fitting process, and the dispersion parameter, *k*. The null deviance and AIC are 25589.75 and 62012.28, respectively.

Parameter	Df	ΔDeviance	ΔDeviance/Df	% Deviance	Pr>|χ2|	ΔAIC	Median Pearson Residual	*k*
Intercept	1						-0.3705	0.303
Years	16	-2108.9	-131.81	5.69%	< 2.2e-16	-1485.87	-0.3629	0.366
Quarters	3	-1610.4	-536.80	4.34%	< 2.2e-16	-1294.09	-0.3401	0.418
Regions	7	-3597.5	-513.93	9.70%	< 2.2e-16	-2951.86	-0.3070	0.610
Set types	1	-825.8	-825.80	2.23%	< 2.2e-16	-702.73	-0.3079	0.687
Bait types	6	-360.5	-60.08	0.97%	< 2.2e-16	-306.72	-0.3029	0.724
SST	1	-804.8	-804.8	2.17%	< 2.2e-16	-734.43	-0.2987	0.816
Vessel length	1	-104.0	-104.0	0.28%	< 2.2e-16	-95.14	-0.2967	0.829
Year:Quarter	48	-478.9	-9.98	1.29%	< 2.2e-16	-352.56	-0.2925	0.909
Year: Set type	16	-232.2	-14.51	0.63%	< 2.2e-16	-189.28	-0.2925	0.961
Quarter:Region	21	-309.4	-14.73	0.83%	< 2.2e-16	-261.54	-0.2915	1.020
Set type: Hooks per float	2	-192.1	-96.05	0.52%	< 2.2e-16	-187.00	-0.2905	1.060

Table 2.4. Summary of the zero-inflated Poisson GLM variable selection analysis of deviance table. Table entries include the degrees of freedom associated with each variable (Df), the *P*-value of the sequential chi-squared test (Pr>|χ2|), the reduction in AIC (ΔAIC), the percent reduction in AIC per degree of freedom, and the median Pearson residual at each fitting step.

Zero-inflated Poisson GLM Analysis of Deviance Table: Counts Model

Parameter	Df	Pr>|χ2|	ΔAIC	ΔAIC/df	Median Pearson Residual
Intercept	1				-0.3992
Years	16	2.2e-16	-1821.58	-113.85	-0.3854
Quarters	3	2.2e-16	-1238.00	-412.67	-0.3593
Regions	7	2.2e-16	-3687.04	-526.72	-0.3296
Set types	1	2.2e-16	-96.8	-96.8	-0.3308
Bait types	6	2.2e-16	-403.67	-67.28	-0.3159
SST	1	2.2e-16	-829.1	-829.1	-0.3100
Vessel length	1	2.2e-16	-109.93	-109.93	-0.3076
Year:Quarter	48	2.2e-16	-481.62	-10.03	-0.3017
Year: Set type	16	2.2e-16	-259.10	-16.19	-0.3013
Quarters: Regions	21	2.2e-16	- 322.07	-15.34	-0.2994
Set type: Hooks per float	2	2.2e-16	-228.81	-114.41	-0.2979

Zero-inflated Poisson GLM Analysis of Deviance Table: Zeros Model

Parameter	Df	Pr>|χ2|	ΔAIC	ΔAIC/df	Median Residual
Intercept	1				-0.2979
Years	16	6.944e-06	-21.23	-1.33	-0.2982
Quarters	3	3.094e-15	-64.65	-21.55	-0.2973
Regions	7	2.2e-16	-253.46	-36.21	-0.2813

Table 2.5. Summary of the zero-inflated negative binomial GLM variable selection analysis of deviance table. Table entries include the degrees of freedom associated with each variable (Df), the significance of the chi-squared test (Pr>|χ2|), the reduction in AIC (ΔAIC), the reduction in AIC per degree of freedom, the median Pearson residual at each fitting step, and the dispersion parameter.

Zero-inflated Negative Binomial GLM Analysis of Deviance Table: Counts Model

Parameter	Df	Pr>|χ2|	ΔAIC	ΔAIC/df	Median Pearson Residual	*k*
Intercept	1				-0.3685	0.3047
Years	16	2.2e-16	-982.03	-61.38	-0.3594	0.3511
Quarters	3	2.2e-16	-1256.49	-418.83	-0.3389	0.4120
Regions	7	2.2e-16	-3931.09	-561.58	-0.3130	0.6625
Set types	1	3.47e-11	-41.89	-41.89	-0.3183	0.6726
Bait types	6	2.2e-16	-250.09	-41.68	-0.3055	0.7059
SST	1	2.2e-16	-749.42	-749.42	-0.3029	0.7974
Years:Quarters	48	2.2e-16	-350.20	-7.30	-0.2978	0.8669
Years: Set types	16	2.2e-16	-147.48	-9.22	-0.2974	0.9021
Quarters: Regions	21	2.2e-16	-231.93	-11.04	-0.2974	0.9474
Set types: Hooks per float	2	2.2e-16	-147.56	-73.78	-0.2945	0.9754

Zero-inflated Negative Binomial GLM Analysis of Deviance Table: Zeros Model

Parameter	Df	Pr>|χ2|	ΔAIC	ΔAIC/df	Median Residual	*k*
Intercept	1				-0.2930	1.0429
Years	16	8.89e-14	-45.88	-2.87	-0.2931	1.1740
Bait types	6	0.0164	-14.03	-2.34	-0.2930	1.2643
SST	1	2.79e-11	-33.77	-33.77	-0.2942	1.2708
Vessel length	1	1.12e-06	-21.71	-21.71	-0.2928	1.3769
Set type: Hooks per float	2	2.2e-16	-81.18	-40.59	-0.2925	1.3658

Table 3. Model fit comparison from the GLM analyses. Table entries include the model AIC, the change (i.e., reduction) from the null model AIC (ΔAIC), the *pseudo*-coefficient of determination (when calculable), and the linear regression of observed on fitted values. Each regression was initially fitted with an intercept; if this was non-significant, the regression was re-fitted through the origin. The *t*-values are tests of slopes. Likelihood ratio tests compare nested models.

Model	Model AIC	ΔAIC	Model pseudo-R^2	Linear regression: Observed on fitted values	Likelihood ratio tests
Delta lognormal Binomial	38791.25	-6957.38	15.74%	$Y = 1.007X$; $R^2 = 0.298$ $t = 147.9$; $P < 2e\text{-}16$	----
Lognormal	12497.73	-8811.48	65.37%	$Y = 0.769X - 0.085$; $R^2 = 0.309$ $t = 61.70$; $P < 2e\text{-}16$	----
Poisson	55125.21	- 13735.46	28.1%	$Y = 0.996X$; $R^2 = 0.296$ $t = 147.2$; $P < 2e\text{-}16$	----
Zero-inflated Poisson	53802.31	-9989.61	NA	$Y = 1.038X - 0.007$; $R^2 = 0.201$ $t = 113.7$; $P < 2e\text{-}16$	ZI Poisson vs Poisson $\chi2=1374.9$ $P < 2.2e\text{-}16$
Negative binomial	53451.06	-8561.22	28.7%	$Y = 0.995X$; $R^2 = 0.283$ $t = 142.7$; $P < 2e\text{-}16$	ZINB vs Negative binomial $\chi2=186.12$ $P < 2.2e\text{-}16$
Zero-inflated negative binomial	53316.94	-8695.74	NA	$Y = 0.992X$; $R^2 = 0.286$ $t = 143.7$; $P < 2e\text{-}16$	ZI NB vs ZI Poisson $\chi2=485.37$ $P < 2.2e\text{-}16$

Table 4. Matrix of Pearson correlation coefficients (lower section) and angular deviations (upper section) between the annual mean nominal blue marlin CPUE and the annual effect coefficients vectors from the GLM analyses. Significance values are from *t*-tests of the correlation coefficients with 16 degrees of freedom.

Analysis	Poisson	Negative Binomial	Zero-Inflated Poisson	Zero-Inflated Negative Binomial	Annual Mean Nominal CPUE	Delta lognormal
Poisson	----	2.6°	1.2°	2.4°	11.7°	9.9°
Negative Binomial	r = 0.995 P =2.2e-16	----	2.2°	1.2°	11.6°	9.8°
Zero-Inflated Poisson	r = 0.999 P =2.2e-16	r = 0.996 P =2.2e-16	----	2.0°	12.1°	10.1°
Zero-Inflated Negative Binomial	r = 0.996 P =2.2e-16	r = 0.999 P =2.2e-16	r = 0.998 P =2.2e-16	----	11.5°	9.8°
Annual Mean Nominal CPUE	r = 0.969 P =2.2e-16	r = 0.964 P=4.49e-10	r = 0.965 P <0.001	r = 0.963 P <0.001	----	5.0°
Delta lognormal	r = 0.964 P =2.2e-16	r = 0.961 P=9.06e-10	r = 0.963 P =5.75e-10	r = 0.959 P =1.37e-09	r = 0.991 P =1.33e-14	----

Table 5.1. Summary of blue marlin *Makaira nigricans* eye to fork length (EFL) measurements from the Hawaii-based longline fishery from 1995 to early 2003. Results (cm) are presented as the mean, standard deviation, and sample size (*N*) sorted by regions, fishery sectors, and calendar quarters. Data from all years are pooled. See text for fishing region and fishery sector definitions.

Fishing Regions								
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Deep-set Sector								
Quarter 1	176.6±39.3 (16)	157.6±21.9 (104)	154.0±30.2 (133)	157.5±27.8 (167)	155.3±33.3 (42)	151.7±30.1 (104)	NA	NA
Quarter 2	173.7±30.3 (15)	169.2±25.6 (64)	171.1±25.4 (102)	164.1±19.0 (821)	183.7±34.3 (20)	171.5±25.4 (157)	NA	NA
Quarter 3	164.9±21.0 (29)	166.0±22.3 (190)	169.8±19.3 (159)	168.7±24.4 (241)	192.1±36.9 (58)	177.5±37.5 (50)	224.3±25.7 (3)	154.6±36.9 (14)
Quarter 4	160.2±17.7 (41)	160.3±17.2 (130)	163.0±27.7 (95)	160.6±23.2 (339)	170.4±41.5 (159)	153.8±29.9 (212)	NA	143.8±29.1 (21)
Shallow-set Sector								
Quarter 1	NA	NA	175.6±13.5 (5)	NA	166.6±28.2 (10)	185.0±28.4 (6)	160.3±37.1 (4)	169.5±11.6 (4)
Quarter 2	NA	NA	181.8±20.5 (21)	213 (1)	180.3±27.4 (59)	177.6±28.8 (67)	167 (1)	186 (1)
Quarter 3	NA	NA	173.0±20.4 (190)	166.1±23.0 (117)	174.7±24.6 (71)	176.1±25.1 (106)	NA	180.2±57.5 (22)
Quarter 4	NA	NA	167.5±21.5 (27)	163.1±11.3 (13)	169.8±36.2 (98)	193.6±22.3 (14)	167.1±7.1 (7)	200.3±27.9 (4)

Table 5.2. Summary of blue marlin *Makaira nigricans* eye to fork length (EFL) measurements from the Hawaii-based longline fishery taken by PIROP observers in 2003–2012. Results (cm) are presented as the mean, standard deviation, and sample size (*N*) sorted by regions, fishery sectors and calendar quarters. Data from all years are pooled. See text for fishing region and fishery sector definitions.

Fishing Regions								
	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Deep-set Sector								
Quarter 1	197 (1)	154.4±27.5 (30)	158.9±29.0 (81)	160.0±20.6 (435)	154.9±35.5 (41)	165.4±29.2 (47)	NA	NA
Quarter 2	162.0±49.2 (6)	176.4±33.9 (39)	162.3±19.7 (230)	164.1±18.0 (831)	190.0±36.7 (86)	177.7±27.1 (104)	290.0±33.9 (2)	199.5±12.7 (6)
Quarter 3	189.6±39.7 (5)	150.5±20.0 (72)	166.8±22.4 (200)	162.9±19.4 (358)	182.0±39.1 (315)	179.2±34.6 (66)	191.5±35.0 (51)	186.0±36.2 (21)
Quarter 4	NA	148.9±20.3 (16)	156.3±33.1 (152)	156.0±26.5 (313)	166.5±42.3 (330)	157.9±35.1 (246)	207.5±65.8 (2)	181.5±26.2 (2)
Shallow-set Sector								
Quarter 1	NA	NA	NA	NA	182 (1)	181.0±26.5 (3)	168.9±12.4 (17)	169.5±22.4 (8)
Quarter 2	NA	NA	203.0±31.1 (2)	161.7±11.8 (6)	193.1±28.2 (81)	179.1±27.8 (398)	286 (1)	172.2±19.8 (5)
Quarter 3	NA	NA	NA	NA	180.6±18.6 (7)	172.7±27.4 (10)	197.5±50.2 (2)	176.0±34.9 (12)
Quarter 4	NA	NA	NA	NA	179 (1)	NA	166.4±10.7 (8)	NA

Figure 1. Blue marlin *Makaira nigricans* observed quarterly catch rates by sector in the Hawaii longline fishery in 1995–2011. Figures 1.1 and 1.2 present catch per set and nominal CPUE.

Figure 1.1.

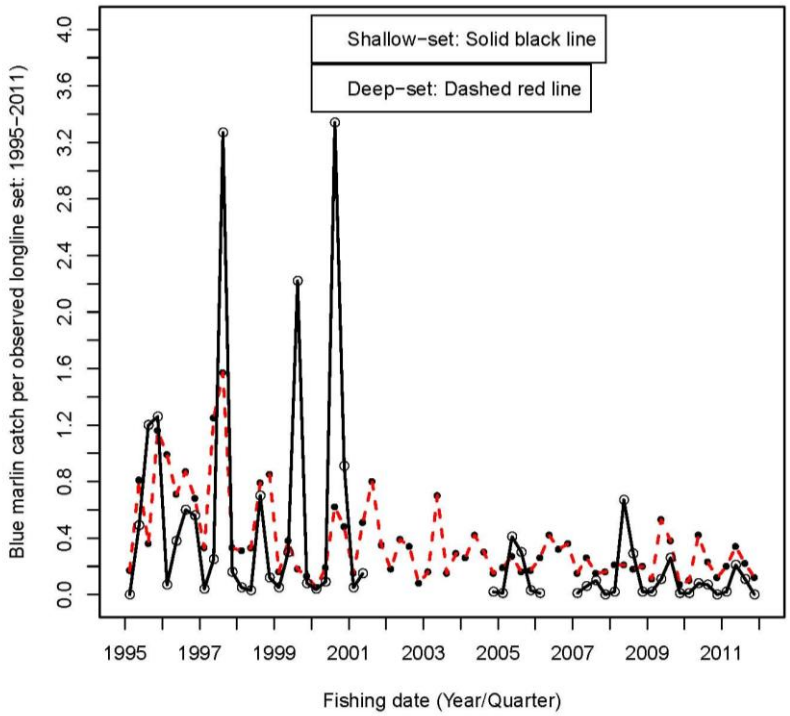


Figure 1.2.

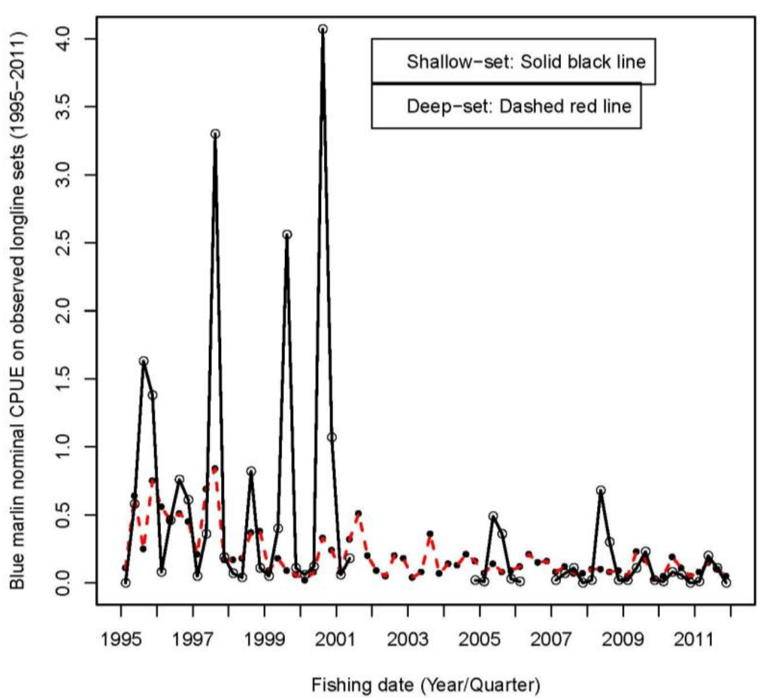


Figure 2. Blue marlin *Makaira nigricans* zero catches and CPUE on sets with positive catches as calculated from PIROP fishery observer data in the Hawaii longline fishery in 1995–2011. The upper frame (dotted blue line) is the annual percentage of sets with zero blue marlin catches. The lower frame is the nominal mean CPUE from the sets with positive catches (*N*=8532 observed longline sets: red dashed line. The upper response axis ranges from 50–100%; the lower response axis ranges from 0–2.0. Fishery sectors are pooled.

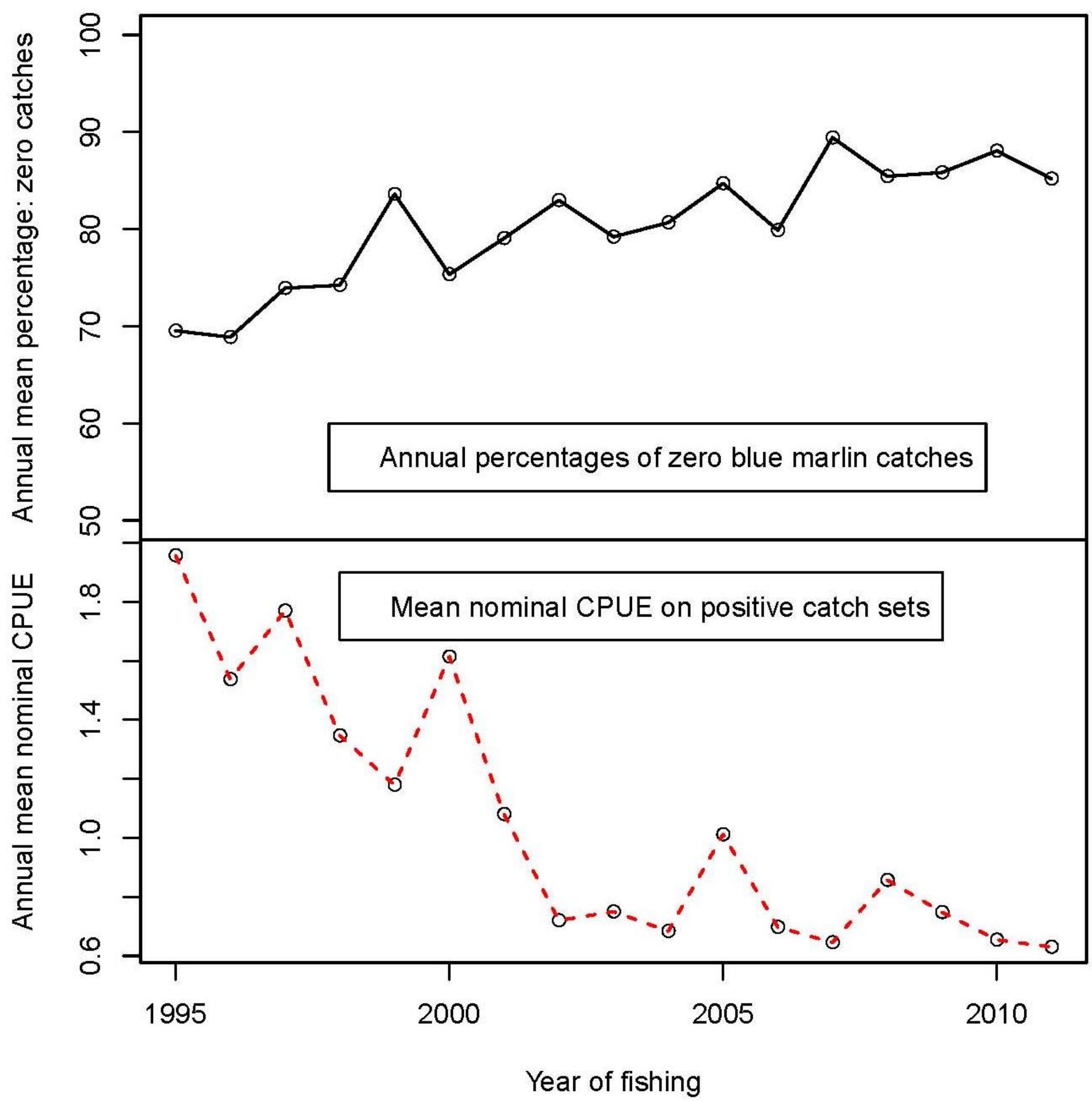


Figure 3. Blue marlin *Makaira nigricans* catches per observed set in the Hawaii-based longline fishery in 1995–2011.

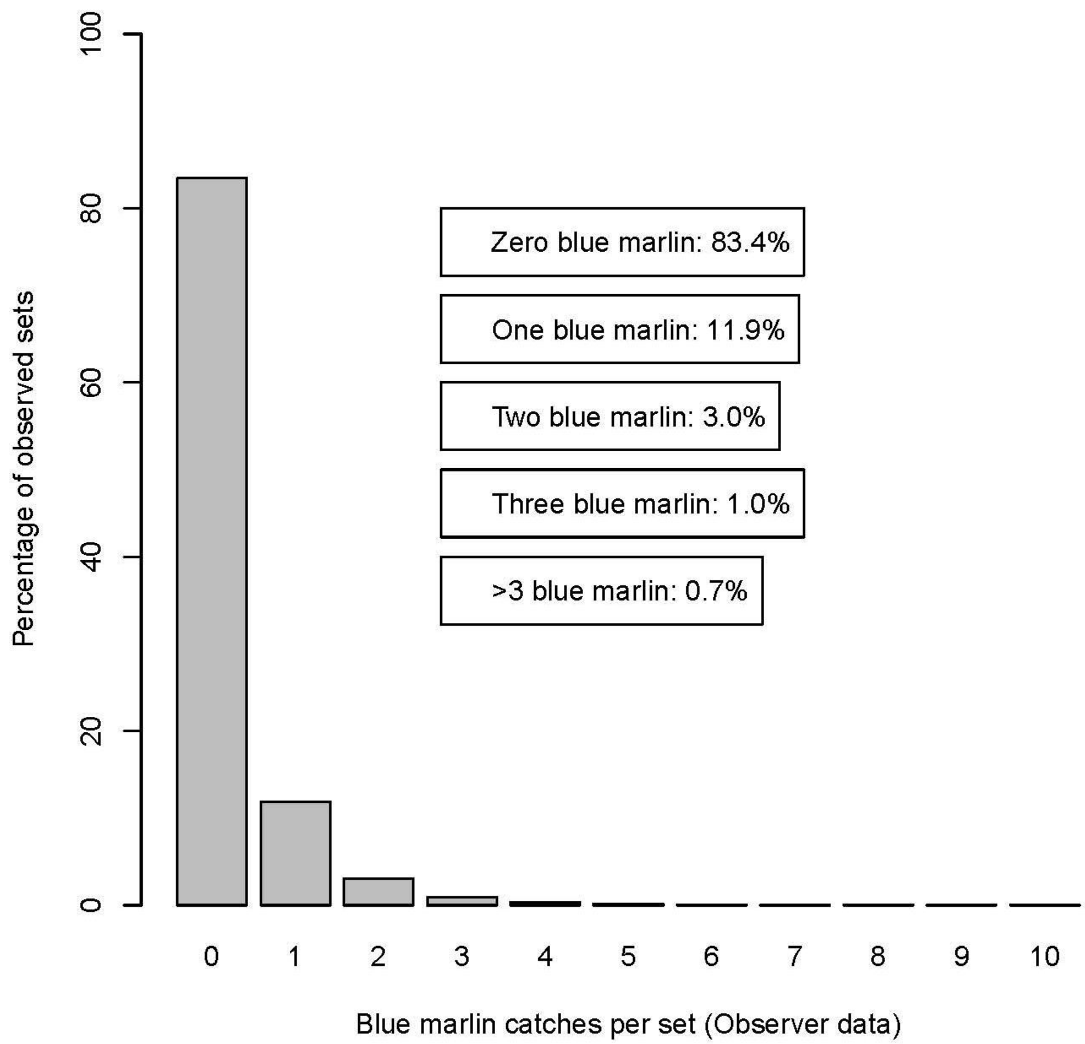
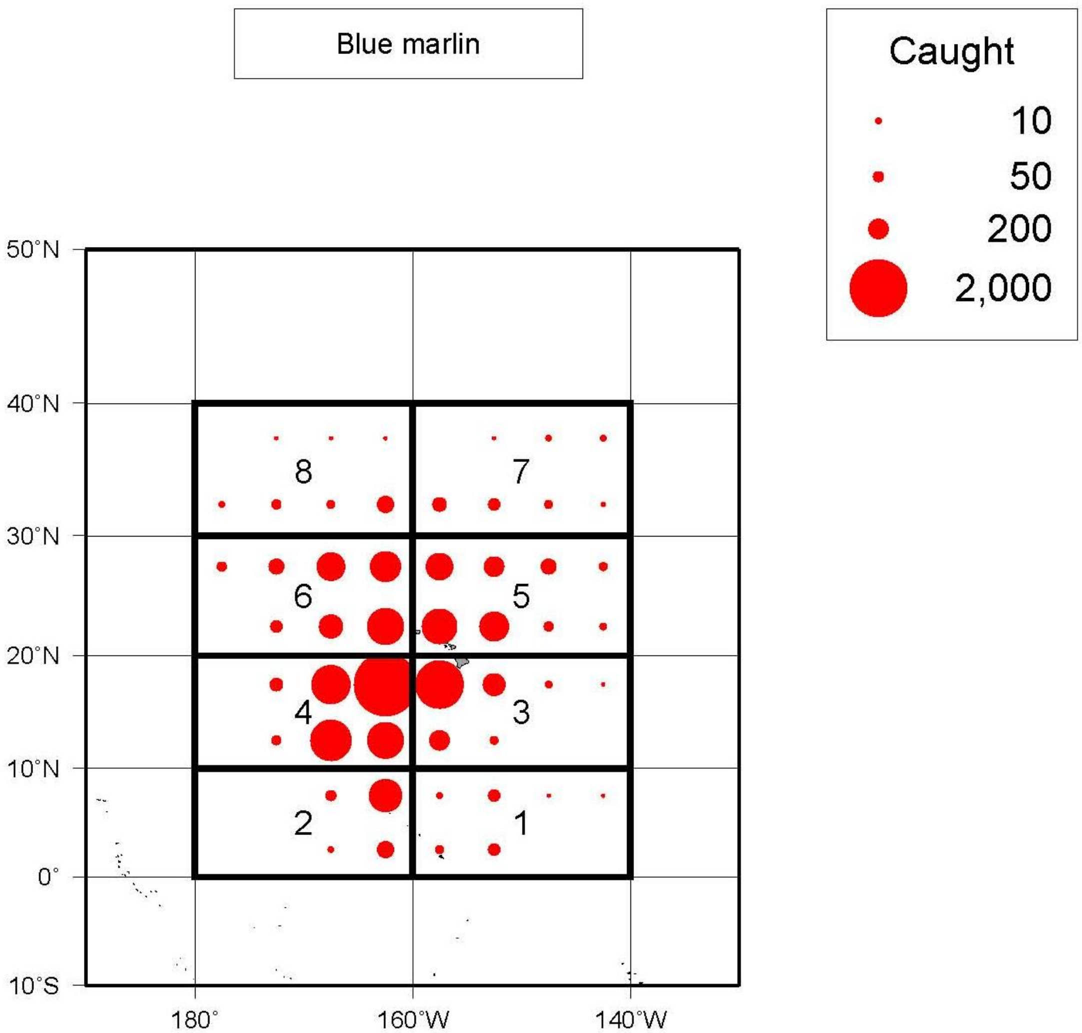


Figure 4.1. Blue marlin *Makaira nigricans* catches reported by PIROP fishery observers in the Hawaii-based pelagic longline fishery in 1995–2011. The eight fishing regions are defined by 10° latitudinal increments and a longitudinal separation at 160°W. The sizes of the circles are proportional to the catch size. Each circle represents a catch total from one 5°×5° square[3].



[3] The authors thank Karen L. Sender of the PIFSC for preparing these catch and CPUE maps.

Figure 4.2. Blue marlin *Makaira nigricans* nominal CPUE as reported by PIROP fishery observers in the Hawaii-based pelagic longline fishery in 1995–2011. The eight fishing regions are defined by 10° latitudinal increments and a longitudinal separation at 160°W. The sizes of the circles are proportional to the CPUE. Each circle represents a catch total from one 5°×5° square.

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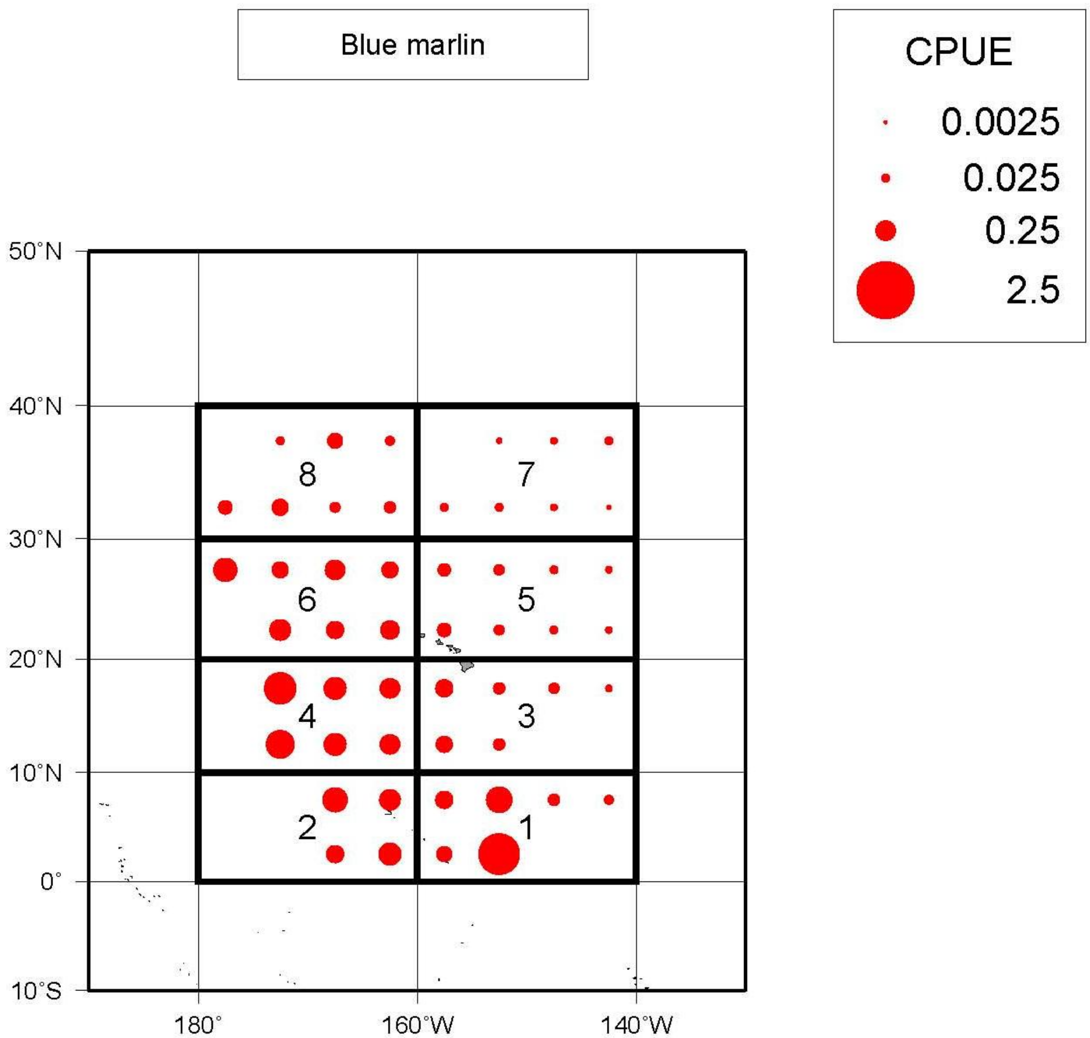


Figure 5.1. Indices of relative abundance. The mean annual effects from each of the counts models are plotted against the years of fishing.

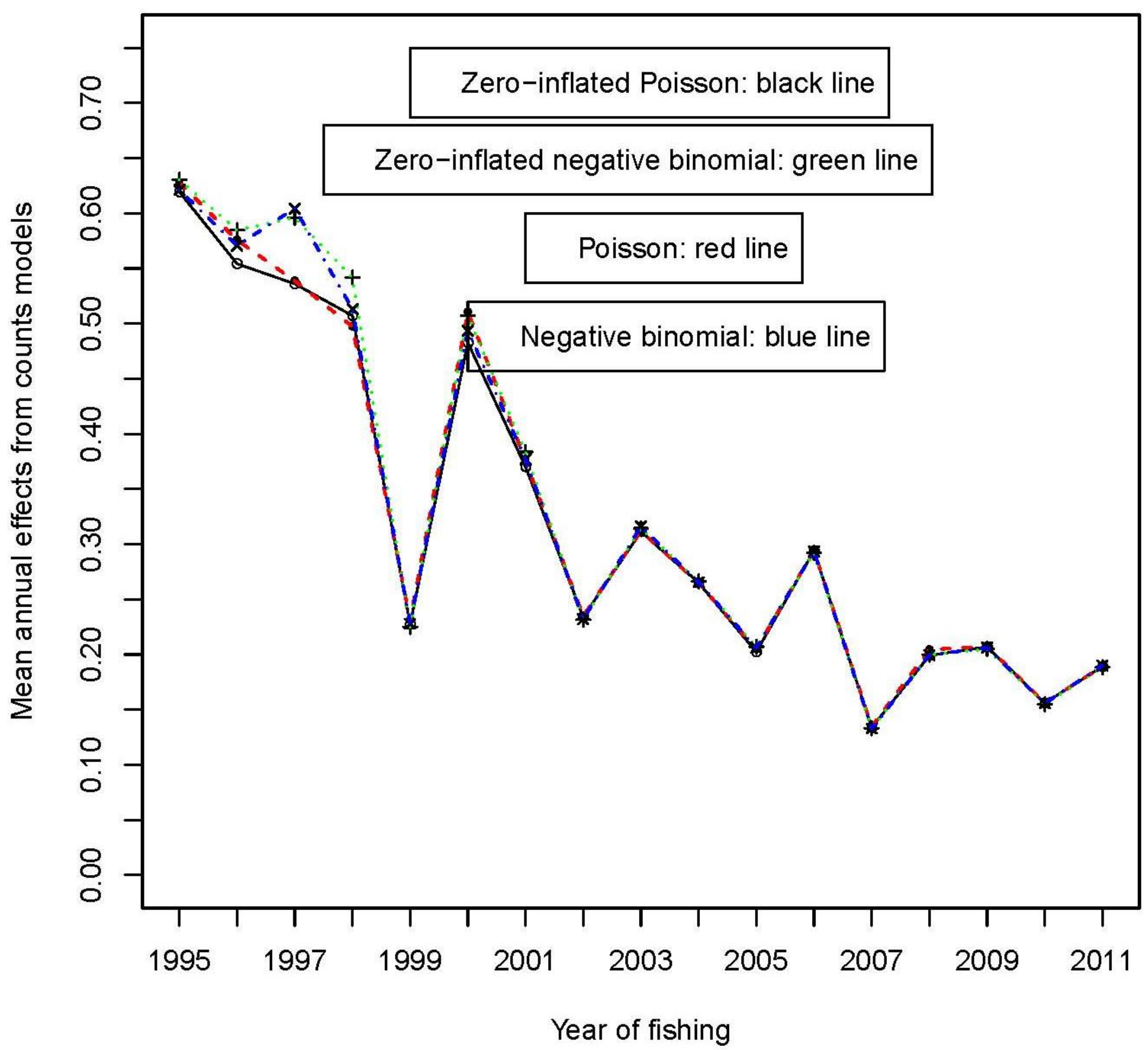


Figure 5.2. Indices of relative abundance. The mean annual effects from the delta lognormal analysis plotted along with the nominal CPUE against the years of fishing.

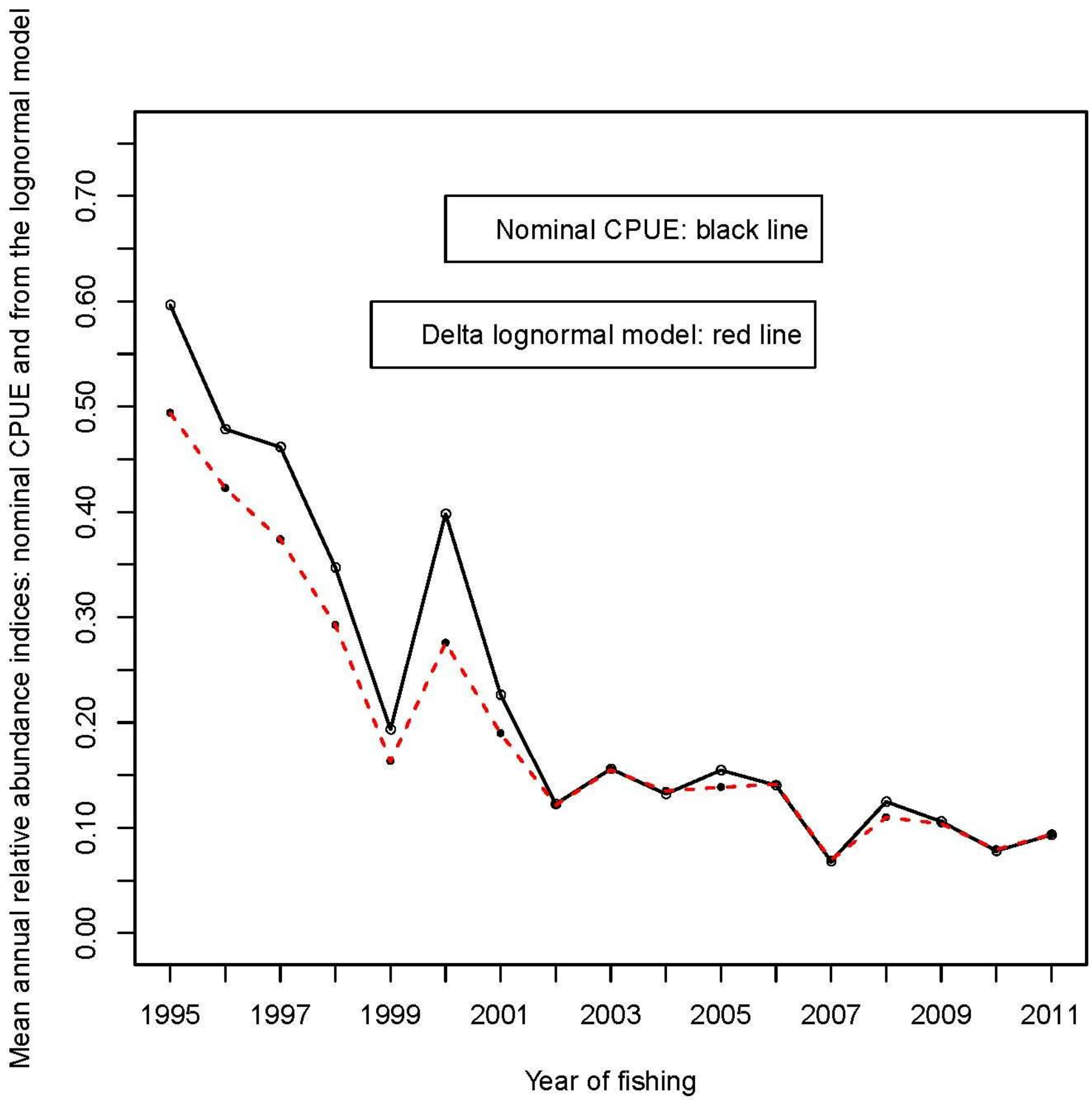


Figure 6.1. Quarterly effects on blue marlin standardized CPUE as estimated with the zero-inflated negative binomial GLM.

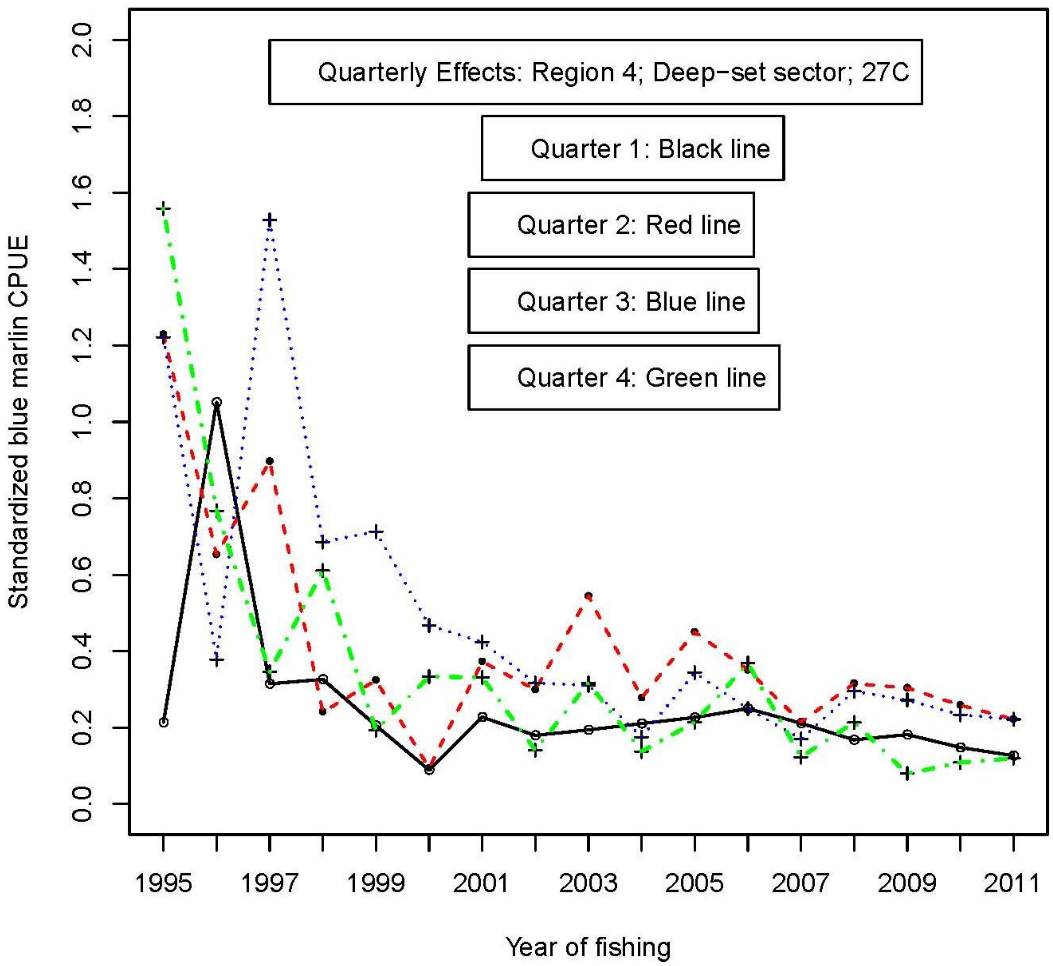


Figure 6.2. Set type and gear depth effects on standardized blue marlin CPUE as estimated with the zero-inflated negative binomial GLM associated with different numbers of hooks per float in the two fishery sectors in Region 6.

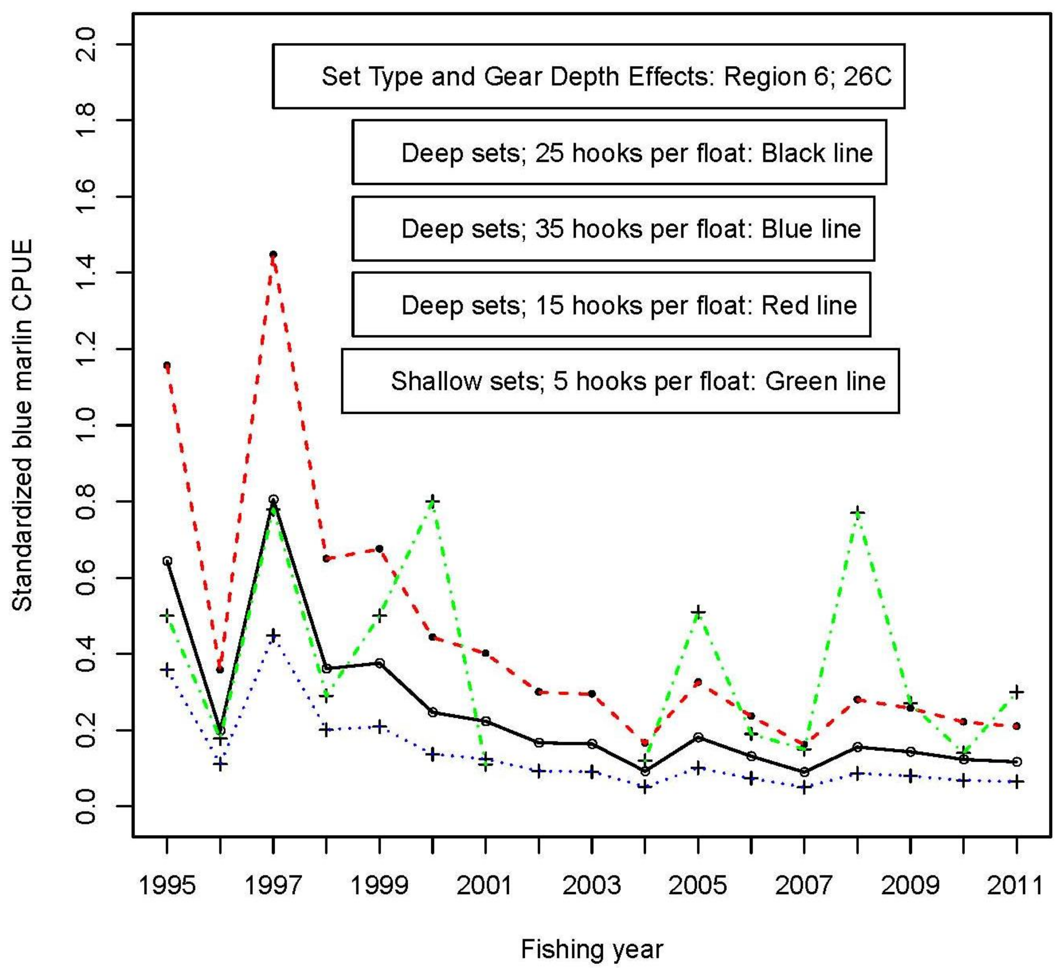


Figure 6.3. Bait type effects on blue marlin standardized CPUE as estimated with the zero-inflated negative binomial GLM.

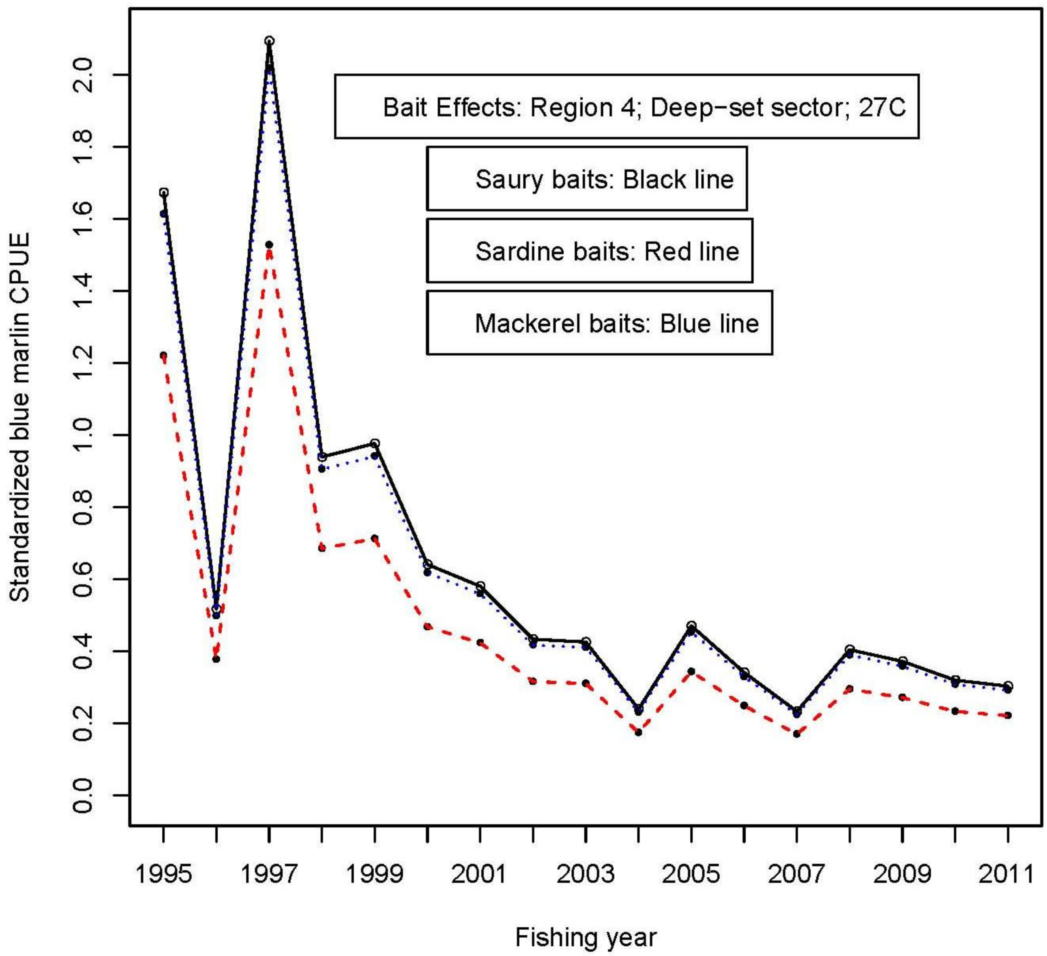


Figure 6.4. Sea surface temperature effects on blue marlin standardized CPUE as estimated with the zero-inflated negative binomial GLM.

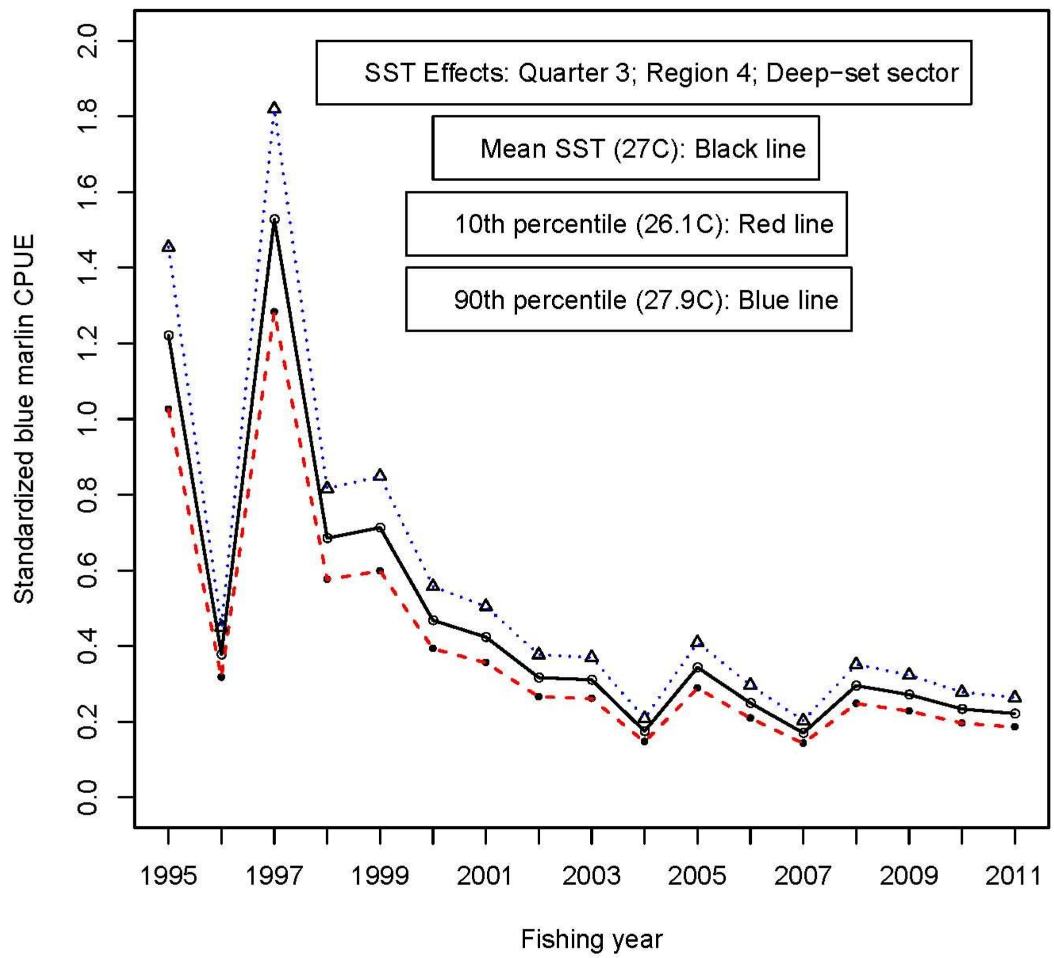


Figure 7. Time series plot of annual mean blue marlin *Makaira nigricans* eye-fork lengths. Trends are presented for the fishery sectors pooled and individually. There are no shallow-set measurements from 2002 and 2003 because the sector was closed.

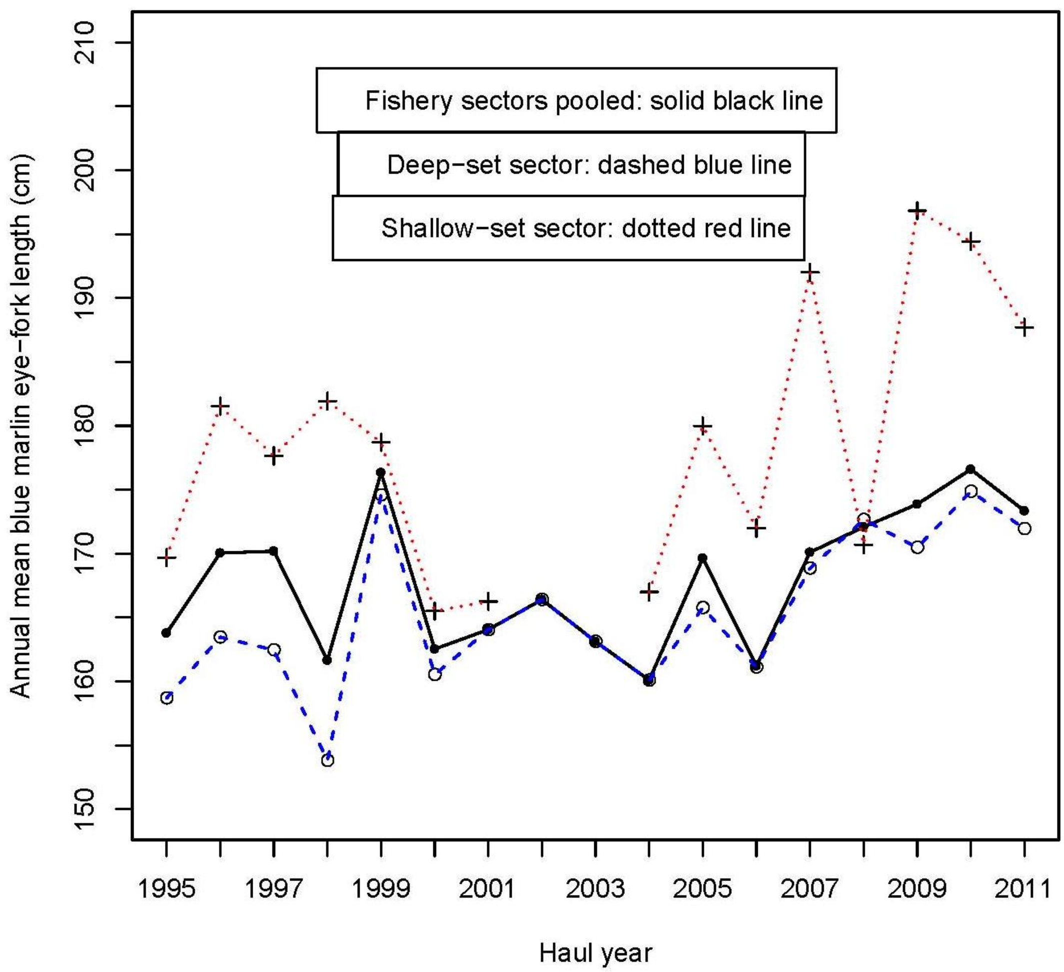


Figure 8.1. Distribution of blue marlin *Makaira nigricans* eye-fork lengths measured by fishery observers from 1995 through 2011. Fish were caught in both sectors of the Hawaii-based pelagic longline fishery.

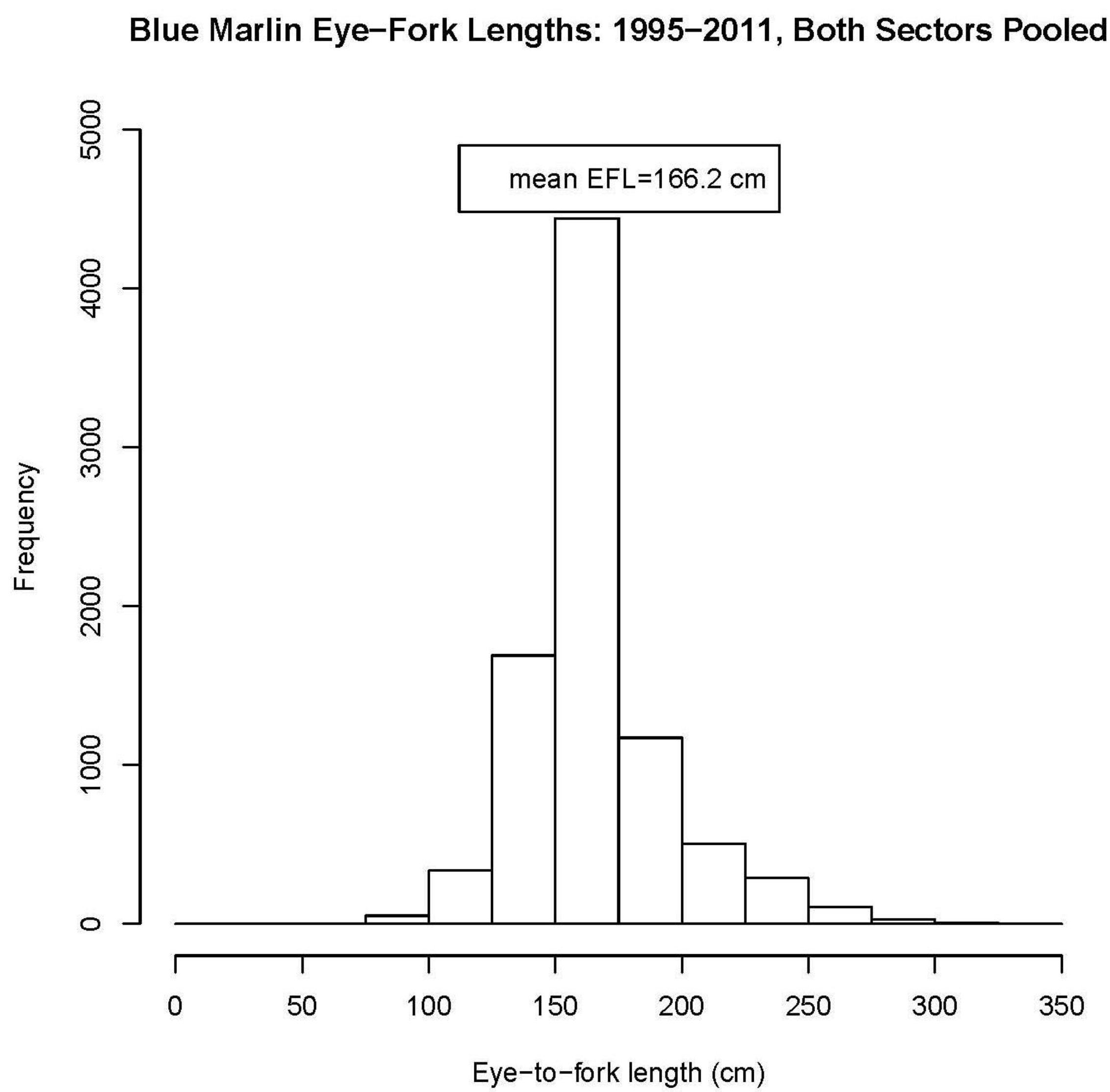
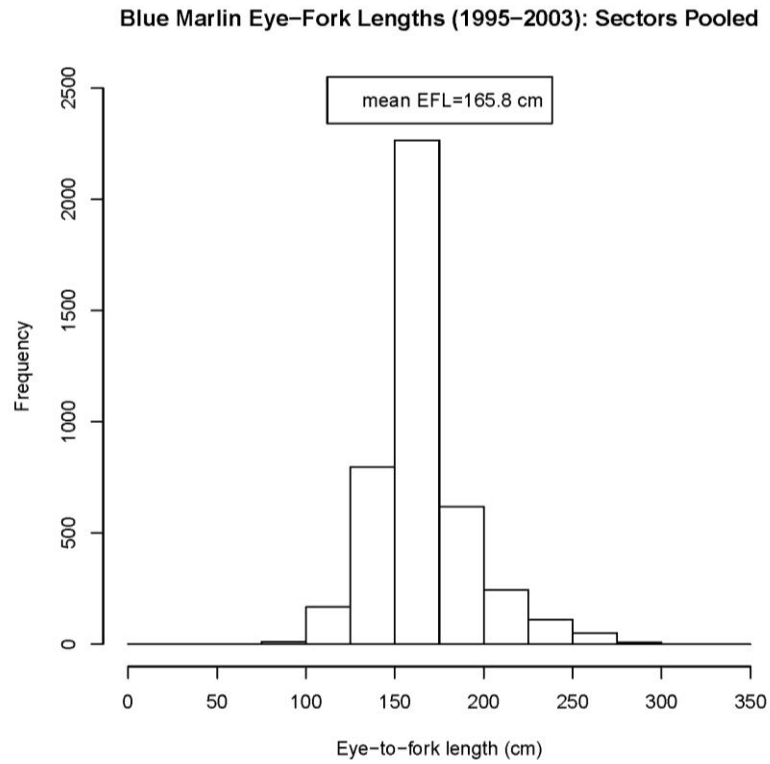


Figure 8.2. Distributions of blue marlin *Makaira nigricans* eye-fork lengths measured by fishery observers from 1995 to early 2003 (upper panel) and from mid-2003 through 2011 (lower panel). Fish were caught in both sectors of the Hawaii-based pelagic longline fishery.



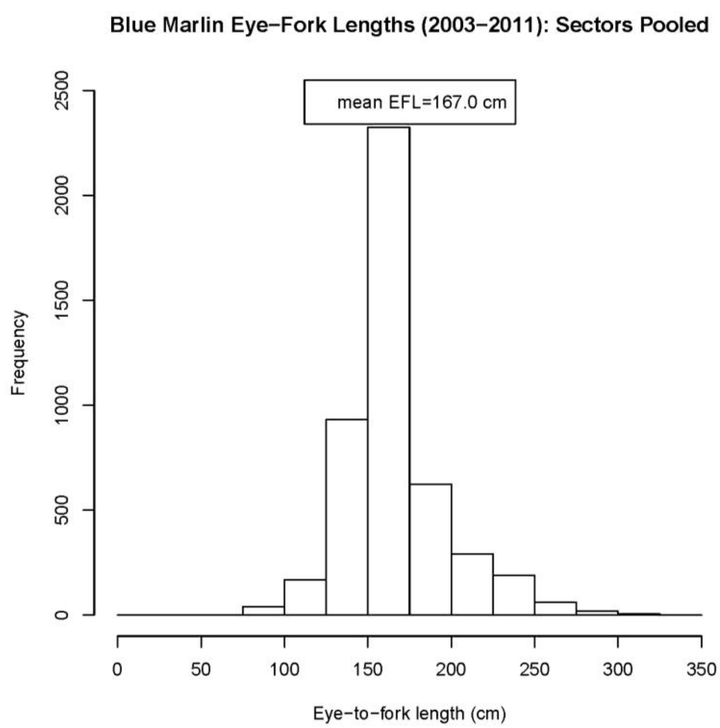


Figure 8.3. Distribution of blue marlin *Makaira nigricans* eye-fork lengths measured by fishery observers from 1995 through 2011. All fish were caught in the deep-set sector of the Hawaii-based pelagic longline fishery.

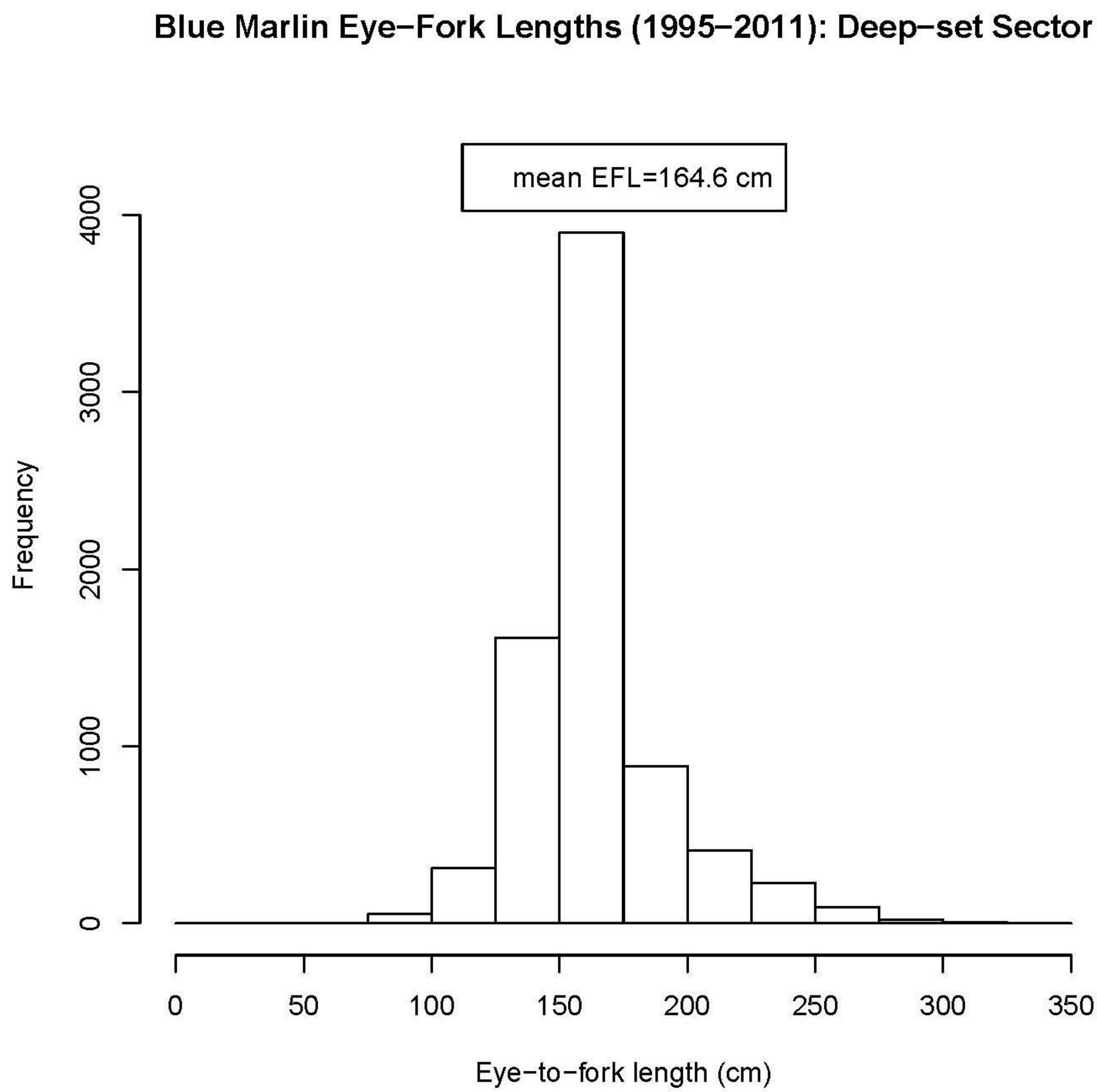
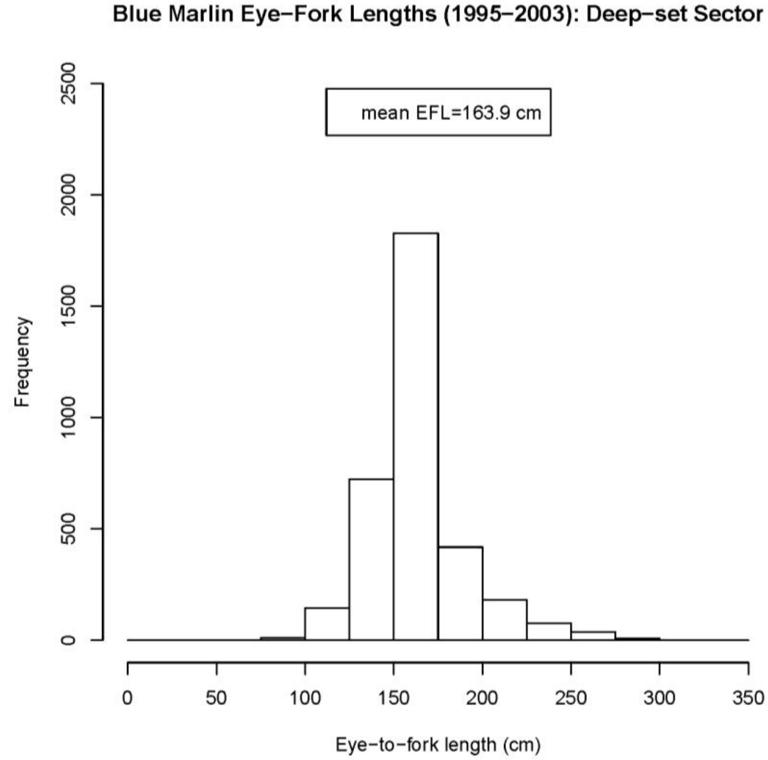


Figure 8.4. Distributions of blue marlin *Makaira nigricans* eye-fork lengths measured by fishery observers from 1995 through early 2003 (upper panel) and from mid 2003 through 2011 (lower panel). All fish were caught in the deep-set sector of the Hawaii-based pelagic longline fishery.



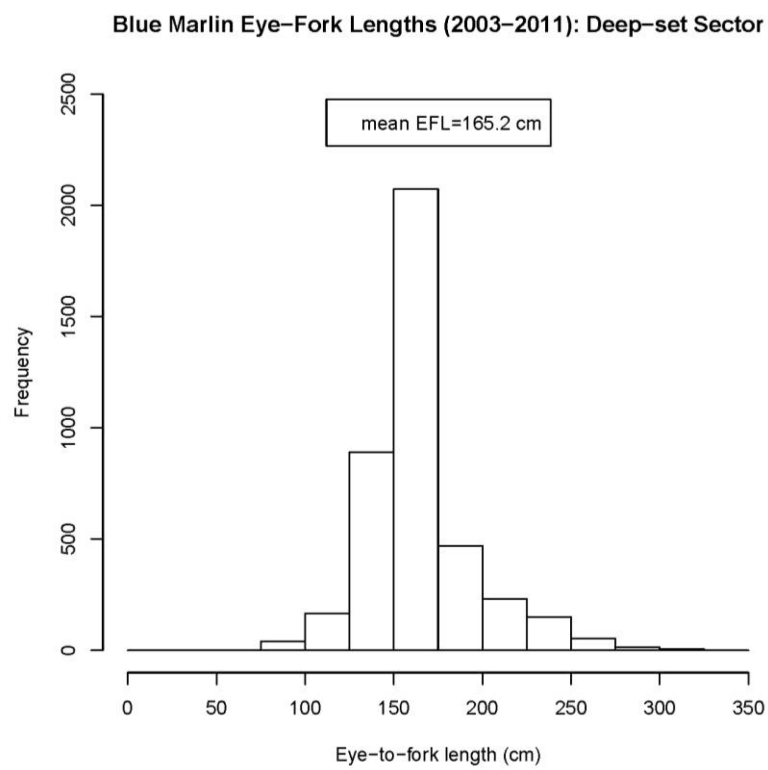


Figure 8.5. Distribution of blue marlin *Makaira nigricans* eye-fork lengths measured by fishery observers from 1995 through 2011. All fish were caught in the shallow-set sector of the Hawaii-based pelagic longline fishery.

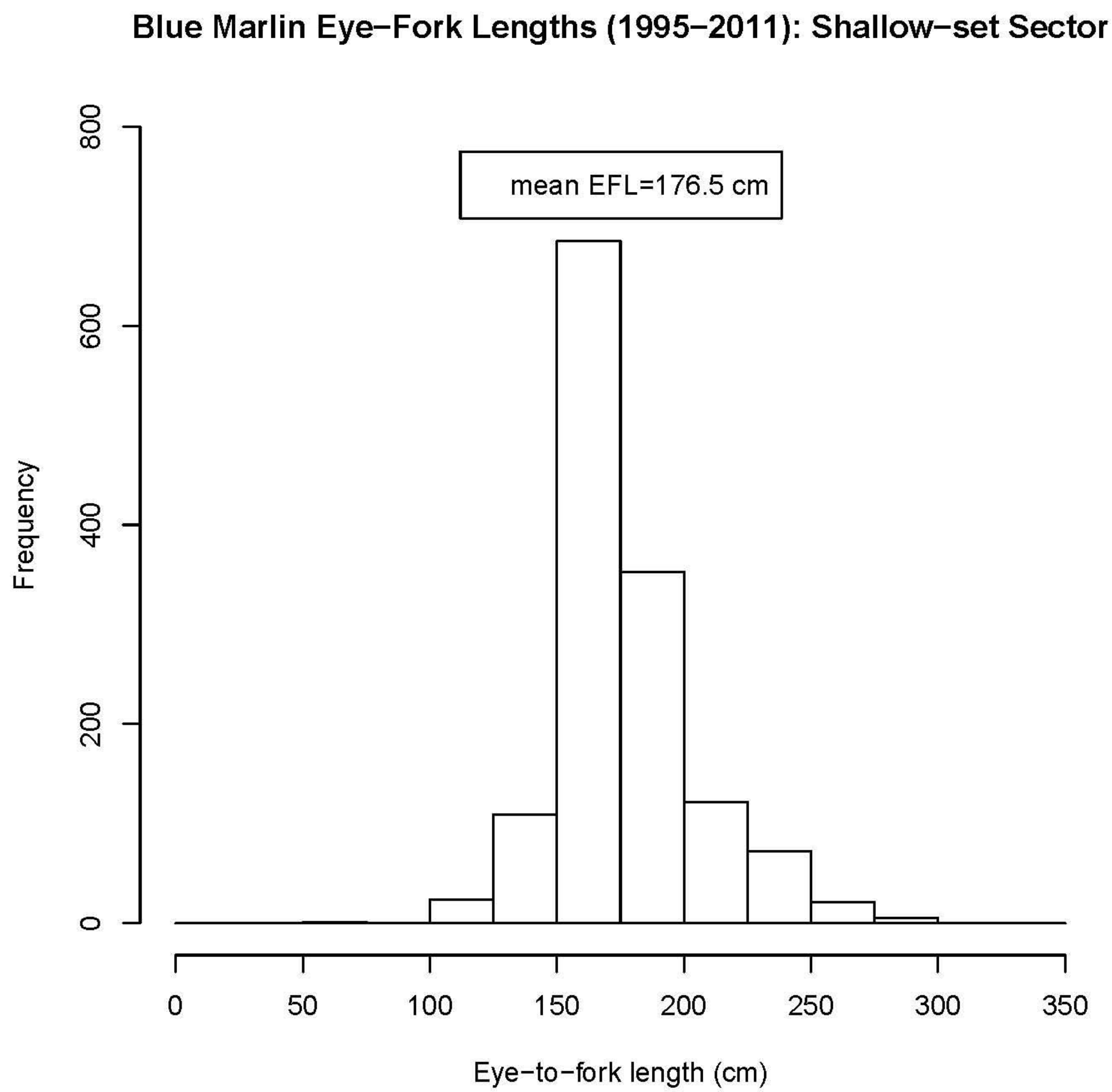
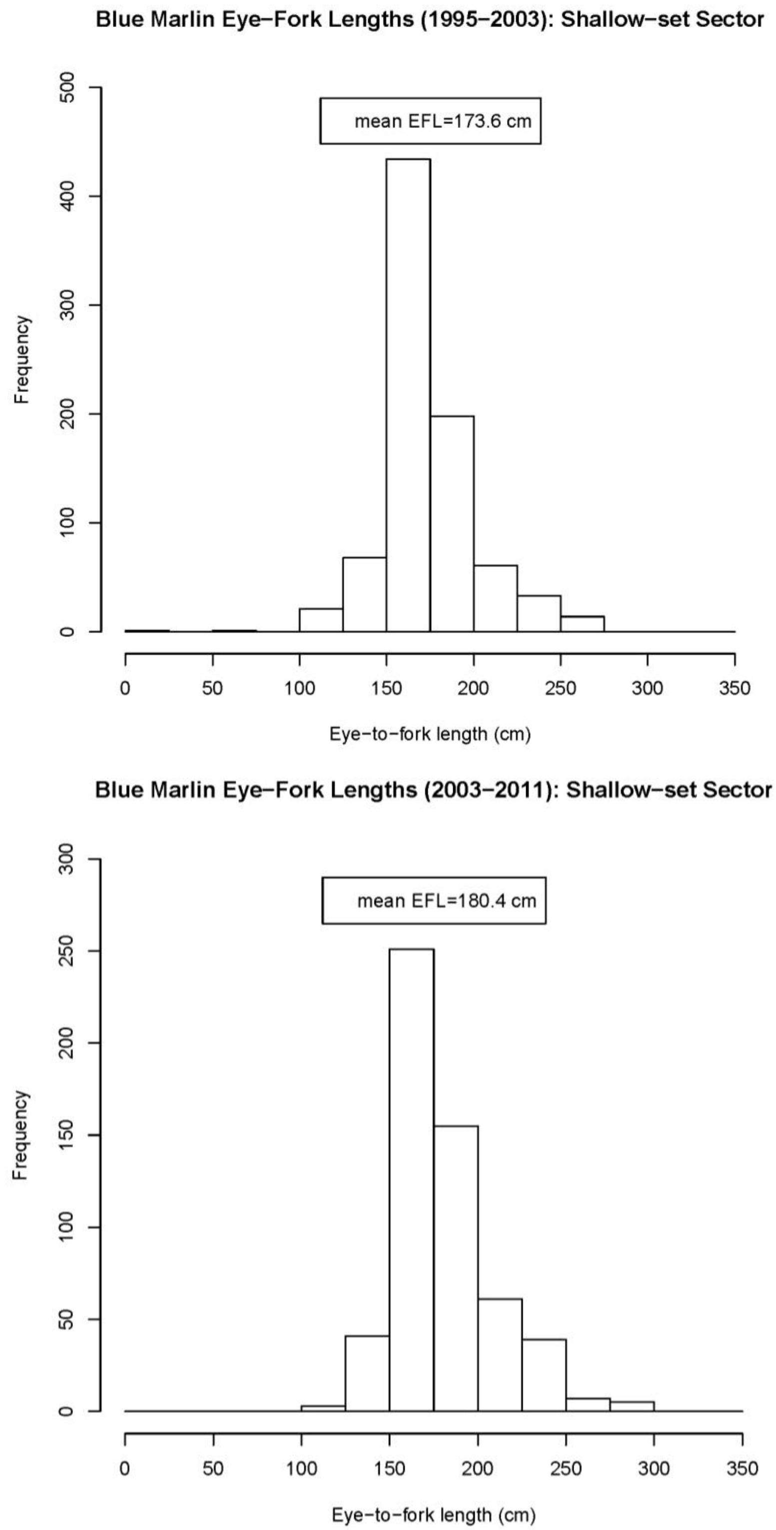


Figure 8.6. Distributions of blue marlin *Makaira nigricans* eye-fork lengths measured by fishery observers from 1995 through early 2003 (upper panel) and from mid 2003 through 2011 (lower panel). All fish were caught in the shallow-set sector of the Hawaii-based pelagic longline fishery.



APPENDIX I:

DELTA LOGNORMAL MODEL SUMMARY OUTPUT AND DIAGNOSTICS PLOTS

Table A.1.1. Binomial GLM output in the delta lognormal analysis from the R 'summary' function.

The variable names (main effects) are denoted as follows: "Haulyr" = fishing year (factor); "Quarter" = calendar quarter of fishing (factor); "Region" = fishing region (factor); "settype" = set type (factor); "Bait" = bait types (factor); "SST" = sea surface temperature (continuous); "Vesslen" = vessel length (continuous); "Hkpfl" = hooks per float (continuous). Interactions are denoted with a colon. The R object is named "BlueMarlin_Binomial_GLM".

> summary(BlueMarlin_Binomial_GLM)

Call: glm(formula = BlueMar_yn ~ Haulyr1 + Quarter1 + Region + settype1 + Bait + SST + Haulyr1:Quarter1 + Haulyr1:settype1 + Quarter1:Region + settype1:Hkpfl + offset(log(Hooks)), family = binomial, data = Observer1)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.1648	-0.6009	-0.4090	-0.1678	3.3630

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-10.164516	0.614964	-16.529	< 2e-16 ***
Haulyr 1996	1.377777	0.366958	3.755	0.000174 ***
Haulyr 1997	0.346501	0.418814	0.827	0.408045
Haulyr 1998	0.447111	0.431632	1.036	0.300267
Haulyr 1999	-0.090482	0.463242	-0.195	0.845139
Haulyr 2000	-0.836431	0.469063	-1.783	0.074554 .
Haulyr 2001	-0.265694	0.329751	-0.806	0.420392
Haulyr 2002	-0.273916	0.325029	-0.843	0.399371
Haulyr 2003	-0.392943	0.328910	-1.195	0.232211
Haulyr 2004	-0.031580	0.321290	-0.098	0.921702

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 2005	-0.040874	0.325637	-0.126	0.900111
Haulyr 2006	0.265467	0.340876	0.779	0.436110
Haulyr 2007	-0.074486	0.353097	-0.211	0.832926
Haulyr 2008	-0.340217	0.321682	-1.058	0.290229
Haulyr 2009	-0.243682	0.331276	-0.736	0.461983
Haulyr 2010	-0.381319	0.334700	-1.139	0.254584
Haulyr 2011	-0.557474	0.322098	-1.731	0.083494 .
Quarter 2	-0.038127	0.586501	-0.065	0.948167
Quarter 3	0.133924	0.588819	0.227	0.820078
Quarter 4	1.585995	0.724888	2.188	0.028676 *
Region 2	-1.064402	0.365757	-2.910	0.003613 **
Region3	-1.388959	0.363956	-3.816	0.000135 ***
Region4	-0.782773	0.361759	-2.164	0.030480 *
Region5	-2.371542	0.375447	-6.317	2.67e-10 ***
Region6	-1.896269	0.371832	-5.100	3.40e-07 ***
Region7	-3.038771	0.404921	-7.505	6.16e-14 ***
Region8	-2.777390	0.474806	-5.850	4.93e-09 ***
Set type 2	-1.948110	0.413425	-4.712	2.45e-06 ***
Bait 2	-0.058514	0.162460	-0.360	0.718716
Bait 3	-1.231906	0.258747	-4.761	1.93e-06 ***
Bait 4	-1.256862	0.277539	-4.529	5.94e-06 ***
Bait 5	-1.361815	0.259503	-5.248	1.54e-07 ***
Bait 6	-1.539115	0.264002	-5.830	5.54e-09 ***
Bait 7	-1.594729	0.263766	-6.046	1.48e-09 ***
SST	0.208449	0.010518	19.818	< 2e-16 ***

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 1996:Quarter 2	-2.026328	0.463077	-4.376	1.21e-05 ***
Haulyr 1997:Quarter 2	-0.422292	0.523661	-0.806	0.420000
Haulyr 1998:Quarter 2	-2.366869	0.617419	-3.833	0.000126 ***
Haulyr 1999:Quarter 2	-1.068697	0.556357	-1.921	0.054746 .
Haulyr 2000:Quarter 2	-1.853927	0.598083	-3.100	0.001937 **
Haulyr 2001:Quarter 2	-1.276088	0.424713	-3.005	0.002659 **
Haulyr 2002:Quarter 2	-1.267886	0.413757	-3.064	0.002182 **
Haulyr 2003:Quarter 2	-0.465183	0.417025	-1.115	0.264644
Haulyr 2004:Quarter 2	-1.579023	0.409121	-3.860	0.000114 ***
Haulyr 2005:Quarter 2	-0.911445	0.412034	-2.212	0.026962 *
Haulyr 2006:Quarter 2	-1.507771	0.423185	-3.563	0.000367 ***
Haulyr 2007:Quarter 2	-1.789941	0.434585	-4.119	3.81e-05 ***
Haulyr 2008:Quarter 2	-1.037422	0.406635	-2.551	0.010734 *
Haulyr 2009:Quarter 2	-1.222961	0.417638	-2.928	0.003408 **
Haulyr 2010:Quarter 2	-1.211240	0.420998	-2.877	0.004014 **
Haulyr 2011:Quarter 2	-1.139955	0.411234	-2.772	0.005571 **
Haulyr 1996:Quarter3	-2.442860	0.509143	-4.798	1.60e-06 ***
Haulyr 1997:Quarter 3	0.461197	0.688737	0.670	0.503095
Haulyr 1998:Quarter 3	-1.124479	0.537659	-2.091	0.036489 *
Haulyr 1999:Quarter 3	-0.371513	0.670892	-0.554	0.579743
Haulyr 2000:Quarter 3	-0.441705	0.564834	-0.782	0.434210
Haulyr 2001:Quarter 3	-1.197720	0.436257	-2.745	0.006043 **
Haulyr 2002:Quarter 3	-1.367839	0.430256	-3.179	0.001477 **
Haulyr 2003:Quarter 3	-1.112038	0.435553	-2.553	0.010675 *
Haulyr 2004:Quarter 3	-2.104260	0.423604	-4.968	6.78e-07 ***

	Estimate	Std. Error	z value	Pr(>|z|)	
Haulyr 2005:Quarter 3	-1.290747	0.425670	-3.032	0.002427	**
Haulyr 2006:Quarter 3	-1.885918	0.438173	-4.304	1.68e-05	***
Haulyr 2007:Quarter 3	-1.991167	0.453672	-4.389	1.14e-05	***
Haulyr 2008:Quarter 3	-1.046102	0.423706	-2.469	0.013552	*
Haulyr 2009:Quarter 3	-1.298378	0.429035	-3.026	0.002476	**
Haulyr 2010:Quarter 3	-1.345829	0.433852	-3.102	0.001922	**
Haulyr 2011:Quarter 3	-1.175972	0.424957	-2.767	0.005653	**
Haulyr 1996:Quarter 4	-2.080014	0.461161	-4.510	6.47e-06	***
Haulyr 1997:Quarter 4	-1.358712	0.522644	-2.600	0.009331	**
Haulyr 1998:Quarter 4	-1.670096	0.503773	-3.315	0.000916	***
Haulyr 1999:Quarter 4	-1.633119	0.584597	-2.794	0.005213	**
Haulyr 2000:Quarter 4	-0.542242	0.510944	-1.061	0.288573	
Haulyr 2001:Quarter 4	-1.151822	0.389670	-2.956	0.003118	**
Haulyr 2002:Quarter 4	-1.963380	0.400849	-4.898	9.68e-07	***
Haulyr 2003:Quarter 4	-0.902213	0.387600	-2.328	0.019929	*
Haulyr 2004:Quarter 4	-2.148502	0.383893	-5.597	2.19e-08	***
Haulyr 2005:Quarter 4	-1.705171	0.389404	-4.379	1.19e-05	***
Haulyr 2006:Quarter 4	-1.590079	0.398384	-3.991	6.57e-05	***
Haulyr 2007:Quarter 4	-2.212348	0.408050	-5.422	5.90e-08	***
Haulyr 2008:Quarter 4	-1.314344	0.387044	-3.396	0.000684	***
Haulyr 2009:Quarter 4	-2.380211	0.404124	-5.890	3.87e-09	***
Haulyr 2010:Quarter 4	-1.946959	0.400513	-4.861	1.17e-06	***
Haulyr 2011:Quarter 4	-1.694098	0.389134	-4.354	1.34e-05	***
Haulyr 1996:settype 2	-0.003186	0.324203	-0.010	0.992160	
Haulyr 1997:settype 2	-0.089974	0.378903	-0.237	0.812301	

	Estimate	Std. Error	z value	Pr(>|z|)	
Haulyr 1998:settype 2	0.155395	0.357838	0.434	0.664100	
Haulyr 1999:settype 2	0.391452	0.407546	0.961	0.336799	
Haulyr 2000:settype 2	1.200640	0.316909	3.789	0.000151	***
Haulyr 2001:settype 2	-0.141876	0.454554	-0.312	0.754949	
Haulyr 2002:settype 2	-8.192746	133.324124	-0.061	0.951001	
Haulyr 2003:settype 2	-9.097659	97.947941	-0.093	0.925997	
Haulyr 2004:settype 2	0.639095	0.827437	0.772	0.439890	
Haulyr 2005:settype 2	1.281366	0.381982	3.355	0.000795	***
Haulyr 2006:settype 2	0.563436	0.552567	1.020	0.307885	
Haulyr 2007:settype 2	0.909342	0.407033	2.234	0.025478	*
Haulyr 2008:settype 2	1.789926	0.381987	4.686	2.79e-06	***
Haulyr 2009:settype 2	1.013107	0.388435	2.608	0.009103	**
Haulyr 2010:settype 2	0.460870	0.398472	1.157	0.247438	
Haulyr 2011:settype 2	1.257536	0.394747	3.186	0.001444	**
Quarter 2:Region2	1.438700	0.458151	3.140	0.001688	**
Quarter 3:Region2	2.256176	0.452650	4.984	6.22e-07	***
Quarter 4:Region2	0.648077	0.648730	0.999	0.317798	
Quarter 2:Region3	1.555250	0.443337	3.508	0.000451	***
Quarter 3:Region3	2.036380	0.436715	4.663	3.12e-06	***
Quarter 4:Region3	-0.097661	0.633774	-0.154	0.877535	
Quarter 2:Region4	1.906922	0.439073	4.343	1.41e-05	***
Quarter 3:Region4	1.795069	0.432085	4.154	3.26e-05	***
Quarter 4:Region4	0.128729	0.631567	0.204	0.838490	
Quarter 2:Region5	1.746876	0.454904	3.840	0.000123	***
Quarter 3:Region5	1.699061	0.443135	3.834	0.000126	***

	Estimate	Std. Error	z value	Pr(>|z|)	
Quarter 4:Region5	0.524792	0.637542	0.823	0.410423	
Quarter 2:Region6	2.310438	0.450067	5.134	2.84e-07	***
Quarter 3:Region6	2.073507	0.447686	4.632	3.63e-06	***
Quarter 4:Region6	0.296581	0.636998	0.466	0.641507	
Quarter 2:Region7	1.062535	0.653573	1.626	0.104007	
Quarter 3:Region7	1.967267	0.475238	4.140	3.48e-05	***
Quarter 4:Region7	0.472163	0.683573	0.691	0.489736	
Quarter 2:Region8	2.150917	0.575996	3.734	0.000188	***
Quarter 3:Region8	2.072721	0.534780	3.876	0.000106	***
Quarter 4:Region8	1.198140	0.749635	1.598	0.109977	
Settype 1:Hkpfl	-0.058485	0.004994	-11.711	< 2e-16	***
Settype 2:Hkpfl	0.052759	0.039703	1.329	0.183898	

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 45747 on 51529 degrees of freedom

Residual deviance: 38547 on 51408 degrees of freedom

AIC: 38791

Number of Fisher Scoring iterations: 10

Table A.1.2. Lognormal GLM output in the delta lognormal analysis from the R 'summary' function.

The variable names (main effects) are denoted as follows: "Haulyr" = fishing year (factor); "Quarter" = calendar quarter of fishing (factor); "Region" = fishing region (factor); "settype" = set type (factor); "Bait" = bait types (factor); "SST" = sea surface temperature (continuous); "Vesslen" = vessel length (continuous); "Hkpfl" = hooks per float (continuous). Interactions are denoted with a colon. The R object is named "BM_Lognormal_GLM".

```
> summary(BM_Lognormal_GLM)

Call: glm(formula = log(BlueMarlin_PC$cpue) ~ Haulyr1 + Quarter1 + Region + settype1 + Bait
+ Vesslen + Haulyr1:Quarter1 + Haulyr1:settype1 + Quarter1:Region + settype1:Hkpfl +
offset(log(Hooks)), family = gaussian, data = BlueMarlin_PC)

Deviance Residuals:

     Min        1Q    Median        3Q       Max

-1.50149  -0.33374  -0.08408   0.27170   3.16908

Coefficients: (2 not defined because of singularities)

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

(Intercept)     -4.9633074  0.2253986 -22.020  < 2e-16 ***

Haulyr11996      0.2881795  0.1601694   1.799 0.072020 .

Haulyr11997      0.1112923  0.1865905   0.596 0.550889

Haulyr11998     -0.0914442  0.1920387  -0.476 0.633961

Haulyr11999     -0.3186233  0.2086497  -1.527 0.126780

Haulyr12000     -0.3603912  0.2216030  -1.626 0.103925

Haulyr12001     -0.1248527  0.1500309  -0.832 0.405331

Haulyr12002     -0.2858547  0.1470550  -1.944 0.051945 .

Haulyr12003     -0.2665131  0.1493642  -1.784 0.074408 .

Haulyr12004     -0.3236110  0.1452313  -2.228 0.025890 *

Haulyr12005     -0.4461413  0.1471721  -3.031 0.002441 **

Haulyr12006     -0.5573940  0.1522216  -3.662 0.000252 ***
```

	Estimate	Std. Error	t value	Pr(>|t
Haulyr 2007	-0.3606318	0.1605654	-2.246	0.024729 *
Haulyr 2008	-0.5336621	0.1460125	-3.655	0.000259 ***
Haulyr 2009	-0.5787823	0.1507848	-3.838	0.000125 ***
Haulyr 2010	-0.6040128	0.1522254	-3.968	7.31e-05 ***
Haulyr 2011	-0.7228199	0.1461043	-4.947	7.67e-07 ***
Quarter 2	0.0878732	0.2386480	0.368	0.712724
Quarter 3	0.7060129	0.2396721	2.946	0.003231 **
Quarter 4	2.3894919	0.2688997	8.886	< 2e-16 ***
Region 2	-0.0457384	0.1379365	-0.332	0.740207
Region 3	-0.0309989	0.1383968	-0.224	0.822774
Region 4	-0.0162487	0.1365399	-0.119	0.905276
Region 5	-0.1570129	0.1448006	-1.084	0.278246
Region 6	-0.0798539	0.1430095	-0.558	0.576598
Region 7	-0.2223189	0.1622415	-1.370	0.170631
Region 8	-0.2244697	0.2047867	-1.096	0.273060
Settype 2	-0.4491633	0.1566355	-2.868	0.004147 **
Bait 2	-0.0292614	0.0625142	-0.468	0.639742
Bait 3	-1.1091584	0.0903748	-12.273	< 2e-16 ***
Bait 4	-1.1844530	0.1008202	-11.748	< 2e-16 ***
Bait 5	-1.1787833	0.0907487	-12.990	< 2e-16 ***
Bait 6	-1.2822786	0.0928657	-13.808	< 2e-16 ***
Bait 7	-1.1397571	0.0932615	-12.221	< 2e-16 ***
Vesslen	-0.0072735	0.0006299	-11.547	< 2e-16 ***

	Estimate	Std. Error	t value	Pr(>|t)	
Haulyr 1996:Quarter 2	-0.6103257	0.1926081	-3.169	0.001536	**
Haulyr 1997:Quarter 2	-0.3675205	0.2173188	-1.691	0.090844	.
Haulyr11998:Quarter 2	-0.4268844	0.2709206	-1.576	0.115137	
Haulyr 1999:Quarter 2	-0.4242333	0.2413933	-1.757	0.078880	.
Haulyr 2000:Quarter 2	-0.6905341	0.2711415	-2.547	0.010890	*
Haulyr 2001:Quarter 2	-0.3568804	0.1811060	-1.971	0.048807	*
Haulyr 2002:Quarter 2	-0.4213254	0.1754475	-2.401	0.016353	*
Haulyr 2003:Quarter 2	-0.2986411	0.1766037	-1.691	0.090869	.
Haulyr 2004:Quarter 2	-0.4845738	0.1731492	-2.799	0.005144	**
Haulyr 2005:Quarter 2	-0.3717761	0.1755975	-2.117	0.034272	*
Haulyr 2006:Quarter 2	-0.2838288	0.1786095	-1.589	0.112075	
Haulyr 2007:Quarter 2	-0.6279365	0.1870982	-3.356	0.000794	***
Haulyr 2008:Quarter 2	-0.4884290	0.1737110	-2.812	0.004939	**
Haulyr 2009:Quarter 2	-0.4388011	0.1779922	-2.465	0.013710	*
Haulyr 2010:Quarter 2	-0.4902743	0.1796363	-2.729	0.006361	**
Haulyr 2011:Quarter 2	-0.4824795	0.1749586	-2.758	0.005834	**
Haulyr 1996:Quarter 3	-1.0148979	0.2115886	-4.797	1.64e-06	***
Haulyr 1997:Quarter 3	-0.5732859	0.2397956	-2.391	0.016837	*
Haulyr11998:Quarter13	-0.6908883	0.2279411	-3.031	0.002445	**
Haulyr 1999:Quarter 3	-0.5954889	0.2790973	-2.134	0.032902	*
Haulyr 2000:Quarter 3	-0.1626365	0.2521554	-0.645	0.518954	
Haulyr 2001:Quarter 3	-0.6221115	0.1869021	-3.329	0.000877	***
Haulyr 2002:Quarter 3	-0.5568211	0.1851521	-3.007	0.002643	**
Haulyr 2003:Quarter 3	-0.7551208	0.1889579	-3.996	6.49e-05	***
Haulyr 2004:Quarter 3	-0.7303320	0.1821534	-4.009	6.14e-05	***

	Estimate	Std. Error	t value	Pr(>|t)	
Haulyr 2005:Quarter 3	-0.5836645	0.1840066	-3.172	0.001519	**
Haulyr 2006:Quarter 3	-0.6004485	0.1874343	-3.204	0.001363	**
Haulyr 2007:Quarter 3	-0.9279649	0.1976475	-4.695	2.71e-06	***
Haulyr 2008:Quarter 3	-0.7305771	0.1832065	-3.988	6.73e-05	***
Haulyr 2009:Quarter 3	-0.6829374	0.1857876	-3.676	0.000238	***
Haulyr 2010:Quarter 3	-0.6910853	0.1880339	-3.675	0.000239	***
Haulyr 2011:Quarter 3	-0.7258456	0.1830733	-3.965	7.41e-05	***
Haulyr 1996:Quarter 4	-0.5535938	0.1943406	-2.849	0.004402	**
Haulyr 1997:Quarter 4	-0.9639811	0.2265059	-4.256	2.10e-05	***
Haulyr 1998:Quarter 4	-0.6576461	0.2173263	-3.026	0.002485	**
Haulyr 1999:Quarter 4	-0.6367493	0.2595469	-2.453	0.014175	*
Haulyr 2000:Quarter 4	-0.4353573	0.2344658	-1.857	0.063374	.
Haulyr 2001:Quarter 4	-0.6012442	0.1699755	-3.537	0.000407	***
Haulyr 2002:Quarter 4	-0.6076158	0.1761457	-3.450	0.000564	***
Haulyr 2003:Quarter 4	-0.6560232	0.1682425	-3.899	9.72e-05	***
Haulyr 2004:Quarter 4	-0.7468117	0.1667115	-4.480	7.57e-06	***
Haulyr 2005:Quarter 4	-0.5346575	0.1693004	-3.158	0.001594	**
Haulyr 2006:Quarter 4	-0.4224729	0.1714075	-2.465	0.013732	*
Haulyr 2007:Quarter 4	-0.8911905	0.1790840	-4.976	6.61e-07	***
Haulyr 2008:Quarter 4	-0.7613715	0.1683999	-4.521	6.23e-06	***
Haulyr 2009:Quarter 4	-0.8021451	0.1787939	-4.486	7.34e-06	***
Haulyr 2010:Quarter 4	-0.7794583	0.1754327	-4.443	8.98e-06	***
Haulyr 2011:Quarter 4	-0.6993633	0.1696063	-4.123	3.77e-05	***

	Estimate	Std. Error	t value	Pr(>|t)
Haulyr 1996:settype 2	0.2448899	0.1229847	1.991	0.046489 *
Haulyr 1997:settype 2	0.4084796	0.1429617	2.857	0.004284 **
Haulyr 1998:settype 2	0.3256768	0.1376599	2.366	0.018013 *
Haulyr 1999:settype 2	0.6805995	0.1608660	4.231	2.35e-05 ***
Haulyr 2000:settype 2	0.9381823	0.1184219	7.922	2.63e-15 ***
Haulyr 2001:settype 2	0.2658602	0.1988081	1.337	0.181171
Haulyr 2002:settype 2	NA	NA	NA	NA
Haulyr 2003:settype 2	NA	NA	NA	NA
Haulyr 2004:settype 2	1.6000184	0.3947401	4.053	5.09e-05 ***
Haulyr 2005:settype 2	1.7512172	0.1426171	12.279	< 2e-16 ***
Haulyr 2006:settype 2	1.8350861	0.2438475	7.526	5.79e-14 ***
Haulyr 2007:settype 2	1.6773937	0.1574311	10.655	< 2e-16 ***
Haulyr 2008:settype 2	1.8589095	0.1415671	13.131	< 2e-16 ***
Haulyr 2009:settype 2	1.5982871	0.1449225	11.029	< 2e-16 ***
Haulyr 2010:settype 2	1.5236439	0.1513739	10.065	< 2e-16 ***
Haulyr 2011:settype 2	1.5841237	0.1494077	10.603	< 2e-16 ***
Quarter 2:Region 2	0.3773181	0.1810310	2.084	0.037165 *
Quarter 3:Region 2	0.2676992	0.1722116	1.554	0.120108
Quarter4:Region 2	-1.4871275	0.2258276	-6.585	4.81e-11 ***
Quarter 2:Region 3	0.4019204	0.1759519	2.284	0.022381 *
Quarter 3:Region 3	0.1389025	0.1693827	0.820	0.412210
Quarter 4:Region 3	-1.7406360	0.2224969	-7.823	5.77e-15 ***
Quarter 2:Region 4	0.4873486	0.1728502	2.819	0.004821 **
Quarter 3:Region 4	0.1467959	0.1664665	0.882	0.377892
Quarter 4:Region 4	-1.7280547	0.2204604	-7.838	5.12e-15 ***

	Estimate	Std. Error	t value	Pr(>|t)	
Quarter12:Region5	0.3346564	0.1824603	1.834	0.066670	.
Quarter13:Region5	-0.0310973	0.1746304	-0.178	0.858668	
Quarter14:Region5	-1.6921361	0.2252671	-7.512	6.43e-14	***
Quarter12:Region6	0.4251462	0.1799405	2.363	0.018165	*
Quarter 3:Region 6	-0.0008249	0.1757398	-0.005	0.996255	
Quarter 4:Region 6	-1.7336011	0.2248867	-7.709	1.42e-14	***
Quarter 2:Region 7	0.2767115	0.2972259	0.931	0.351890	
Quarter 3:Region 7	-0.0304420	0.1938045	-0.157	0.875189	
Quarter 4:Region 7	-1.7241926	0.2579519	-6.684	2.47e-11	***
Quarter 2:Region 8	0.3271171	0.2532897	1.291	0.196575	
Quarter 3:Region 8	-0.0328873	0.2295022	-0.143	0.886058	
Quarter 4:Region 8	-1.4968197	0.2913994	-5.137	2.86e-07	***
Settype 1:Hkpfl	-0.0431495	0.0021880	-19.721	< 2e-16	***
Settype 2:Hkpfl	-0.0983510	0.0179521	-5.479	4.41e-08	***

(Dispersion parameter for gaussian family taken to be 0.2497563)

Null deviance: 6068.1 on 8531 degrees of freedom

Residual deviance: 2100.9 on 8412 degrees of freedom

AIC: 12498

Number of Fisher Scoring iterations: 2

Figure A1.1. Mean residuals per observed trip from the lognormal GLM plotted against the mean fitted values per observed fishing trip.

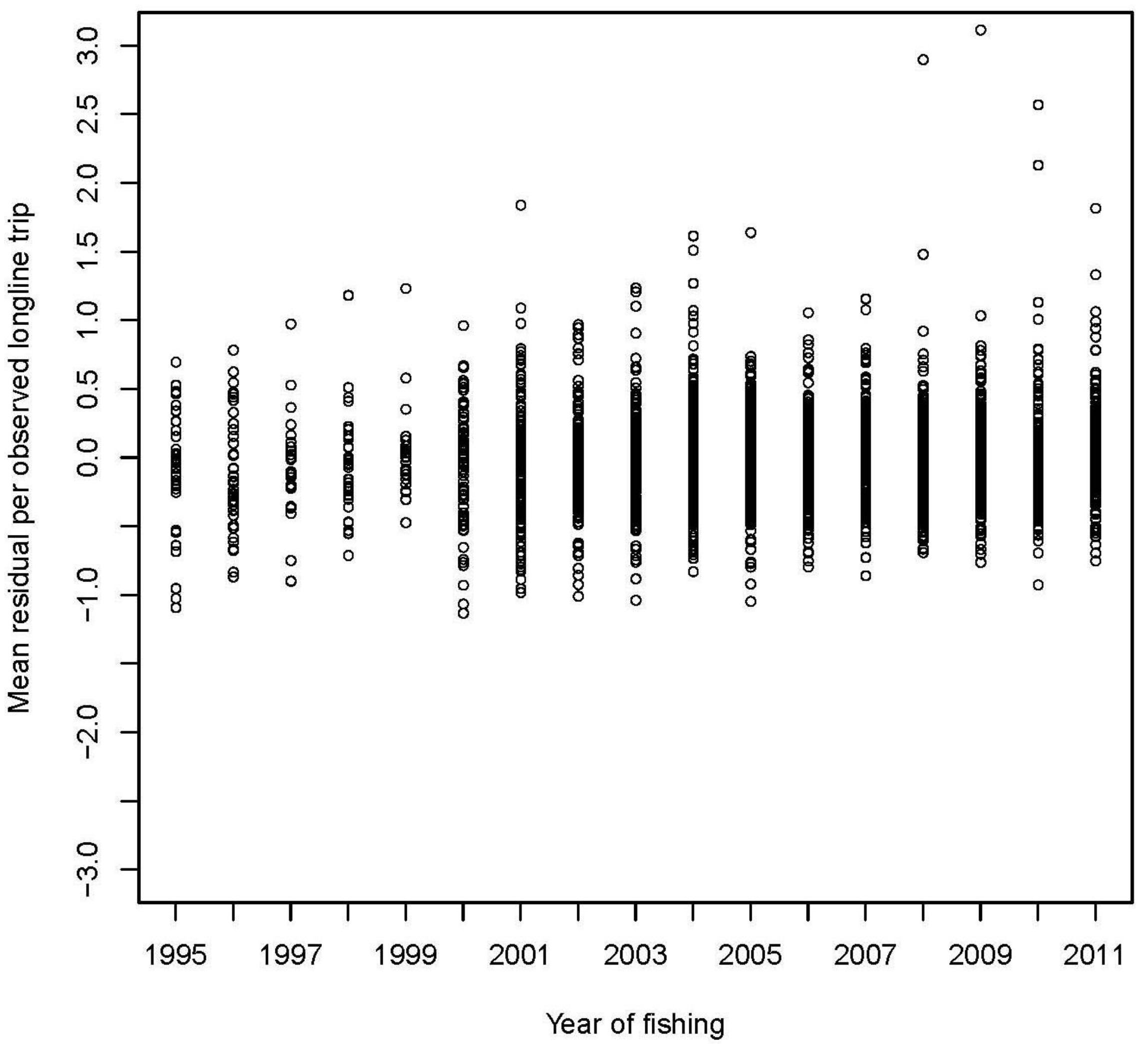


Figure A1.2 Histogram of residuals from the lognormal GLM.

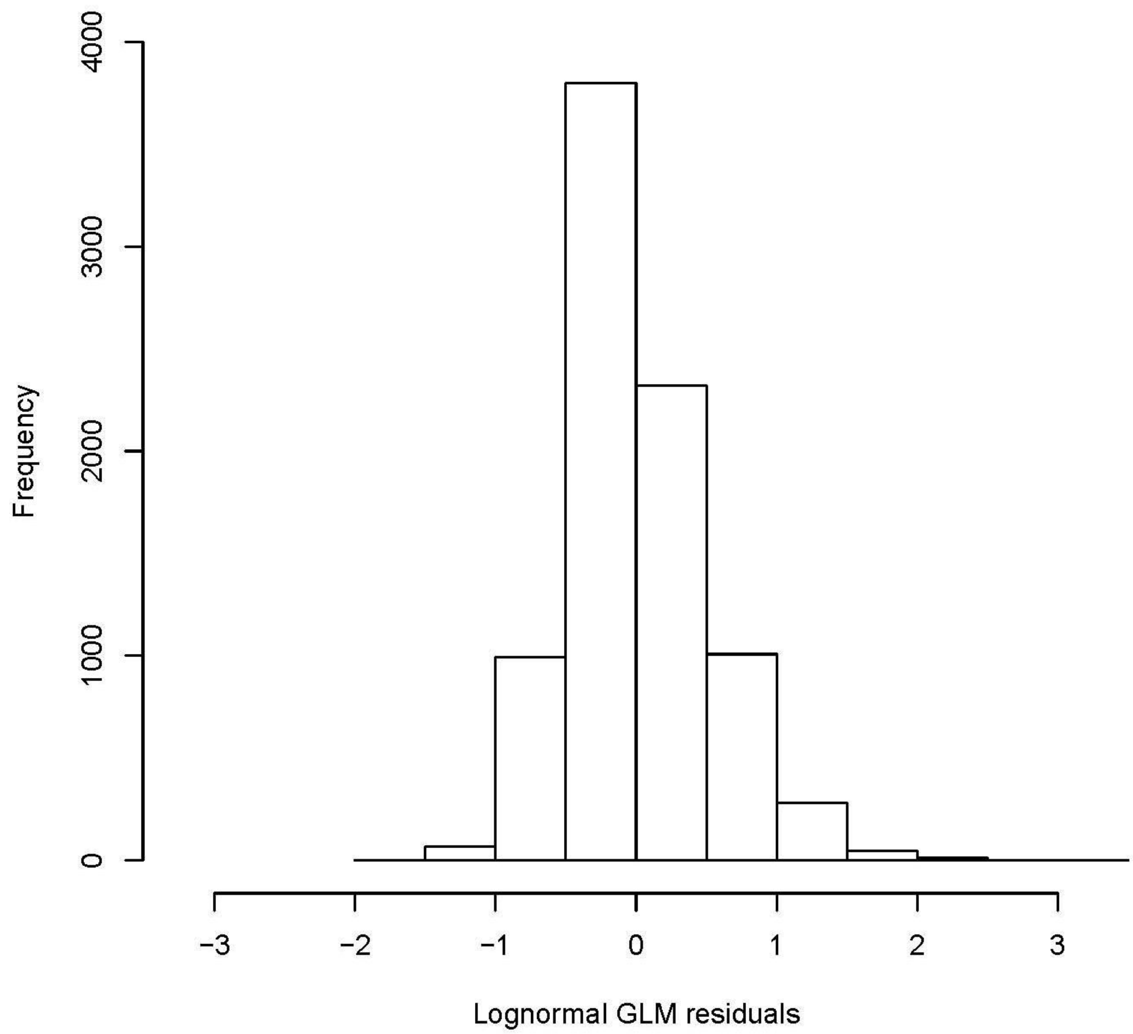


Figure A.1.3. Normal probability (quantile/quantile) plot of the mean residuals per observed trip from the lognormal GLM.

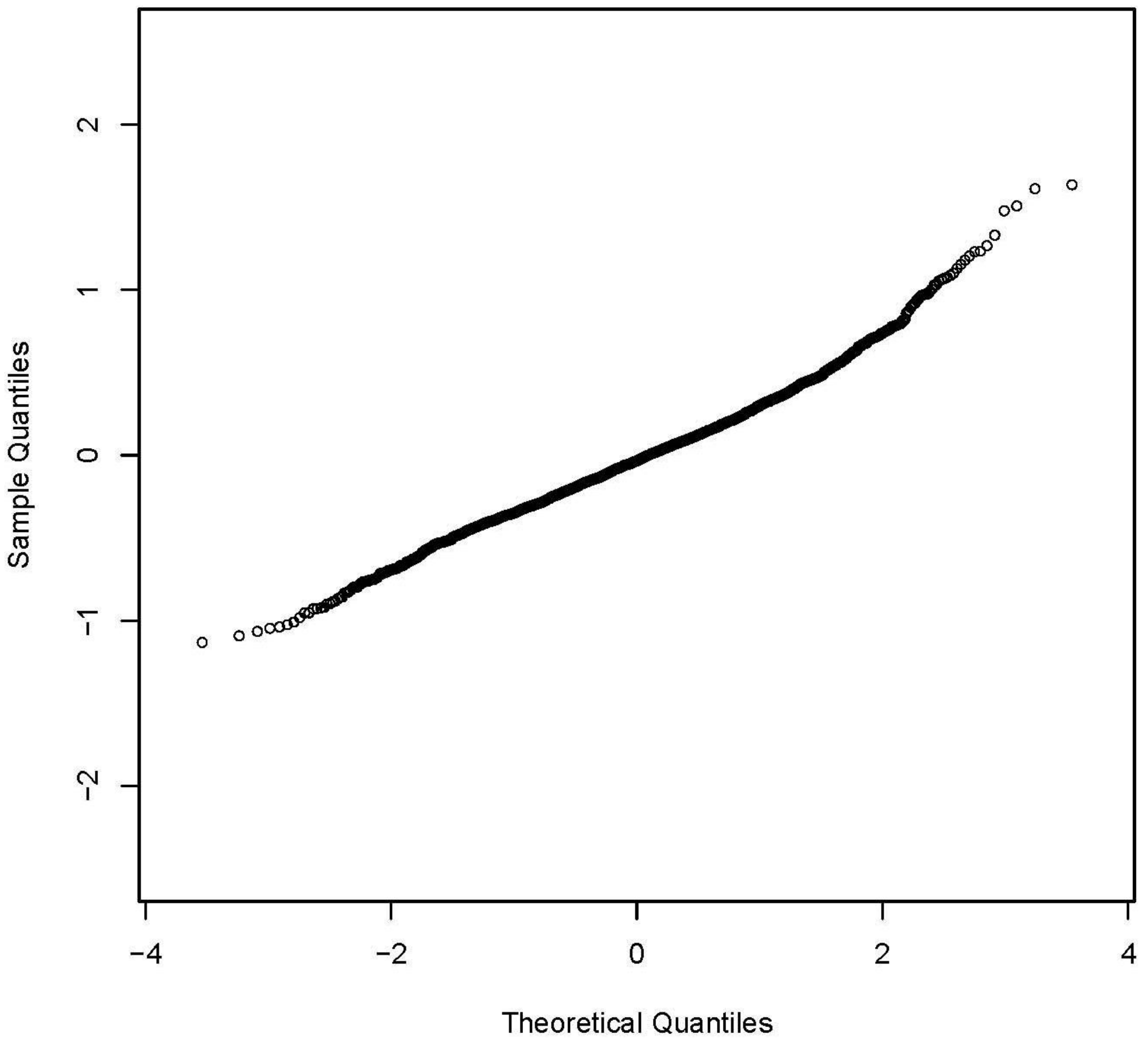
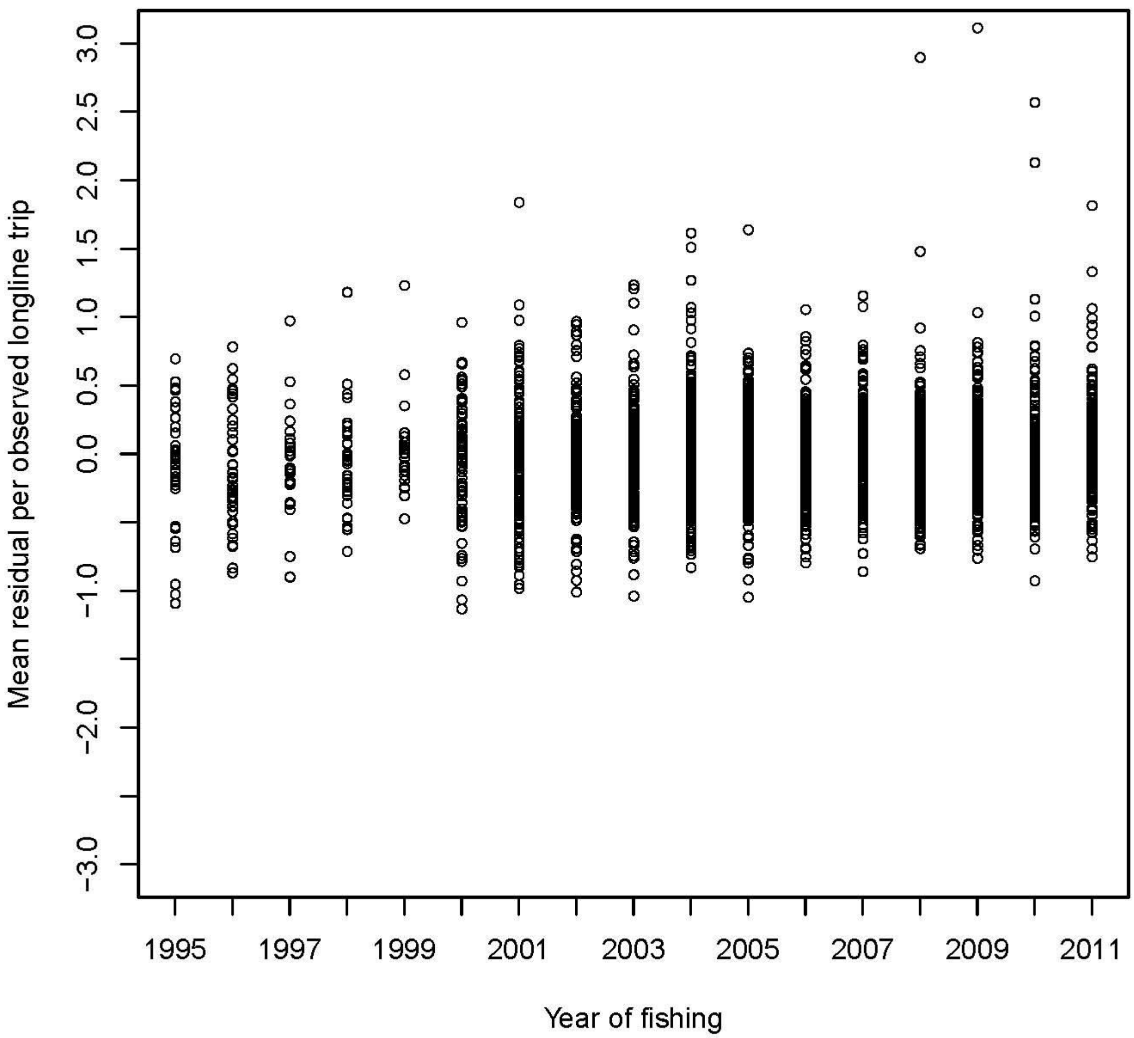


Figure A1.4. Mean residuals per observed trip from the lognormal GLM plotted against the year of fishing.



APPENDIX II:
ZERO-INFLATED MODEL SUMMARY OUTPUT AND DIAGNOSTICS PLOTS

Table A.2.1. Zero-inflated negative binomial GLM output from the R 'summary' function.

The variable names (main effects) are denoted as follows: "Haulyr" = fishing year (factor); "Quarter" = calendar quarter of fishing (factor); "Region" = fishing region (factor); "settype" = set type (factor); "Bait" = bait types (factor); "SST" = sea surface temperature (continuous); "Vesslen" = vessel length (continuous); "Hkpfl" = hooks per float (continuous). Interactions are denoted with a colon. The R object is named "BM_ZI_NegBin_GLM".

Model formula:

(BlueMarlin~Haulyr1+Quarter1+Region+settype1+Bait+Haulyr1:Quarter1+Haulyr1:settype1+ Quarter1:Region+settype1:Hkpfl+offset(log(Hooks)) | Haulyr1+Bait+Vesslen+settype1:Hkpfl)

Model call:

```
> BM_ZI_NegBin_GLM<-zeroinfl(f_NB_16,dist="negbin",link="logit",data=Observer1)
```

Model summary: Pearson residuals:

Minimum	1Q	Median	3Q	Maximum
-0.9969	-0.4121	-0.2925	-0.1166	28.9648

Count model coefficients (negbin with log link):

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-8.392315	0.530316	-15.825	< 2e-16 ***
Haulyr 1996	1.921578	0.343327	5.597	2.18e-08 ***
Haulyr 1997	0.803711	0.412167	1.950	0.051180 .
Haulyr 1998	0.769882	0.415114	1.855	0.063649 .
Haulyr 1999	-0.150400	0.416290	-0.361	0.717885
Haulyr 2000	-0.554077	0.456599	-1.213	0.224944
Haulyr 2001	0.503277	0.322970	1.558	0.119168
Haulyr 2002	-0.174325	0.309458	-0.563	0.573213
Haulyr 2003	0.078653	0.315040	0.250	0.802851
Haulyr 2004	0.101309	0.304950	0.332	0.739726
Haulyr 2005	0.051948	0.304757	0.170	0.864651

Table A.2.1, continued.

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 2006	0.087070	0.316202	0.275	0.783038
Haulyr 2007	-0.116798	0.329863	-0.354	0.723279
Haulyr 2008	-0.312887	0.301316	-1.038	0.299084
Haulyr 2009	-0.313825	0.310828	-1.010	0.312667
Haulyr 2010	-0.551194	0.313431	-1.759	0.078648 .
Haulyr 2011	-0.617484	0.302283	-2.043	0.041079 *
Quarter 2	-0.041592	0.495079	-0.084	0.933048
Quarter 3	0.739918	0.478735	1.546	0.122209
Quarter 4	2.484184	0.516492	4.810	1.51e-06 ***
Region2	-0.757833	0.286829	-2.642	0.008239 **
Region3	-1.174948	0.289079	-4.064	4.81e-05 ***
Region4	-0.568308	0.285583	-1.990	0.046592 *
Region5	-2.130050	0.301183	-7.072	1.52e-12 ***
Region6	-1.563678	0.296194	-5.279	1.30e-07 ***
Region7	-2.483557	0.336318	-7.385	1.53e-13 ***
Region8	-2.217339	0.410894	-5.396	6.80e-08 ***
settype 2	-1.824186	0.324888	-5.615	1.97e-08 ***
Bait02	-0.341286	0.158795	-2.149	0.031617 *
Bait03	-0.723622	0.177121	-4.085	4.40e-05 ***
Bait04	-0.850257	0.198613	-4.281	1.86e-05 ***
Bait05	-0.852397	0.178216	-4.783	1.73e-06 ***
Bait06	-1.105357	0.186242	-5.935	2.94e-09 ***
Bait07	-1.010861	0.184450	-5.480	4.24e-08 ***
SST	0.126984	0.010393	12.218	< 2e-16 ***

Table A.2.1, continued.

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 1996:Quarter 2	-2.430832	0.397015	-6.123	9.20e-10 ***
Haulyr 1997:Quarter12	-0.880598	0.460095	-1.914	0.055627 .
Haulyr 1998:Quarter 2	-2.134221	0.552768	-3.861	0.000113 ***
Haulyr 1999:Quarter 2	-1.119577	0.476130	-2.351	0.018703 *
Haulyr 2000:Quarter 2	-1.728037	0.547442	-3.157	0.001596 **
Haulyr 2001:Quarter 2	-1.387664	0.368061	-3.770	0.000163 ***
Haulyr 2002:Quarter 2	-1.205963	0.355696	-3.390	0.000698 ***
Haulyr 2003:Quarter 2	-0.756253	0.357910	-2.113	0.034603 *
Haulyr 2004:Quarter 2	-1.452285	0.350477	-4.144	3.42e-05 ***
Haulyr 2005:Quarter 2	-1.130455	0.354592	-3.188	0.001432 **
Haulyr 2006:Quarter 2	-1.371904	0.361753	-3.792	0.000149 ***
Haulyr 2007:Quarter 2	-1.649938	0.377193	-4.374	1.22e-05 ***
Haulyr 2008:Quarter 2	-1.183226	0.349014	-3.390	0.000698 ***
Haulyr 2009:Quarter 2	-1.092564	0.358697	-3.046	0.002320 **
Haulyr 2010:Quarter 2	-1.071771	0.361196	-2.967	0.003004 **
Haulyr 2011:Quarter 2	-1.164980	0.352720	-3.303	0.000957 ***
Haulyr 1996:Quarter 3	-3.097375	0.438977	-7.056	1.71e-12 ***
Haulyr 1997:Quarter 3	-0.805029	0.529074	-1.522	0.128114
Haulyr 1998:Quarter 3	-1.252765	0.479706	-2.612	0.009014 **
Haulyr 1999:Quarter 3	-0.332378	0.541199	-0.614	0.539116
Haulyr 2000:Quarter 3	-0.316435	0.507142	-0.624	0.532656
Haulyr 2001:Quarter 3	-1.348861	0.378661	-3.562	0.000368 ***
Haulyr 2002:Quarter 3	-1.161026	0.371267	-3.127	0.001765 **
Haulyr 2003:Quarter 3	-1.280283	0.378739	-3.380	0.000724 ***
Haulyr 2004:Quarter 3	-1.952302	0.365804	-5.337	9.45e-08 ***

Table A.2.1, continued.

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 2005:Quarter 3	-1.355028	0.368715	-3.675	0.000238 ***
Haulyr 2006:Quarter 3	-1.697078	0.377325	-4.498	6.87e-06 ***
Haulyr 2007:Quarter 3	-1.891029	0.395606	-4.780	1.75e-06 ***
Haulyr 2008:Quarter 3	-1.196086	0.366277	-3.266	0.001093 **
Haulyr 2009:Quarter 3	-1.198018	0.371535	-3.225	0.001262 **
Haulyr 2010:Quarter 3	-1.170647	0.375429	-3.118	0.001820 **
Haulyr 2011:Quarter 3	-1.177392	0.367055	-3.208	0.001338 **
Haulyr 1996:Quarter 4	-2.467171	0.392580	-6.285	3.29e-10 ***
Haulyr 1997:Quarter 4	-2.279663	0.478454	-4.765	1.89e-06 ***
Haulyr 1998:Quarter 4	-1.329307	0.440095	-3.020	0.002524 **
Haulyr 1999:Quarter 4	-1.965655	0.510900	-3.847	0.000119 ***
Haulyr 2000:Quarter 4	-0.817966	0.468880	-1.745	0.081070 .
Haulyr 2001:Quarter 4	-1.746834	0.340100	-5.136	2.80e-07 ***
Haulyr 2002:Quarter 4	-2.252744	0.349464	-6.446	1.15e-10 ***
Haulyr 2003:Quarter 4	-1.551066	0.336231	-4.613	3.97e-06 ***
Haulyr 2004:Quarter 4	-2.421596	0.332517	-7.283	3.27e-13 ***
Haulyr 2005:Quarter 4	-2.084544	0.336826	-6.189	6.06e-10 ***
Haulyr 2006:Quarter 4	-1.564347	0.341788	-4.577	4.72e-06 ***
Haulyr 2007:Quarter 4	-2.461180	0.355260	-6.928	4.27e-12 ***
Haulyr 2008:Quarter 4	-1.740151	0.334067	-5.209	1.90e-07 ***
Haulyr 2009:Quarter 4	-2.770951	0.354303	-7.821	5.25e-15 ***
Haulyr 2010:Quarter 4	-2.219914	0.348715	-6.366	1.94e-10 ***
Haulyr 2011:Quarter 4	-2.072653	0.337404	-6.143	8.10e-10 ***

Table A.2.1, continued.

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 1996:settype 2	0.394972	0.255042	1.549	0.121465
Haulyr 1997:settype 2	0.635411	0.317155	2.003	0.045126 *
Haulyr 1998:settype 2	0.243748	0.299560	0.814	0.415825
Haulyr 1999:settype 2	0.255906	0.321190	0.797	0.425601
Haulyr 2000:settype 2	1.637114	0.244818	6.687	2.28e-11 ***
Haulyr 2001:settype 2	-0.057385	0.470898	-0.122	0.903008
Haulyr 2002:settype2	-7.670916	157.43320	-0.049	0.961139
Haulyr 2003:settype 2	-8.548089	373.24305	-0.023	0.981728
Haulyr 2004:settype 2	2.181498	1.103038	1.978	0.047961 *
Haulyr 2005:settype 2	1.328025	0.291430	4.557	5.19e-06 ***
Haulyr 2006:settype 2	-0.442274	0.492341	-0.898	0.369021
Haulyr 2007:settype 2	0.392354	0.346639	1.132	0.257684
Haulyr 2008:settype 2	1.948785	0.288774	6.748	1.49e-11 ***
Haulyr 2009:settype 2	0.616270	0.317180	1.943	0.052020 .
Haulyr 2010:settype 2	-0.070899	0.304277	-0.233	0.815755
Haulyr 2011:settype 2	0.865129	0.314119	2.754	0.005885 **
Quarter 2:Region 2	1.394274	0.380051	3.669	0.000244 ***
Quarter 3:Region 2	1.477061	0.340590	4.337	1.45e-05 ***
Quarter 4:Region 2	-0.055917	0.423067	-0.132	0.894849
Quarter 2:Region 3	1.581390	0.370728	4.266	1.99e-05 ***
Quarter 3:Region 3	1.382102	0.335312	4.122	3.76e-05 ***
Quarter 4:Region 3	-0.684654	0.418421	-1.636	0.101781
Quarter 2:Region 4	1.786350	0.365677	4.885	1.03e-06 ***
Quarter 3:Region 4	1.054051	0.329967	3.194	0.001401 **
Quarter 4:Region 4	-0.467998	0.413491	-1.132	0.257709

Table A.2.1, continued.

	Estimate	Std. Error	z value	Pr(>|z|)
Quarter 2:Region 5	1.757965	0.382358	4.598	4.27e-06 ***
Quarter 3:Region 5	1.053829	0.344570	3.058	0.002225 **
Quarter 4:Region 5	0.048387	0.423651	0.114	0.909067
Quarter 2:Region 6	2.240389	0.376693	5.948	2.72e-09 ***
Quarter 3:Region 6	1.296097	0.346291	3.743	0.000182 ***
Quarter 4:Region 6	-0.259674	0.422197	-0.615	0.538519
Quarter 2:Region 7	0.761557	0.607067	1.254	0.209666
Quarter 3:Region 7	1.039574	0.385906	2.694	0.007063 **
Quarter 4:Region 7	-0.187012	0.490018	-0.382	0.702727
Quarter 2:Region8	1.821569	0.514630	3.540	0.000401 ***
Quarter 3:Region 8	1.123004	0.450803	2.491	0.012734 *
Quarter 4:Region 8	0.746933	0.553553	1.349	0.177227
settype 1:Hkpfl	-0.075065	0.004501	-16.678	< 2e-16 ***
settype 2:Hkpfl	0.034763	0.043512	0.799	0.424328
Log(theta)	0.311716	0.051926	6.003	1.94e-09 ***

Zero-inflation model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	12.91223	1.36855	9.435	< 2e-16 ***
Haulyr 1996	1.38652	0.60975	2.274	0.022971 *
Haulyr 1997	1.43319	0.65697	2.182	0.029144 *
Haulyr 1998	1.82656	0.69287	2.636	0.008384 **
Haulyr 1999	-3.50071	3.43059	-1.020	0.307521
Haulyr 2000	1.52415	0.61126	2.493	0.012650 *
Haulyr 2001	2.06747	0.56947	3.630	0.000283 ***

Table A.2.1, continued.

	Estimate	Std. Error	z value	Pr(>|z|)
Haulyr 2002	-0.04693	0.80513	-0.058	0.953522
Haulyr 2003	1.12969	0.63369	1.783	0.074633 .
Haulyr 2004	0.93422	0.66938	1.396	0.162820
Haulyr 2005	-2.11828	0.67406	-3.143	0.001675 **
Haulyr 2006	-16.60990	512.78841	-0.032	0.974160
Haulyr 2007	-3.93176	1.17394	-3.349	0.000810 ***
Haulyr 2008	-2.09046	0.68305	-3.061	0.002210 **
Haulyr 2009	-3.24671	1.05366	-3.081	0.002061 **
Haulyr 2010	-21.14524	5355.5137	-0.004	0.996850
Haulyr 2011	-3.98787	1.28695	-3.099	0.001944 **
Bait 2	-0.79850	0.49711	-1.606	0.108213
Bait 3	3.79029	0.60032	6.314	2.72e-10 ***
Bait 4	3.48047	0.54919	6.337	2.34e-10 ***
Bait 5	3.45945	0.60022	5.764	8.23e-09 ***
Bait 6	3.93956	0.67122	5.869	4.38e-09 ***
Bait 7	4.12807	0.72068	5.728	1.02e-08 ***
SST	-0.44477	0.03411	-13.038	< 2e-16 ***
Vesslen	-0.05800	0.00827	-7.013	2.33e-12 ***
settype1:Hkpfl	-0.15223	0.02421	-6.288	3.21e-10 ***
settype 2:Hkpfl	0.02563	0.12048	0.213	0.831546

Theta = 1.3658

Number of iterations in BFGS optimization: 180

Log-likelihood: -2.651e+04 on 150 Df

Figure A2.1. Mean Pearson residuals per observed trip from the zero-inflated negative binomial GLM plotted against the mean fitted values per observed fishing trip.

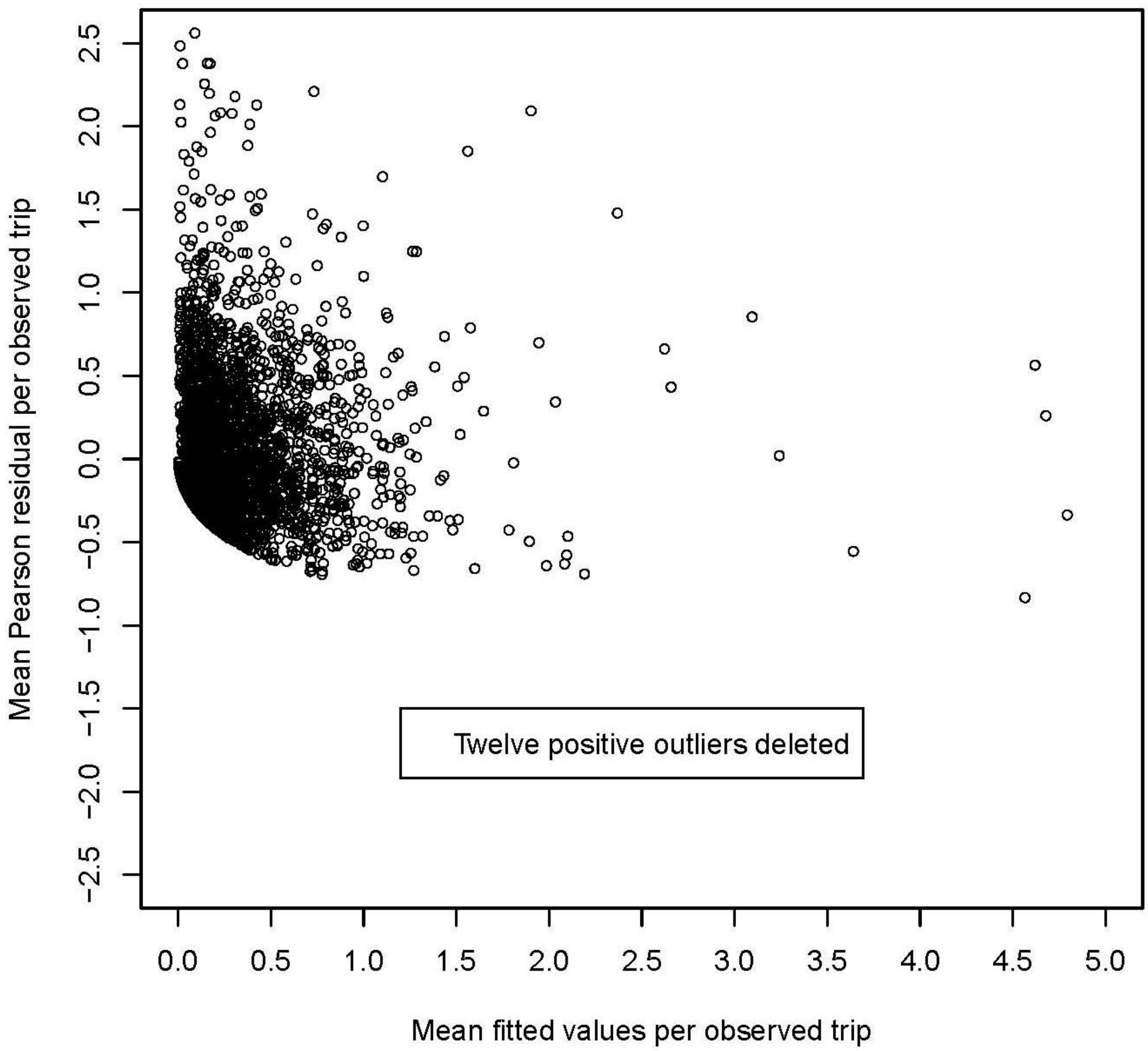


Figure A.2.2. Histogram of mean Pearson residuals per observed fishing trips.

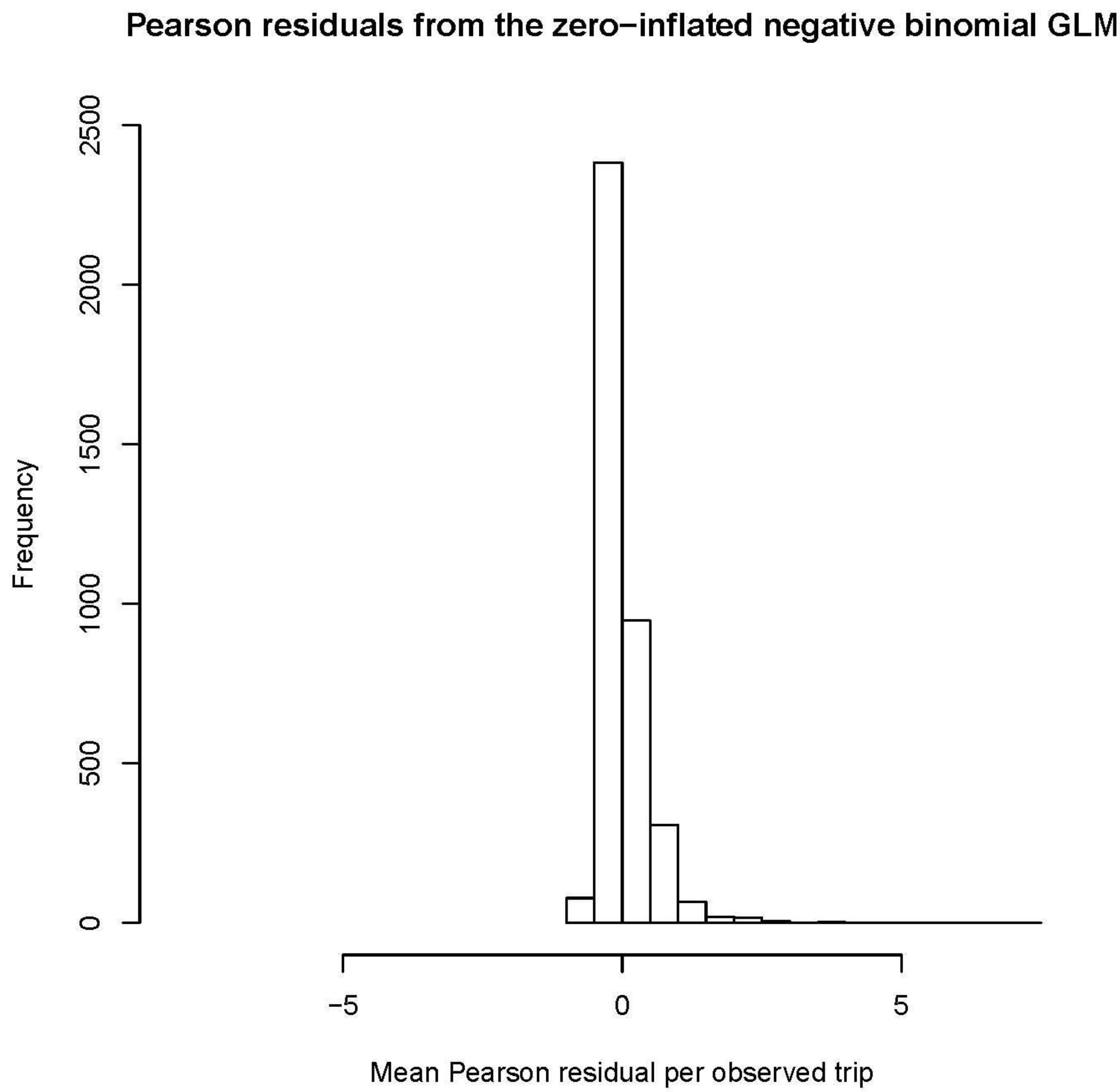


Figure A.2.3. Mean Pearson residuals per observed fishing trip plotted on the fishing years.

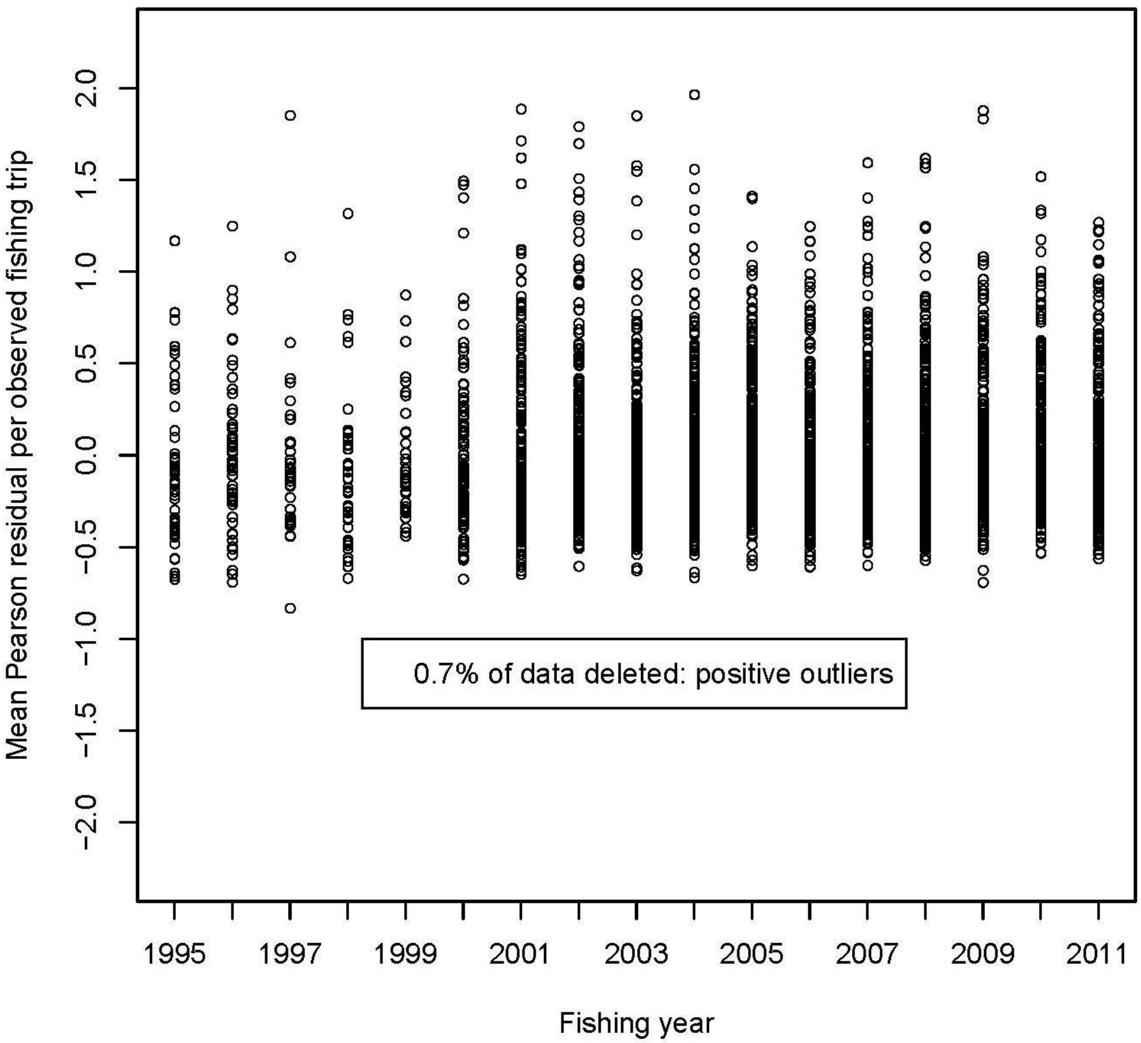


Figure A.2.4. Mean Pearson residuals per observed fishing trip plotted on the calendar quarters of fishing.

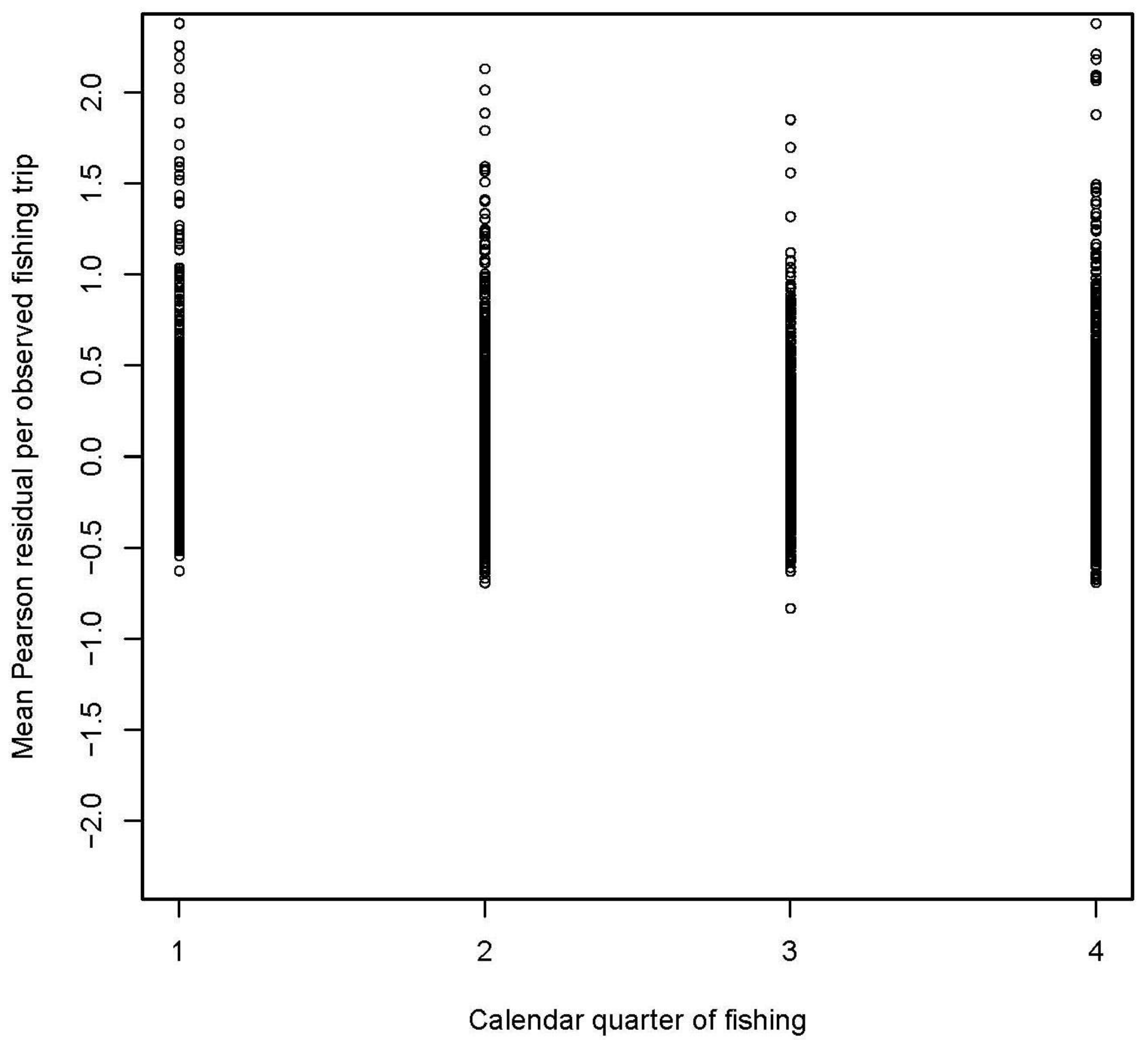


Figure A.2.5. Mean Pearson residuals per observed fishing trips plotted on the regions of fishing:
Region 1: 0–10°N, east of 160°W; Region 2: 0–10°N, west of 160°W;
Region 3:10–20°N, east of 160°W; Region 4: 10–20°N, west of 160°W;
Region 5:20–30°N, east of 160°W; Region 6:20–30°N, west of 160°W;
Region 7: above 30°N, east of 160°W; Region 8: above 30°N, west of 160°W.

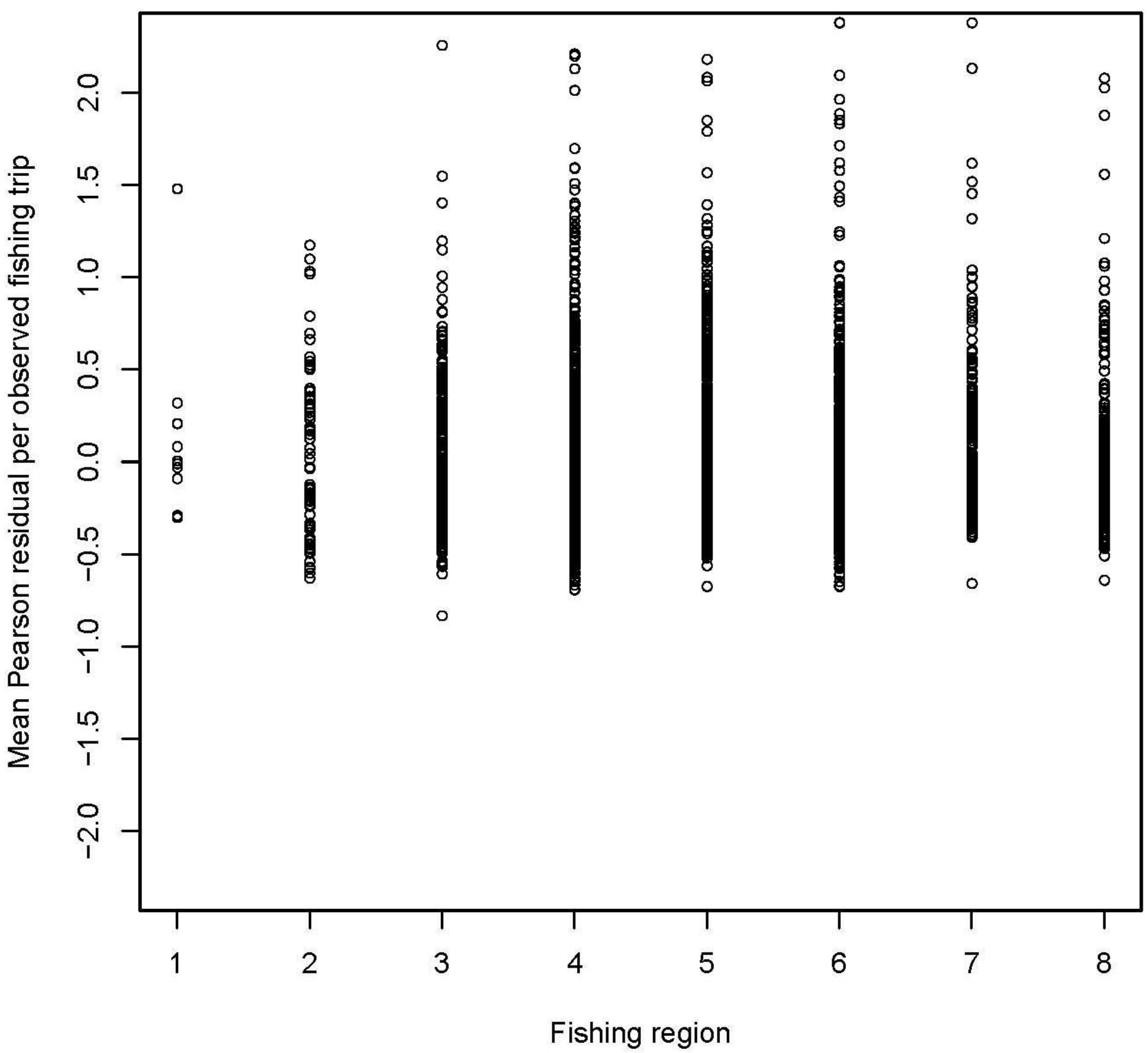
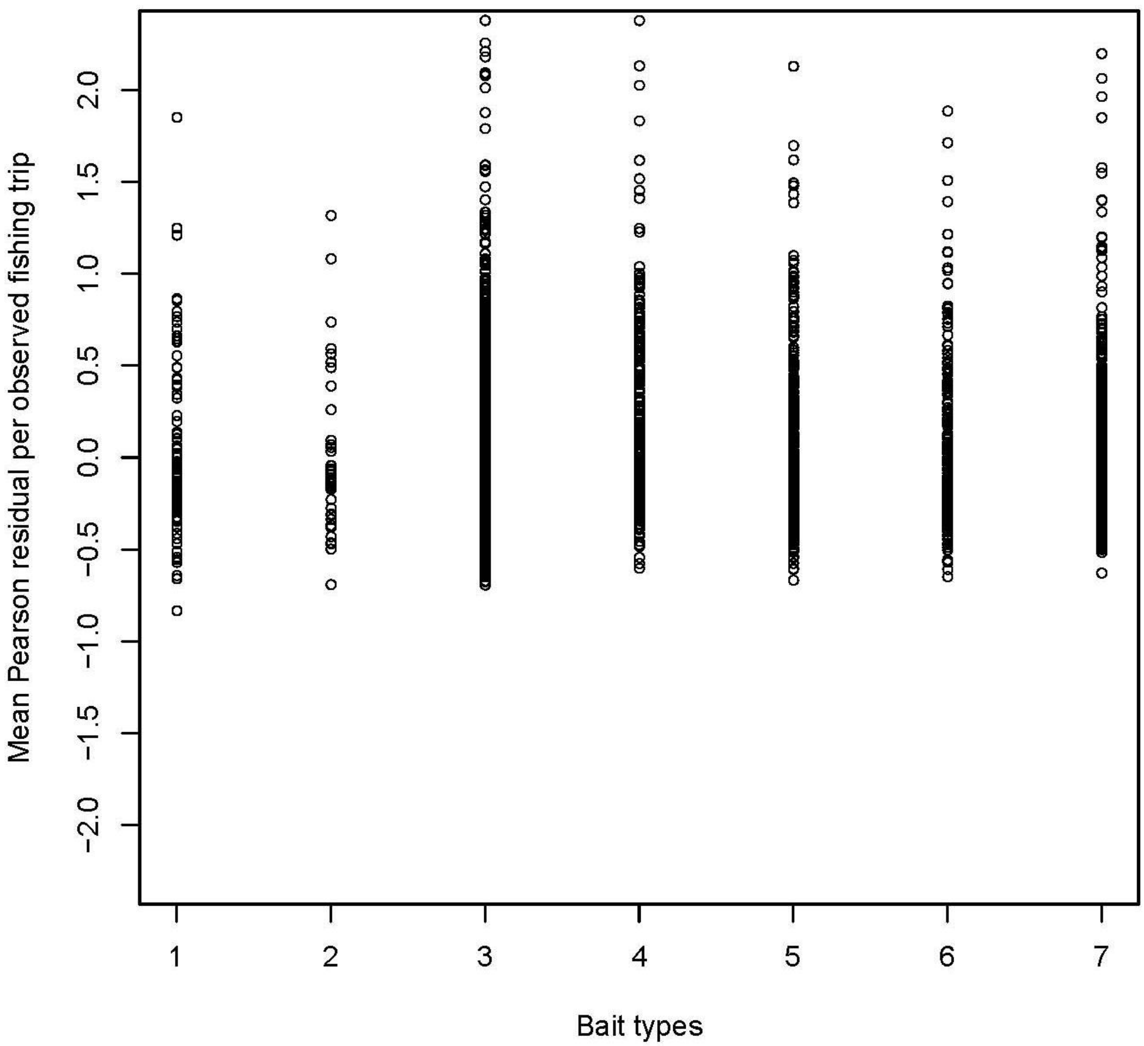


Figure A.2.6. Mean Pearson residuals per observed fishing trips plotted on the bait types, defined as:
Type 1 = large squid; Type 2 = small squid; Type 3 = sauries *Cololabis* sp.;
Type 4 = mackerel *Scomber japonicus*; Type 5 = “Mixed fish”; Type 6 = “Other”;
Type 7 = sardines (Clupeidae). .



APPENDIX III:

DELTA LOGNORMAL MODEL BOOTSTRAPPING OUTPUT

Table A.3.1. Means and coefficients of variation of standardized CPUE derived from the delta-log-normal model by using the bootstrap approach.

Year	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	mean	CV	mean	CV	mean	CV	mean	CV
1995	0.26	21.62	0.90	12.60	1.11	14.54	0.99	11.47
1996	0.74	11.89	0.61	9.35	0.50	15.21	0.69	14.75
1997	0.39	20.24	0.82	9.92	1.44	16.12	0.40	15.60
1998	0.36	19.28	0.29	26.28	0.63	11.88	0.44	15.43
1999	0.25	24.59	0.39	14.56	0.71	17.91	0.27	20.87
2000	0.13	28.91	0.13	28.10	0.61	10.98	0.37	6.66
2001	0.25	9.79	0.41	8.11	0.46	8.78	0.37	7.02
2002	0.21	8.75	0.34	5.24	0.38	7.83	0.20	12.39
2003	0.22	10.21	0.55	4.63	0.39	8.42	0.36	5.91
2004	0.25	6.76	0.33	5.28	0.24	6.26	0.19	8.08
2005	0.25	8.26	0.45	5.17	0.42	6.43	0.27	7.84
2006	0.27	9.07	0.40	4.43	0.33	5.75	0.38	6.29
2007	0.26	12.50	0.26	7.73	0.24	8.52	0.17	6.65
2008	0.20	8.11	0.34	4.94	0.36	5.99	0.26	7.97
2009	0.21	9.70	0.35	5.61	0.35	5.33	0.12	11.98
2010	0.19	9.75	0.30	5.16	0.31	6.50	0.16	9.16
2011	0.16	7.40	0.27	5.81	0.28	6.34	0.17	9.04

Fig. A. 3. 1. Quarterly effects on blue marlin standardized CPUE as estimated with the delta-lognormal GLM. The black dash line and shadow indicated the means and 95% confidence intervals for the standardized CPUE, respectively.