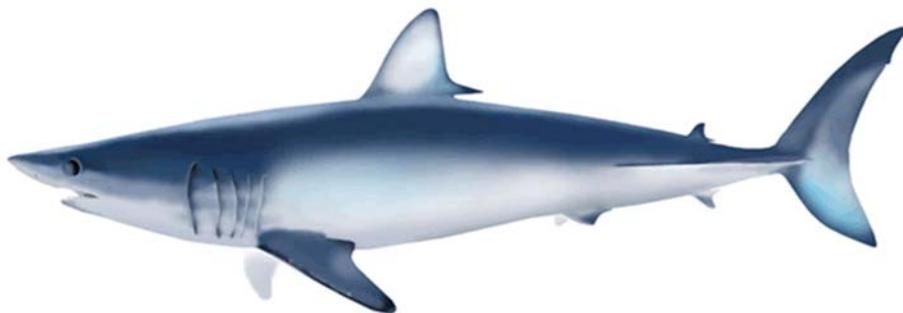


**Hawaii Longline Blue Shark Catch Rate Standardizations:  
A Summary and Recompilation of Information submitted to the ISC SHARKWG in  
2011-2014**

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## **Abstract**

This document consists primarily of information previously submitted to the SHARKWG, with a blue shark *Prionace glauca* catch rate standardization analysis from 2012, an updated analysis provided in January 2014, and a new addendum to the latter document. This document is provided in response to inquiries from the SHARKWG chair regarding previous work about catch rate standardizations for blue shark in the Hawaii-based pelagic longline fishery. The inquiries questioned data quality, use and preparation, statistical accuracy and validity, and conformity to appropriate standards of scientific rigor and integrity.

## **Introduction**

This document presents information previously submitted to the SHARKWG with some new information appended. The largest section consists of an insert of an ISC SHARKWG working paper from 2012. This document is provided in response to inquiries from the SHARKWG chair regarding data quality, statistical accuracy, and conformity to appropriate standards of scientific rigor. The fishery in question is the Hawaii-based pelagic longline fishery; the data source is the NOAA Fisheries Pacific Islands Regional Observer Program; and the species of interest is blue shark *Prionace glauca*.

In response to the recent inquiry, this report underwent independent review and was deemed to conform fully to best scientific practices standards. Therefore, the previous work has not been revised or rewritten, and statistical procedures in the update were not changed substantively. The principal difference was use of a counts model (negative binomial) rather than a mixture model (delta-lognormal) for catch rate standardization.

**Catch Statistics, Length Data and Standardized CPUE for Blue Shark *Prionace glauca*  
taken by Longline Fisheries based in Hawaii and California<sup>1</sup>**

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**Abstract**

This working paper (WP) presents compilations of catches, length distributions, catch per unit effort (CPUE) standardizations and other information for blue shark *Prionace glauca* in US Pacific longline fisheries. The objective of this WP is to provide inputs to a stock assessment for blue shark to be conducted under the auspices of the ISC Sharks Working Group in 2012. The blue shark catch in waters near Hawaii from 1991 through 2011 was estimated by using fishery observer data and self-reported data from mandatory commercial logbooks. CPUE was standardized by the delta-lognormal method for both the deep-set (target: bigeye tuna) and shallow-set sectors (target: swordfish) of the Hawaii-based longline fishery. The haul year, haul quarter, and region of fishing were factor variables, and a cubic function of SST was a continuous explanatory variable in all models. The indices of relative abundance decreased over time in both sectors. Mean total lengths of both sexes in the two sectors of the Hawaii-based longline fishery varied by 9.7% (shallow-set sector males: 211.9 cm; shallow-set sector females: 207.5 cm; deep-set sector males: 227.7 cm; deep-set sector females: 211.8 cm). Blue shark sex ratios were characterized by predominance of males in tropical waters (0–10°N) and above 30°N in the deep-set sector and predominance of females at 20–30°N in the shallow-set sector. Other results from Hawaii include maps of observed catches and CPUE in 1996, 2001, 2006 and 2011, and a summary of the typical bias in self-reported blue shark catch data. Results from California include catch data from two fisheries in 1988–2004.

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<sup>1</sup> PIFSC Working Paper WP-12-003. Issued 23 May 2012

## Introduction

This working paper (WP) presents compilations of catches, catch per unit effort (CPUE) standardizations, sex ratios and total length distributions for blue shark *Prionace glauca* in US Pacific longline fisheries. The main sources of data are commercial logbooks and observer reports from the Hawaii-based pelagic longline fishery, but data from vessels that operated wholly or in part in California are also included.

The blue shark is a widely distributed, oceanic, pelagic shark (Compagno 1984; Nakano and Stevens 2008; Grubbs 2010) and is by far the predominant species in the shark catch of the Hawaii-based longline fishery, comprising 84.5% of all sharks reported by fishery observers in 1995–2000 and 2004–2006 (Walsh et al. 2009). Despite its predominance, however, the population status of blue shark in waters fished by the Hawaii-based pelagic longline fleet is presently unclear. Kleiber et al. (2009) conducted a blue shark stock assessment for the North Pacific Ocean for 1971 through 2002, and concluded that abundance at the end of the time series probably exceeded that at the beginning. In contrast, Polovina et al. (2009) concluded that catch rates for this species declined by 2.6% per year between 1996 and 2006 in the deep-set sector of this fishery. More recently, Clarke et al. (2011) reported that standardized blue shark CPUE from observed longline fishing in the northern hemisphere in regions overseen by the Western and Central Pacific Fisheries Commission (WCPFC) declined significantly between 1996 and 2010.

The objective of this WP is to provide catch, size, and abundance index inputs to a stock assessment for blue shark to be conducted under the auspices of the ISC Sharks Working Group in 2012. The period to be assessed is 1971–2010.

## Methods

### Shark reporting patterns

Blue shark catch rates from observer records, logbooks from the observed trips, and logbooks from unobserved trips were tabulated to identify and estimate sources of reporting bias in the deep-set sector (target: bigeye tuna *Thunnus obesus*) of the Hawaii-based longline fishery. Results are presented for two periods. The first was 1995–1999, following the establishment of the Pacific Islands Regional Observer Program (PIROP) in 1994, when coverage rates were 3.5–5.6% per year. The second period (2001–2011) was selected because the PIROP expanded substantially in 2000 (Walsh et al. 2009), permitting coverage rates of 20.3–24.6% per year.

Data from the shallow-set sector (target: swordfish *Xiphias gladius*) were tabulated from 1995–1999 and 2004–2011. The latter years represent the period since the reopening of this sector with mandatory 100% observer coverage (i.e., an observer is aboard on all shallow-set trips).

## Compilation of catch from Hawaii

The Hawaii catch data from 1991–1994 are taken from the PIFSC longline logbook reports. These are available at <http://www.pifsc.noaa.gov/fmb/reports.php>.

The methods employed in the blue shark catch compilations for Hawaii from 1995–2011 are adapted from previous work with blue shark (Walsh et al. 2002). The catch was estimated by adding three components. The first was the catch data from the Pacific Islands Regional Observer Program (PIROP), which were assumed to be correct. The second was the self-reported catch data from logbooks on unobserved trips that were not considered questionable. Self-reported catch data from logbooks of unobserved trips identified as questionable according to statistical criteria were replaced by predicted catches generated by a statistical model, which represented the third component of the catch.

This blue shark catch compilation is similar to that in Walsh et al. (2002). Generalized linear models (GLMs) were used in combination with regression techniques to identify questionable data (Walsh et al. 2002). In the previous study, very conservative standards were used in order to infer that logbook data were questionable (e.g., two or more sets on a trip with logbook reports of zeroes and predicted catches of at least 25 blue sharks). For this project, however, because error patterns and the occurrence of underreporting have been thoroughly documented, the decision was to use less stringent criteria for the logbook data evaluations to increase the chances of removing inaccuracies to the greatest possible extent.

This logbook data evaluation was conducted using the “predict” function in R with a Poisson GLM to estimate catches per set (a Poisson GLM is convenient for this purpose because the catch is recorded as individual sharks). The log-log regression of the reported values from the logbooks on the predicted values was computed, and the studentized residuals (SR) were obtained (Draper and Smith 1981). All sets with  $|SR| > 2$  were considered to have “large residuals”, and their reported catches were replaced with predicted values from the GLM.

Released sharks (live, dead, or in unknown condition) were estimated by using the annual mean rates as reported by the observers. This procedure was used because prior experience has shown that underreporting of sharks and other species in logbooks from the Hawaii-based longline fishery often reflects failure to report released fish (Walsh, unpublished data). The release rate from the observers was used to correct the logbook data from unobserved trips.

In order to permit combination of the two data sources, blue shark TL was converted to weight with the regression

$\log(Y) = -5.396 + 3.13439\log(X)$ , where Y is weight (kg) and X is TL, assumed to be 215 cm (Strasburg 1958).

## Compilation of catch from California

The California pelagic longline fishery and the experimental longline fishery collected data in vessel logbooks, and also had onboard observers. For the pelagic longline fishery, however, there were only 23 observed trips during an observation period that spanned 4 years. Preliminary analysis comparing vessel logbooks with observer records indicated that commercial landings and logbook records for blue and mako sharks were not fully representative of the effects of this fishery. It was not possible to obtain the observer data for the experimental longline fishery from the California Department of Fish and Game (CDFG), which made impossible to assess the accuracy of these logbook records for blue shark.

There were also insufficient observer data to model the changes in CPUE by year, quarter or area for the California-based pelagic longline fishery. As an alternative, catch and effort (in thousands of hooks) data were extracted from the observer database and used to calculate an overall average CPUE. The blue shark catch in any specific year was then calculated by multiplying the average observer-derived CPUE by the logbook-recorded annual effort and the average weight of fish caught (based on observer-recorded lengths). The total number of complete logbook records was 11574. It was not necessary to correct for non-submission of logbooks because reporting compliance was very high (>95%) in this fishery. Catches after 2004 are not reported because only one vessel remained active in this fishery and data are confidential.

The paucity of observer data and the unknown reliability of logbook records from the California-based experimental longline fishery precluded use of observer-derived CPUE estimates to estimate annual catches. It was possible, however, to approximate the catches by using reported landings and effort from this fishery. In 1990, the experimental longline fishery was required to land at least 40,000 lbs (20 tons) of blue shark, and actually landed 42,818 lbs (O'Brien and Sunada 1994). If we assume that the landings per unit effort in 1990 were representative of the average CPUE, we could then extrapolate this to the reported effort (in hook-hours) in the other three years. These estimates of reported effort were: 609,026 hook-hours in 1998; 377,382 hook-hours in 1999; 461,524 hook-hours in 2000; and 157,720 hook-hours in 2001.

## CPUE standardizations of Hawaii data

Blue shark CPUE was standardized by fitting GLMs to data gathered by PIROP observers. The models were fitted separately for the deep- and shallow-set sectors of the fishery because they are managed as separate entities and because the shallow-set sector was closed for more than three years from early in 2001 into mid-2004. The haul year (1995–2011), calendar quarter, and region of fishing<sup>2</sup> were the factor variables included in the GLMs. Sea surface temperature

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<sup>2</sup>Region 1: 0–10°N, 140–160°W. Region 2: 0–10°N, 160–175°W. Region 3: 10–20°N, 135–160°W. Region 4: 10–20°N, 160–180°W. Region 5: 20–30°N, 135–160°W. Region 6: 20–30°N, 160–180°W. Region 7: 30–45°N, 125–160°W. Region 8: 30–45°N, 160–180°W.

(SST) was a continuous variable tested as a third-order polynomial, and several additional operational parameters (e.g., soak duration, begin-set time) were tested as linear continuous variables. Although the two fishery sectors are defined on the basis of hooks per float (shallow-set sector: <15 hooks per float; deep-set sector:  $\geq 15$  hooks per float), the models were fitted within sectors, which allowed hooks per float to be tested as an additional explanatory variable. The linear interactions of the factor variables were also examined, but excessive missing combinations resulted in unrealistic factor variable coefficients in most cases.

The analyses were conducted by the delta-lognormal method, which entailed fitting a binomial GLM of the probability of positive catch and a lognormal GLM of CPUE on sets with positive catch for each sector. Because the number of degrees of freedom was large, explanatory variables were required to reduce the null deviance by at least 0.25% and reduce both the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). The haul year was always the first GLM entry because temporal variation in CPUE was of primary interest.

The models are presented in summary analysis of deviance tables. Annual effect coefficients are plotted as an index of relative abundance and tabulated with standard errors. Residuals plots are provided in Appendix I.

The “predict” function in R was also used to estimate standardized CPUE trends. Data sets consisting of specific factor levels and the means of the corresponding continuous variables (e.g., the mean SST for Region 1 in Quarter 4) were prepared, and the model coefficients were applied to these constant values while allowing time to vary. The resulting standardized CPUE trends were plotted against time.

Standardized abundance indices were not estimated for the California-based longline fisheries because observer data were lacking from both fisheries. In addition, the California experimental longline fishery only operated in a small area within the US EEZ and an abundance index from that fishery would probably not have been representative of the stock as a whole.

#### Compilation of size frequencies and sex ratios

Sizes (total lengths: TL) of blue sharks were compiled from observer measurements taken throughout the study period. Because there were more fork length (FL) measurements than TLs, a bivariate regression of TL on FL was calculated using data from sets with both. This was used to convert FL to TL when only the former measurement was obtained.

The TL data from Hawaii were tabulated by fishery sector (i.e., deep- and shallow-set), sexes, and region of fishing. Annual mean values from fishing regions with large sample sizes were plotted in an attempt to identify any temporal trend(s) of diminishing blue shark lengths in the Hawaii-based fishery. Blue shark TLs and FLs are also presented as histograms by sexes and sectors. An additional, more detailed compilation of individual measurements, by sex, sector,

haul year, and haul quarter and binned in 1-cm increments, was provided separately (not shown herein for purposes of brevity) and is available for use in the stock assessment.

Size data from the California-based pelagic longline fishery were not compiled because relatively small numbers of blue sharks were measured by observers. However, a preliminary examination of the data suggested that the blue sharks caught by this fishery are similar in size to those taken by the Hawaii-based longline fishery. Blue sharks caught in the experimental longline fishery are usually similar in size to those caught by NOAA's Southern California juvenile shark survey conducted in the same area and season.

Blue shark sex ratios from the Hawaii-based fishery were tabulated by sectors and fishing regions. There are no sex ratio data from California fisheries.

## **Results**

### Catch reporting patterns in Hawaii

Catch reporting in the deep set sector (Table 1) in 2001–2011 followed the pattern of greater observer reported mean catch rates than those from logbooks from observed trips, which in turn were greater than those from logbooks from unobserved trips. The primary reason was that released sharks were reported less frequently in the absence than in the presence of observers, although some logbooks did not list released sharks even with an observer present.

The shallow-set sector results (Table 1) were comparable to those from the deep-set sector. In 1995–1999, observers reported more finned sharks and reported releases more frequently than was in the logbooks. Since 2004, despite 100% observer coverage, the mean catch rates in logbooks from observed trips were still less than those reported by observers because the frequencies of reporting differed (observer: 96.1%; logbooks from observed trips: 89.9%).

### Blue shark catches

Table 2 presents the annual summary of blue shark catches by Hawaii- and California-based vessels from 1988–2011. Estimated blue shark catches for both California-based longline fisheries were relatively low. The pelagic longline fishery typically had <200 t of blue shark catch (1990 is an exception) and the experimental longline fishery typically has <25 t of blue shark catch. The Hawaii data include estimates for releases based on the observer data. These values demonstrate that mortality has decreased greatly since the finning prohibition in 2001.

Table 3 presents a more detailed breakdown. Catches are tabulated by haul year, haul quarter, and fishery sector. In general, there were high catches in the shallow-set sector early in the time series, but the shallow-set catches have decreased considerably as effort in the sector has decreased.

### Catch distributions from fishery observer data

The distributions of observed blue shark catches and nominal mean CPUE in  $5^{\circ} \times 5^{\circ}$  squares from the Hawaii-based fishery are presented as Figure 1. Catches are pooled from both fishery sectors in 1996, 2001, 2006, and 2011.

These maps (non-confidential data) illustrate the increased spatial expanse of PIROP observer coverage over the past two decades. The initial low coverage in 1996 (5.5%) was concentrated near the Main Hawaiian Islands. The shallow-set sector was active and blue shark CPUE was high. Coverage reached 23.0% in 2001, but was again concentrated near the Main Hawaiian Islands, but most blue sharks were taken by the deep-set sector because the shallow-set sector was closed most of the year. After the shallow-set sector re-opening in 2004, effort expanded to the north and northeast. A large (7623 blue sharks; CPUE=11.53/1000 hooks) catch was taken from  $30^{\circ}$ – $35^{\circ}$ N and  $155^{\circ}$ – $160^{\circ}$ W in 2006. Catches in the nearby squares were lower, but CPUE was relatively uniform from  $30^{\circ}$ – $35^{\circ}$ N and  $145^{\circ}$ – $170^{\circ}$ W, with a mean of 9.90/1000 hooks. Shallow-set catches and CPUE were lower in 2011 than in 2006, but spanned  $45^{\circ}$  of longitude and included effort from  $35^{\circ}$ – $40^{\circ}$ N and  $130^{\circ}$ – $150^{\circ}$ W.

Although the data are pooled, differences in catches and CPUE between sectors can be recognized because the distributions of set types were closely related to latitude. Most (79.0%) sets above  $30^{\circ}$ N were in the shallow-set sector, whereas all sets in tropical waters (equator to  $10^{\circ}$ N) were in the deep-set sector. Most sets (87.6%) from  $10^{\circ}$ – $30^{\circ}$ N were also in the deep-set sector. In general, CPUE was greater in the more northerly shallow-set sector, but catches in the past decade were usually greater in the deep-set sector because of a disparity in effort.

### Nominal catch trends in fishery observer data

Annual mean nominal CPUE and catches per set from observer data in the two sectors of the Hawaii-based longline fishery (Figure 2) exhibited negative trends, but with non-coincident peaks. The greatest catch rates in the shallow-set sector occurred in 1997, whereas those in the deep-set sector were in 1998 and 2000.

The annual percentages of sets with zero blue shark catches and nominal CPUE on sets with positive catch exhibited opposite patterns in the two fishery sectors (Figure 3). The annual percentage of zero catch sets increased over time in the deep-set sector, while the CPUE on sets with positive catch remained approximately stable. In the shallow-set sector, the percentage of zero catches remained approximately stable over time, but the CPUE on sets with positive catches decreased.

### CPUE standardizations

The fitted binomial GLM (Table 4) explained 11.6% of the null deviance of the probability of positive blue shark catches in the deep-set sector from 1995 through 2011. The three factor

variables reduced the deviance significantly. Inter-annual effects were least important in relative terms, with the smallest deviance reduction per degree of freedom. Regional effects were relatively most important. The interaction of haul year and haul quarter was fitted, but was not retained in the GLM because its entry caused an increase in the BIC.

The three factor variables were also significant explanatory variables in the lognormal GLM (Table 4) for the deep-set sector. The interaction of haul year and haul quarter yielded small reductions in the AIC, BIC and deviance.

The binomial GLM for the shallow-set sector (Table 5) again indicated that all three factor variables significantly affected the probability of positive catch. This GLM explained a similarly low percentage of the null deviance as the deep-set binomial GLM (shallow-set: 11.05%; deep-set: 11.64%). It was noteworthy that entry of the haul year into the GLM resulted in an increase of the BIC.

The lognormal GLM for the shallow-set sector (Table 5) differed from the other fitted GLMs in terms of the relative importance of the factor variables. In both binomial models and in the deep-set lognormal model, the relative importance of the factors was Region>Haul quarter>Haul year. In the shallow-set lognormal GLM, however, the pattern of relative importance was Haul quarter>Haul year>Region.

Four continuous explanatory variables also significantly affected the probability of positive catch, CPUE on sets with positive catch, or both, in one or more GLMs. A non-linear (cubic polynomial) function of SST was a significant explanatory variable in all models. The positive effect of the soak duration in the deep-set binomial GLM, which ranked second in relative importance, represented a direct linear effect on the probability of blue shark catch. Hooks per float was a significant explanatory variable in the deep-set lognormal GLM, and represented an inverse relationship between CPUE and gear depth. The begin-set time was a significant explanatory variable in both the binomial and lognormal GLMs for the deep-set sector. Its coefficient was negative in both models, which indicated that both the probability of catch and CPUE varied inversely with the begin-set time.

#### Indices of relative abundance

The back-transformed annual effect coefficients (Figure 4) decreased throughout the study period in both sectors. The average changes in the deep-set and shallow-set sectors were -3.5% per year and -3.2% per year, respectively. The coefficients and their standard errors are presented in Table 6.

#### Standardized CPUE

Standardized CPUE plots (Figure 5) are presented for two sets of factor variable combinations, which were selected because CPUE was typically relatively high. The trend in the shallow-set

sector in the first quarter from above 30°N and east of 160°W was negative, but it was not possible to estimate the standardized for this region and sector for 2002–2004. The trend in the deep-set sector in Region 4 (10–20°N, west of 160°W) also appeared to be negative, caused primarily by a peak in 1998, but a linear regression fitted through the annual standardized estimates (ignoring their lack of independence) was not statistically significant (one-sided test:  $P=0.052$ ).

#### Blue shark total lengths

An average of 10.6 sharks was measured on each of 815 observed trips ( $N=8522$ ). The number of FL measurements taken by the observers exceeded the TL measurements by 10.4%. A total of 7594 sharks were measured both were measured for both TL and FL.

An initial fit of a TL on FL regression within sexes revealed that the regression coefficients were identical to the third decimal place. Therefore, when TL was not measured, the sexes were pooled and FL was converted to TL with the regression

$$Y = 10.678 + 1.138X$$

where  $Y=TL$  (cm) and  $X=FL$  (cm).

Size frequencies are presented by sectors and sexes in Figure 6. The mean size of males was 7.5% greater than that of females (♂: 227.7 cm; ♀: 211.8 cm). The mode for males (220–240 cm) was greater than that for females in the deep-set sector and for both sexes in the shallow-set sector, which had modes of 200–220 cm. The two sexes differed by 2.1% in mean TL in the shallow-set sector (♂: 211.9 cm; ♀: 207.5 cm). Figure 7 presents fork lengths in a comparable format.

Mean blue shark TL values sorted by sectors, regions, and sexes (Table 7) include five combinations with <10 measurements and four with zeroes (both sexes in Regions 1 and 2). Deep-set males were always larger than females except in regions with very small sample sizes (Regions 1, 2, and 7). The smallest blue sharks (188.1–194.4 cm TL) were measured above 30°N in Regions 7 and 8 and included both sexes.

Mean blue shark TL of both sexes in Regions 5 and 6 in the deep-set sector remained approximately stable from 1995–2011 (Figure 8). The mean TL values in the shallow-set sector (Figure 9) were difficult to interpret because the closure left a temporal gap and because the number of measurements of females in particular has been small in certain years since its re-opening.

#### Blue shark sex ratios

Blue shark sex ratios by sectors and regions exhibited two principal characteristics (Table 8). In the deep-set sector, male were predominant in tropical waters (Regions 1 and 2) and above 30°N

(Regions 7 and 8). Females predominated in the shallow-set sector in mid-latitudes (Regions 5 and 6).

#### Blue shark sizes, sex ratios, and relation to stock structure

The separation of the Hawaii-based pelagic longline fishery into deep- and shallow-set sectors is analogous to a north-south separation. The deep- and shallow-set sectors were centered about mean latitudes of 18.0°N and 31.3°N, respectively. Males in the deep-set sector were larger on average than those in the shallow-set sector (deep-set: 190.4 cm FL; shallow-set: 176.8 cm FL). The difference in size between sectors among female blue sharks was much smaller (deep-set: 177.5 cm FL; shallow-set: 172.9 cm FL).

Male blue sharks constituted the majority of measured fish in both sectors. In the shallow-set sector, the percentages of males and females were 62.2% and 37.8%, respectively. The disparity was smaller in the deep-set sector, with percentages of 55.5% for males and 44.5% for females.

### **Discussion**

This WP presents catch compilations, relative abundance indices, length distributions and sex ratios for blue sharks taken by California- (1988–2004) and Hawaii-based (1991–2011) longline fisheries for use in the ISC stock assessment. Fishery observer data were used extensively in these analyses. The logbook data used were assessed for accuracy to the extent possible.

The most common source of bias in self-reported blue shark catches in Hawaii is fishermen's tendency not to report released sharks, which reduces the catch estimate. A basis for correction of releases was presented in Table 1. Use of the average annual corrections should have counteracted this typical negative bias and contributed to more accurate catch estimates.

The evaluation of the logbook data from Hawaii also resulted in an increase in the Hawaii catch estimates because the "large residuals" were mostly negative, and many probably reflected systematic under-reporting in the logbooks. Use of this second type of logbook correction should have counteracted such systematic bias and thereby also contributed to greater accuracy in the Hawaii catch estimates. In addition, the high coverage rates in Hawaii in recent years should have had a similar effect by lessening reliance upon logbook data and by providing larger data sets for GLM fitting.

The estimated blue shark catches from the California-based fisheries are relatively uncertain, but are also low and unlikely to influence the assessment results appreciably. The estimated California-based experimental longline fishery landings for 1990 (when the fishery was required to land a minimum of 40,000 lbs of blue shark catch) were assumed to be representative, but may

actually have been closer to a minimum level. If observer data become available before the upcoming assessment, it may become possible to reevaluate these catches. If not, estimates will be required. Only one vessel has been active in the California-based pelagic longline fishery since 2004 so its catches are confidential. Therefore, we recommend adding a small approximate amount to the Hawaii catches to account for California blue shark catches in 2005–2011.

The GLM analyses conducted with the Hawaii observer data had four features requiring mention. First, the relative importance of annual effects was the lowest among the factor variables except in the shallow-set lognormal GLM, where quarterly and annual effects superseded regional effects. The latter result was not surprising because the shallow-set sector operated primarily in northern waters. In the other models, differences among regions were more important than inter-annual trends or quarterly variation. Second, missing data only permitted estimation of the haul year  $\times$  haul quarter interaction. Because the fishery has expanded geographically, spatiotemporal interactions would have been of particular interest. Third, the binomial models for both sectors had low explanatory power. This indicated that the probability of catch was not strongly related to this suite of explanatory variables, at least as fitted in this GLM. Finally, the explanatory power of the lognormal models for both sectors was considered reasonable and the diagnostics plots did not appear problematic.

The indices of relative abundance from Hawaii trended downward in both sectors, with average annual decreases *ca.* 3–4%. While recognizing that this fishery and the associated observer coverage have undergone a major geographic expansion and that some operational practices (e.g., patterns of use of bait and hook types) have changed, the indices did not appear appreciably more optimistic than the nominal CPUE trend.

The standardized CPUE plots were noteworthy because, although the slope was negative, a *t*-test was non-significant for one region in the deep-set sector. This suggests that further investigation of the spatial aspects of blue shark catches or other specific circumstances could be of interest.

Walsh et al. (2009) inferred that most blue sharks of both sexes caught by the Hawaiian fishery were mature on the basis of data in Nakano and Seki (2003). It should be noted that many of the measurements tabulated herein were used previously and do not represent new information.

## Conclusions

Blue shark catches from California and Hawaii were estimated with data assessed for accuracy and completeness and deemed useful for the stock assessment. The maximum catches in California and Hawaii were taken in 2000 and 1993, respectively.

The numbers of released blue sharks indicated that mortality has decreased in the Hawaii-based longline fishery.

Use of corrections to account for under-reporting of released sharks as well as systematic under-reporting increased the estimated Hawaiian catch by 12.8%, improving the accuracy of the estimates.

The indices of relative abundance exhibited downward trends. Standardized CPUE plots indicated that further investigation of possible effects of geographic shifts in effort may be warranted.

Some small patterns were apparent in the GLM diagnostics plots, but were not considered indicators of serious analytical problems.

The length data from Hawaii appeared temporally stable, especially in the deep-set sector, but the measurements were taken opportunistically and did not reflect a long-term sustained sampling protocol. Similarly, sex ratios were not estimated from a sustained sampling protocol.

This WP is expected to meet the catch data and abundance indices from Hawaii- and California-based longline fisheries required for the ISC Sharks WG for the blue shark stock assessment. These analyses can be re-examined, revised or expanded upon request from the ISC Sharks WG.

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Table 1. Summary of blue shark reporting patterns in the Hawaii-based pelagic longline fishery in two periods. Data from 1995–1999 were collected before the expansion of the PIROP. Data from 2005–2011 were collected after the re-opening of the shallow-set sector. Results are presented as mean catches per longline set with standard deviations, organized by data source (i.e., observer, logbooks from observed trips, logbooks from unobserved trips) and fishery sector. Percent reporting frequencies are also presented.

Data source	Fishery sector and period	Blue sharks caught	Blue sharks released	Blue sharks finned	Blue sharks kept	Sets with releases (%)
Observer	Deep-set 1995–1999	5.64±5.36	0.47±0.95	5.12±5.13	0.048±0.308	29.9%
Logbook (Observed)	Deep-set 1995–1999	4.95±4.95	0.22±0.90	4.62±5.02	0.102±0.658	9.6%
Logbook (Unobserved)	Deep-set 1995–1999	4.83±3.95	0.20±1.01	4.62±3.83	0.004±0.153	7.3%
Observer	Deep-set 2000–2011	4.18±4.79	4.16±4.78	0.01±0.28	0.01±0.18	85.9%
Logbook (Observed)	Deep-set 2000–2011	3.69±4.69	3.64±4.67	0.01±0.24	0.04±0.59	74.5%
Logbook (Unobserved)	Deep-set 2000–2011	2.77±3.93	2.74±3.92	0.00±0.06	0.02±0.37	67.8%
Observer	Shallow-set 1995–1999	15.51±22.77	8.54±17.09	6.95±12.45	0.009±0.104	86.3%
Logbook (Observed)	Shallow-set 1995–1999	14.87±24.81	8.50±18.49	6.36±12.30	0.013±0.293	64.9%
Logbook (Unobserved)	Shallow-set 1995–1999	13.53±24.67	7.84±15.74	5.68±15.26	0.008±0.239	73.6%
Observer	Shallow-set 2005–2011	8.26±9.99	8.26±9.99	0	0.002±0.052	96.2%
Logbook (Observed)	Shallow-set 2005–2011	7.92±9.30	7.90±9.30	0	0.03±0.70	90.3%

Table 2. Estimated catches of blue sharks taken by Hawaii- and California-based longline fisheries in 1988–2011. The Hawaii data from 1991–1994 are taken entirely from the PIFSC longline logbook reports. The 1995–2011 data include catch reported by PIROP observers, logbook catch data, and correction estimates used in place of questionable logbook data (e.g., under-reported sharks). California data from 1988–1990 and 1992–2004 are from the experimental and pelagic fisheries, respectively. Data from 1991 are pooled from both.

Year	Hawaii					California (MT)	HI & CA (MT)
	Observer Catch	Unobserved Logbook	Logbook Correction	Total catch	Percent Released	Total	Total
1988	NA	NA	NA	NA	NA	25.6	25.6
1989	NA	NA	NA	NA	NA	15.9	15.9
1990	NA	NA	NA	NA	NA	19.4	19.4
1991	NA	65481	NA	65481	NA	7.7	5390.2
1992	NA	89292	NA	89292	NA	7.2	7347.0
1993	NA	150216	NA	150216	NA	1.5	12349.3
1994	NA	110187	NA	110187	NA	4.8	9110.6
1995	5903	83279	21280	110462	64.9%	25.6	9102.2
1996	6914	73127	17550	97591	47.4%	56.4	8075.4
1997	7491	65059	17412	89962	31.1%	60.9	7453.0
1998	6509	84741	13829	105079	40.4%	74.9	8709.2
1999	3169	74853	17965	92818	35.6%	110.4	7737.2
2000	12144	59265	7112	78521	73.8%	162.7	6614.7
2001	14132	25297	1518	40947	96.7%	145.7	3510.3
2002	13161	26804	1570	41535	98.0%	95.0	3507.9
2003	19119	42409	2545	64073	>99%	87.2	5352.0

Table 2, continued.

Year	Hawaii					California (MT)	HI & CA (MT)
	Observer Catch	Unobserved Logbook	Logbook Correction	Total	Percent Released	Total	Total
2004	23458	41440	2072	66970	>99%	36.9	5539.8
2005	36621	30376	1519	68516	>99%	NA	5629.9
2006	23872	34752	1738	60362	>99%	NA	4959.9
2007	32623	32929	988	66540	>99%	NA	5467.5
2008	23141	29914	897	53952	>99%	NA	4433.2
2009	20405	27802	834	49041	>99%	NA	4029.7
2010	31082	27721	1022	59825	>99%	NA	4915.8
2011	22483	33330	1012	56825	>99%	NA	4669.3

Table 3. Blue shark catches in the Hawaii-based commercial longline fishery in 1995–2011. Catches include observer data and corrected logbook data and are tabulated by haul year, haul quarter, and fishery sector.

Haul year	Haul quarter	Blue shark catches: Deep-set sector	Blue shark catches: Shallow-set sector
1995	1	8616	13451
	2	6651	23833
	3	5423	27930
	4	9124	15434
1996	1	6840	24138
	2	6060	20496
	3	4759	15764
	4	7426	12108
1997	1	7739	23532
	2	7161	20760
	3	5120	8676
	4	9240	7734
1998	1	8193	18287
	2	9079	19927
	3	8480	16257
	4	14318	10538
1999	1	8062	10732
	2	10753	15121
	3	9262	16741
	4	13759	8388
2000	1	9465	11508
	2	8851	16115
	3	7299	7272
	4	14976	3035

Table 3, continued.

Haul year	Haul quarter	Blue shark catch: Deep-set sector	Blue shark catch: Shallow-set sector
2001	1	7496	2422
	2	7356	1358
	3	10465	NA
	4	11850	NA
2002	1	9814	128
	2	7247	1017
	3	9844	355
	4	13130	NA
2003	1	10261	NA
	2	13078	NA
	3	12181	19
	4	28534	NA
2004	1	11099	NA
	2	11321	9
	3	19097	9
	4	24061	1374
2005	1	10057	7257
	2	8185	5560
	3	11502	935
	4	23112	1908
2006	1	10470	9495
	2	8035	NA
	3	12891	NA
	4	19471	NA

Table 3, continued.

Haul year	Haul quarter	Blue shark catch: Deep-set sector	Blue shark catch: Shallow-set sector
2007	1	7276	12574
	2	7810	1510
	3	11876	511
	4	23598	1385
2008	1	8663	7323
	2	8761	1297
	3	8775	430
	4	14764	3939
2009	1	7756	4543
	2	9633	2588
	3	11618	433
	4	11422	1048
2010	1	7080	10858
	2	10934	3463
	3	11741	1421
	4	12473	1855
2011	1	10961	4394
	2	9938	2126
	3	11021	360
	4	16652	1373

Table 4. Summary of a delta-lognormal analysis of observed blue shark catches in the deep-set sector of the Hawaii-based pelagic longline fishery. The first table summarizes the binomial GLM, with the presence or absence of catch as the response variable and the natural logarithm of hooks per set as the offset. The second table summarizes the lognormal GLM, with log-transformed CPUE from sets with positive catch as the response variable. Entries are the reductions in the residual and null deviances, reductions in the AIC and BIC and the significance test probabilities.

Binomial GLM:  $N= 38254$  longline sets; null deviance= 29935.41; null model AIC= 29937.41.

Parameter	Df	$\Delta$ Residual Deviance	$\Delta$ Residual deviance per df	Null deviance reduction	$\Delta$ AIC	$\Delta$ BIC	$\text{Pr}> \chi^2 $
Intercept	1	----	----	----	----	----	----
Haul year	16	897.48	56.09	3.00%	865.48	749.10	2.2e-16
Haul quarter	3	295.49	98.50	0.99%	289.49	267.67	2.2e-16
Fishing region	7	1609.29	229.90	5.38%	1595.29	1544.38	2.2e-16
SST (cubic)	3	398.24	132.75	1.33%	392.24	370.41	2.2e-16
Soak duration	1	187.50	187.50	0.62%	185.50	178.23	2.2e-16
Begin-set time	1	95.27	95.27	0.32%	93.27	86.00	2.2e-16

Pseudo-coefficient of determination=11.64%. Residual deviance=26452.14. Model AIC=26516.14

Table 4, continued.

Lognormal GLM:  $N= 33102$  longline sets; null deviance=24910.65; null model AIC=84532.56.

Parameter	Df	$\Delta$ Residual Deviance	$\Delta$ Residual deviance per df	Null deviance reduction	$\Delta$ AIC	$\Delta$ BIC	$\text{Pr}> \chi^2 $
Intercept	1	----	----	----	----	----	----
Haul year	16	2257.70	141.11	9.06%	3112.86	2967.94	2.2e-16
Haul quarter	3	740.67	246.89	2.97%	1094.41	1069.19	2.2e-16
Fishing region	7	3325.36	475.05	13.35%	5434.22	5375.36	2.2e-16
SST (cubic)	3	995.26	331.75	4.00%	1815.71	1790.49	2.2e-16
Hooks per float	1	100.85	100.85	0.40%	188.31	179.90	2.2e-16
Begin-set time	1	73.08	73.08	0.29%	136.60	128.20	2.2e-16
Haul year × Haul quarter	48	537.67	11.20	2.16%	941.94	538.39	2.2e-16

Pseudo-coefficient of determination=32.23%. Residual deviance=16880.06. Model AIC=71808.51

Table 5. Summary of a delta-lognormal analysis of observed blue shark catches in the shallow-set sector of the Hawaii-based pelagic longline fishery. The first table summarizes the binomial GLM, with the presence or absence of catch as the response variable and the natural logarithm of hooks per set as the offset. The second table summarizes the lognormal GLM, with log-transformed CPUE from sets with positive catch as the response variable. Entries are the reductions in the residual and null deviances, reductions in the AIC and BIC and the significance test probabilities.

Binomial GLM:  $N= 11083$  longline sets; null deviance= 3664.75; null model AIC= 3666.75.

Parameter	Df	$\Delta$ Residual Deviance	$\Delta$ Residual deviance per df	Null deviance reduction	$\Delta$ AIC	$\Delta$ BIC	$\text{Pr}> \chi^2 $
Intercept	1	----	----	----	----	----	----
Haul year	14	124.24	8.87	3.39%	96.24	<b>-6.14</b>	2.2e-16
Haul quarter	3	41.71	13.90	1.14%	35.71	13.77	4.63e-09
Fishing region	5	123.79	24.76	3.38%	113.79	77.22	2.2e-16
SST (cubic)	3	115.11	38.37	3.14%	109.11	87.17	2.2e-16

Pseudo-coefficient of determination= 11.05%. Residual deviance= 3259.90. Model AIC=3311.90.

The BIC for the haul year (**boldface**) as a factor variable was greater than the null model BIC; i.e., it caused a “negative reduction”.

Table 5, continued.

Lognormal GLM:  $N= 10652$  longline sets; null deviance= 9405.22; null model AIC=28907.08.

Parameter	Df	$\Delta$ Residual Deviance	$\Delta$ Residual deviance per df	Null deviance reduction	$\Delta$ AIC	$\Delta$ BIC	$\text{Pr}> \chi^2 $	Median residual
Intercept	1	----	----	----	----	----	----	0.0110
Haul year	14	1346.01	96.14	14.31%	1617.19	1515.36	2.2e-16	0.0220
Haul quarter	3	981.25	327.08	10.43%	1376.96	1355.14	2.2e-16	0.0512
Fishing region	5	417.30	83.46	4.44%	637.29	600.93	2.2e-16	0.0416
SST (cubic)	3	757.20	252.40	8.05%	1279.48	1257.66	2.2e-16	0.0524

Pseudo-coefficient of determination= 37.23%. Residual deviance=5903.46. Model AIC=23996.16.

Table 6. Indices of relative abundance with standard errors computed from the delta lognormal analyses in the two sectors of the Hawaii-based pelagic longline fishery from 1995 through 2011.

Haul year	Deep-set sector	Shallow-set sector
1995	3.255±0.202	14.232±0.911
1996	3.394±0.217	14.191±0.837
1997	3.520±0.232	21.011±1.702
1998	4.152±0.224	13.373±0.963
1999	2.163±0.128	13.639±1.023
2000	4.378±0.140	11.605±0.662
2001	2.876±0.066	7.907±0.593
2002	2.108±0.046	NA
2003	2.939±0.062	NA
2004	2.754±0.052	12.834±0.860
2005	2.015±0.040	11.666±0.315
2006	1.919±0.038	15.454±0.603
2007	2.098±0.044	10.625±0.351
2008	1.370±0.029	8.487±0.280
2009	1.678±0.035	5.263±0.163
2010	1.838±0.040	8.464±0.254
2011	1.872±0.037	5.598±0.190

Table 7. Summary of blue shark total length (TL) data from the Hawaii-based longline fishery from 1995 through 2011. Sharks were measured by PIROP observers. Results (cm) are presented as the mean, standard deviation, and sample size (*N*) sorted by regions, fishery sectors, and sexes.

Fishing Regions							
Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Below 10°N; east of 160°W	Below 10°N; west of 160°W	≥10°–20°N; east of 160°W	≥10°–20°N; west of 160°W	≥20°–30°N; east of 160°W	≥20°–30°N; west of 160°W	Above 30°N; east of 160°W	Above 30°N; west of 160°W
Deep-set: ♂	Deep-set: ♂	Deep-set: ♂					
203.3±12.6 <i>N</i> = 3	217.2±24.0 <i>N</i> = 132	224.2±29.4 <i>N</i> = 370	228.7±24.7 <i>N</i> = 671	226.8±27.9 <i>N</i> = 215	233.4±28.5 <i>N</i> = 512	251.9±24.7 <i>N</i> = 7	201.7±41.0 <i>N</i> = 32
Deep-set: ♀	Deep-set: ♀	Deep-set: ♀					
206.0±5.7 <i>N</i> = 2	202.7±24.2 <i>N</i> = 105	208.0±15.9 <i>N</i> = 416	210.0±16.7 <i>N</i> = 599	219.7±25.5 <i>N</i> = 189	221.1±20.8 <i>N</i> = 240	199.6 <i>N</i> = 1	186.4±44.9 <i>N</i> = 6
Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂					
<i>N</i> = 0	<i>N</i> = 0	226.9±14.8 <i>N</i> = 34	212.5±16.4 <i>N</i> = 19	233.8±25.9 <i>N</i> = 231	215.7±32.4 <i>N</i> = 1500	194.4±41.7 <i>N</i> = 672	212.7±39.0 <i>N</i> = 742
Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀					
<i>N</i> = 0	<i>N</i> = 0	212.5±16.3 <i>N</i> = 28	212.0±19.1 <i>N</i> = 21	217.2±21.7 <i>N</i> = 364	216.6±23.6 <i>N</i> = 852	190.6±42.8 <i>N</i> = 461	188.1±36.3 <i>N</i> = 194

Table 8. Summary of blue shark sex ratios ( $\sigma$  :  $\rho$ ) from the Hawaii-based longline fishery from 1995 through 2011. Shark sexes were identified by PIROP observers. Results are presented by fishing regions and fishery sectors. All ratios were calculated with samples of at least 100 sharks of each sex.

Fishing Regions							
Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
Below 10°N; east of 160°W	Below 10°N; west of 160°W	≥10°–20°N; east of 160°W	≥10°–20°N; west of 160°W	≥20°–30°N; east of 160°W	≥20°–30°N; west of 160°W	Above 30°N; east of 160°W	Above 30°N; west of 160°W
Deep-set	Deep-set	Deep-set	Deep-set	Deep-set	Deep-set	Deep-set	Deep-set
62.7% : 37.3%	53.1% : 46.9%	42.1% : 57.9%	49.0% : 51.0%	50.4% : 49.6%	51.7% : 48.3%	59.8% : 40.2%	60.8% : 39.2%
Shallow-set	Shallow-set	Shallow-set	Shallow-set	Shallow-set	Shallow-set	Shallow-set	Shallow-set
----	----	----	----	41.5% : 58.5%	39.6% : 60.4%	50.9% : 49.1%	49.2% : 50.8%

Figure 1. Maps of blue shark catches and CPUE in 2001, 2006 and 2011 in the Hawaii-based pelagic longline fishery. Data from the deep-set and shallow-set sectors are pooled.

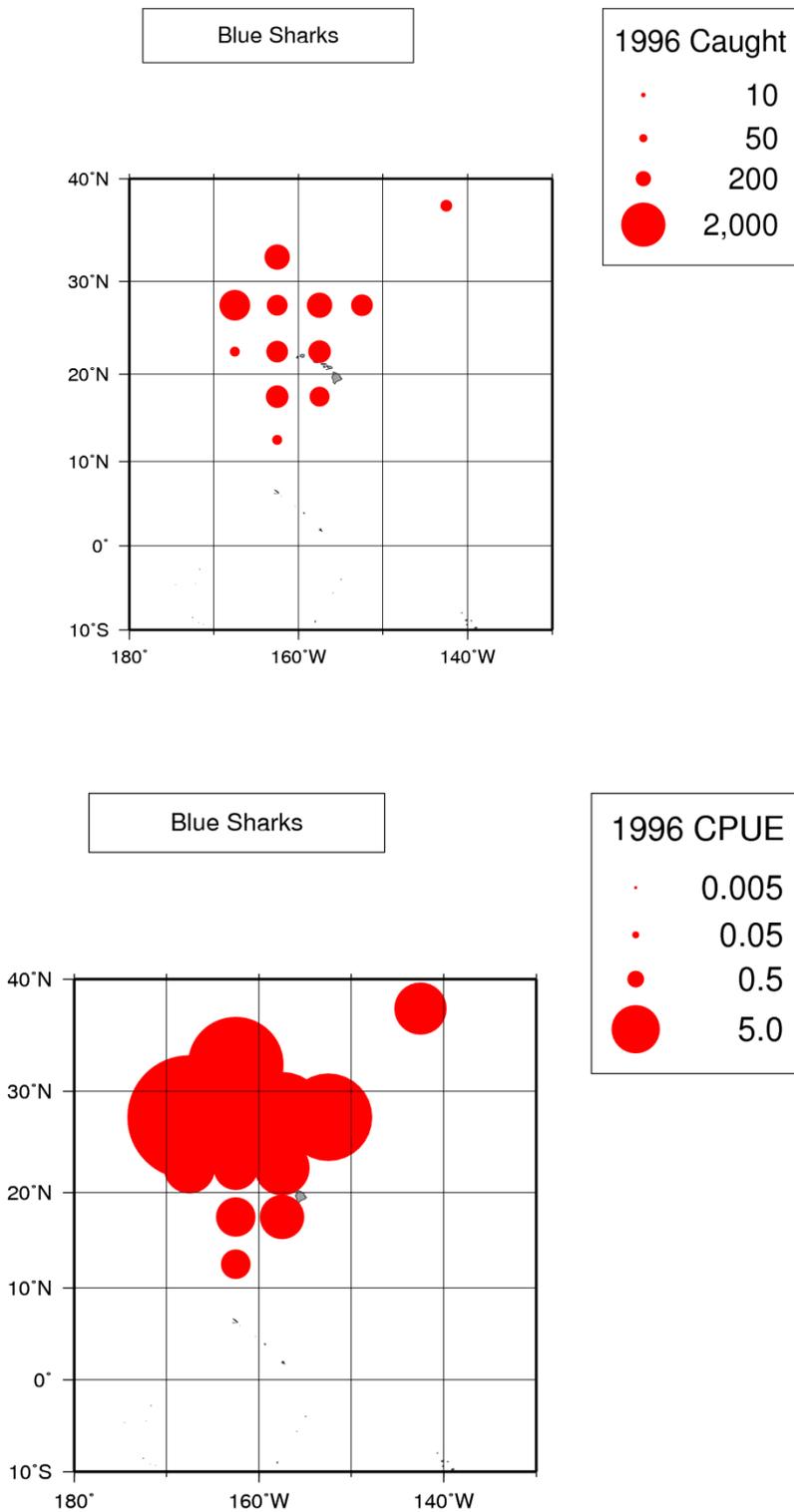


Figure 1, continued.

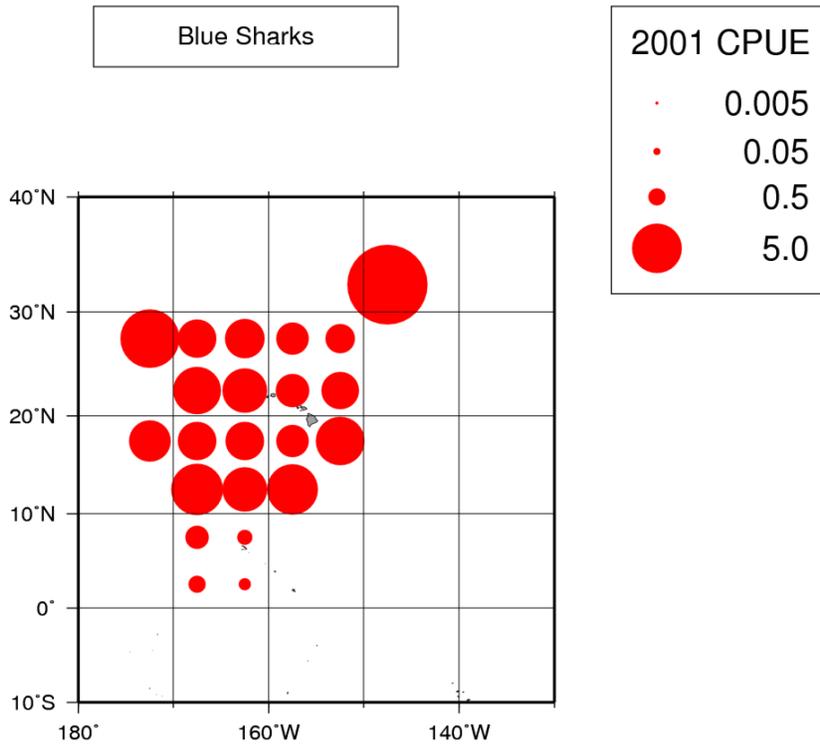
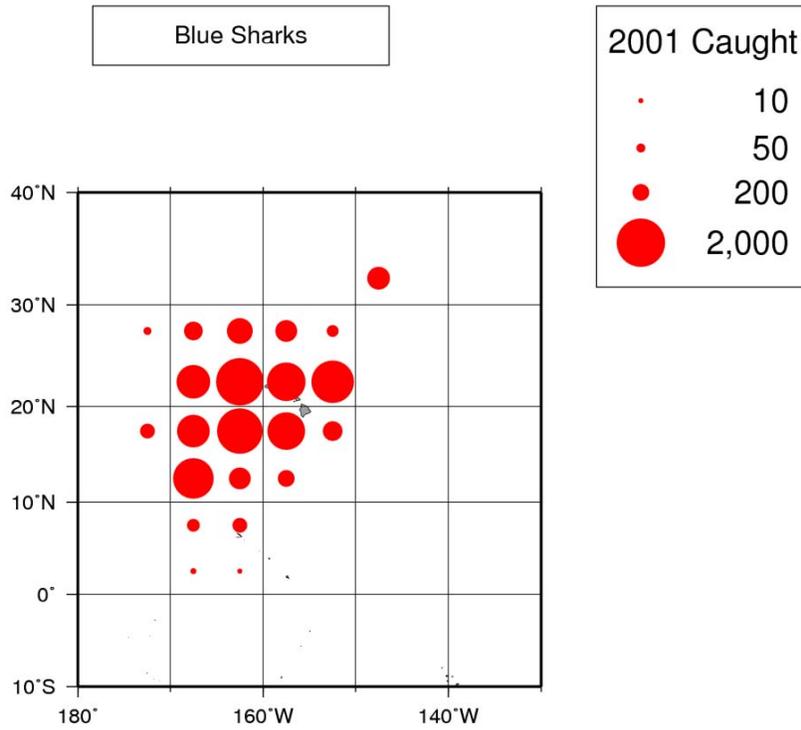


Figure 1, continued.

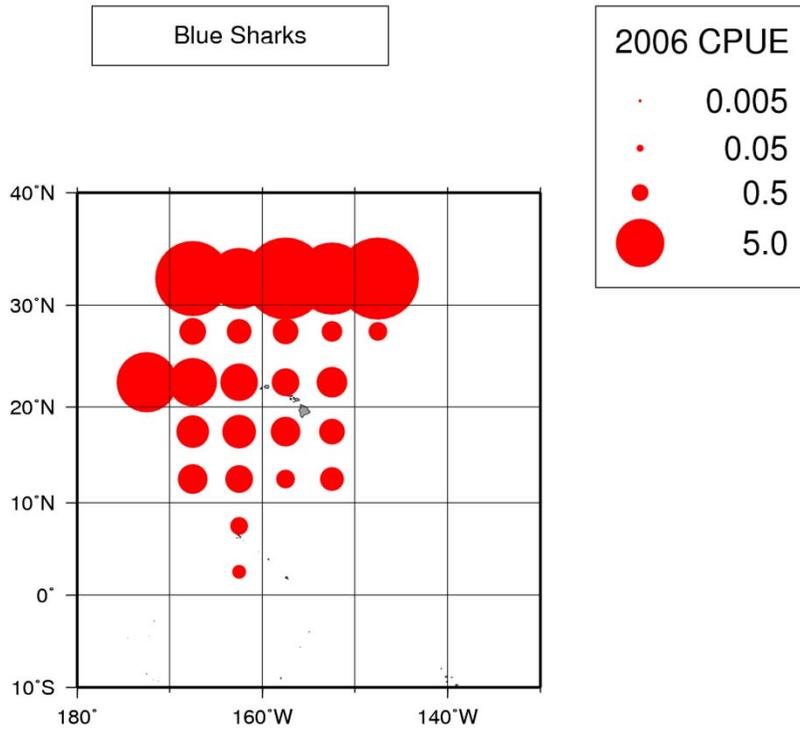
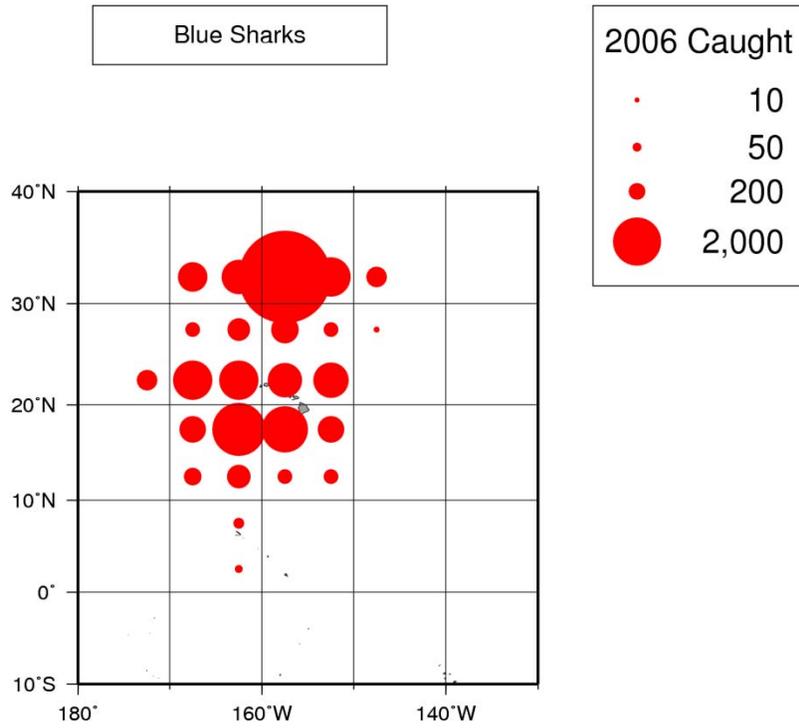


Figure 1, continued.

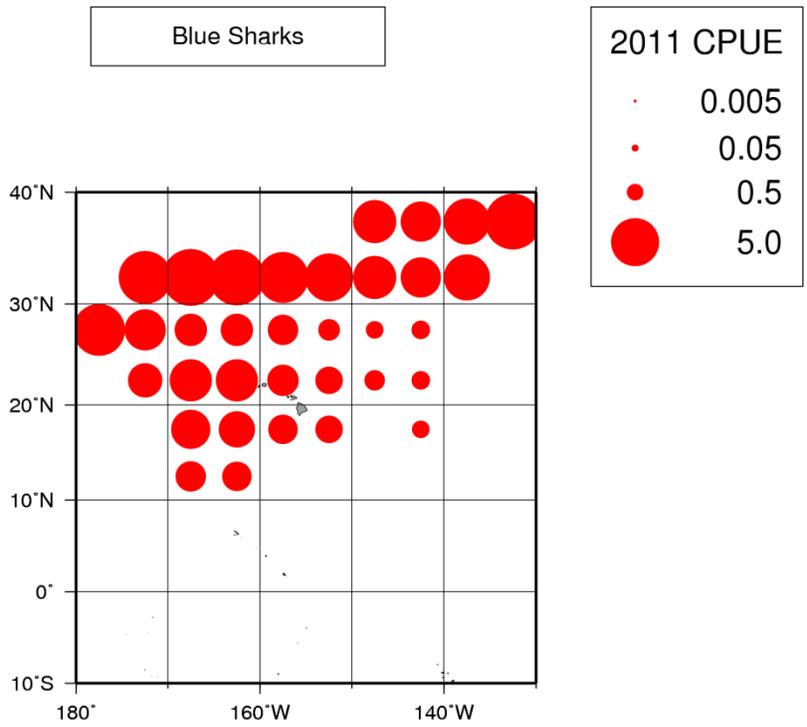
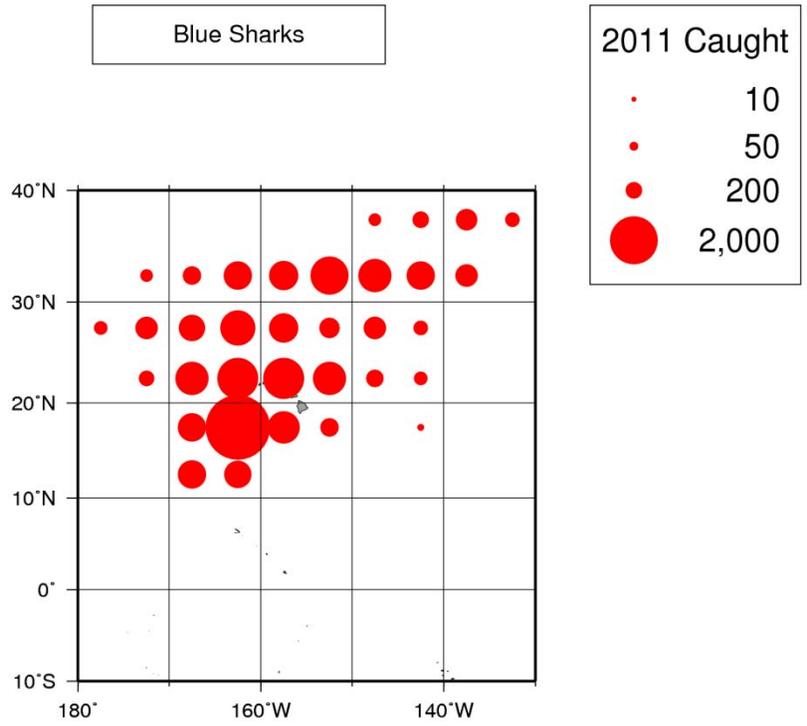


Figure 2. Annual mean blue shark nominal catch rates in the deep-set (upper) and shallow-set sectors (lower) of the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.

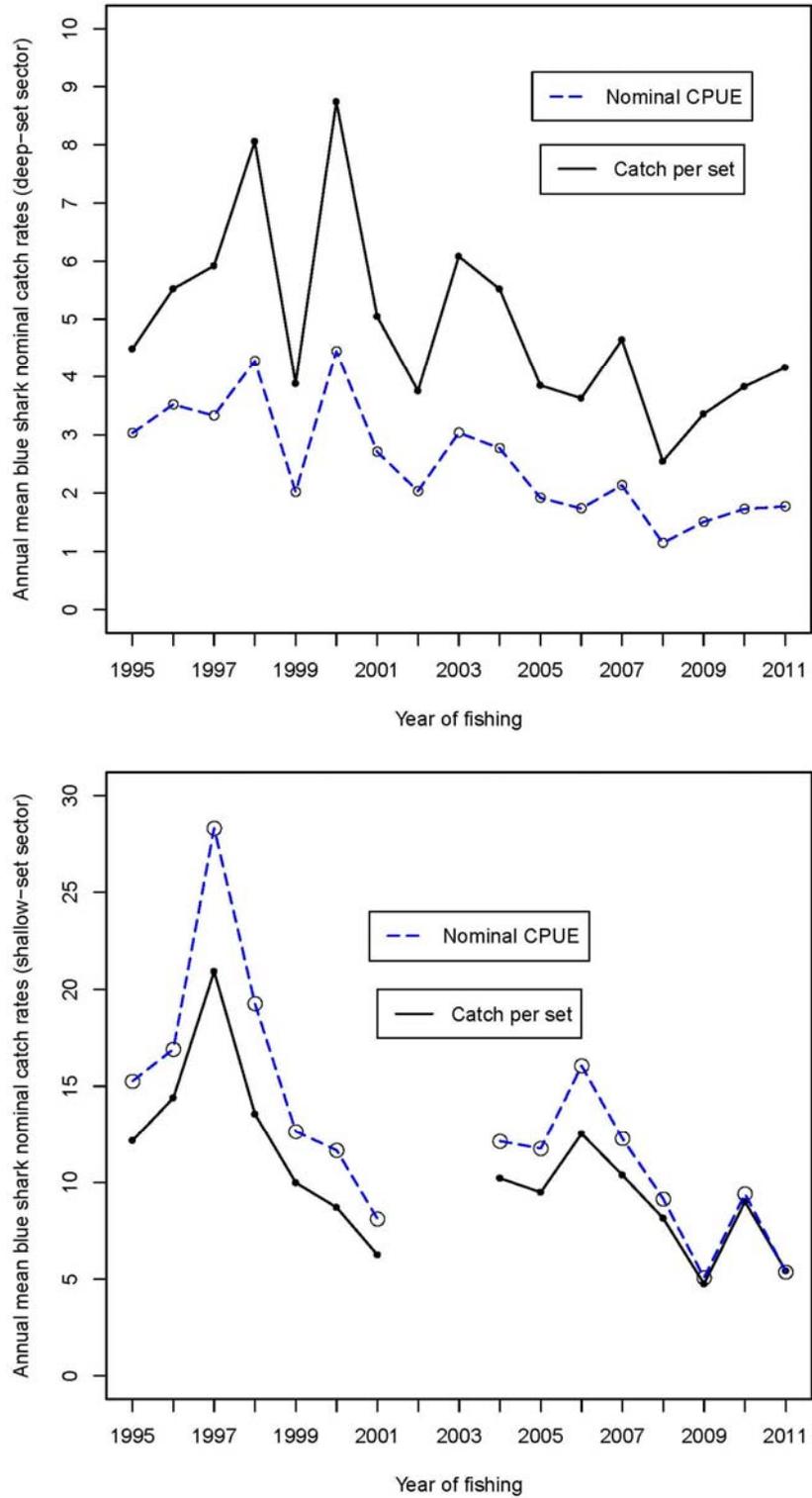


Figure 3. Annual percentages of zero catches (upper) and CPUE on sets with positive blue shark catches (lower) by sector in the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.

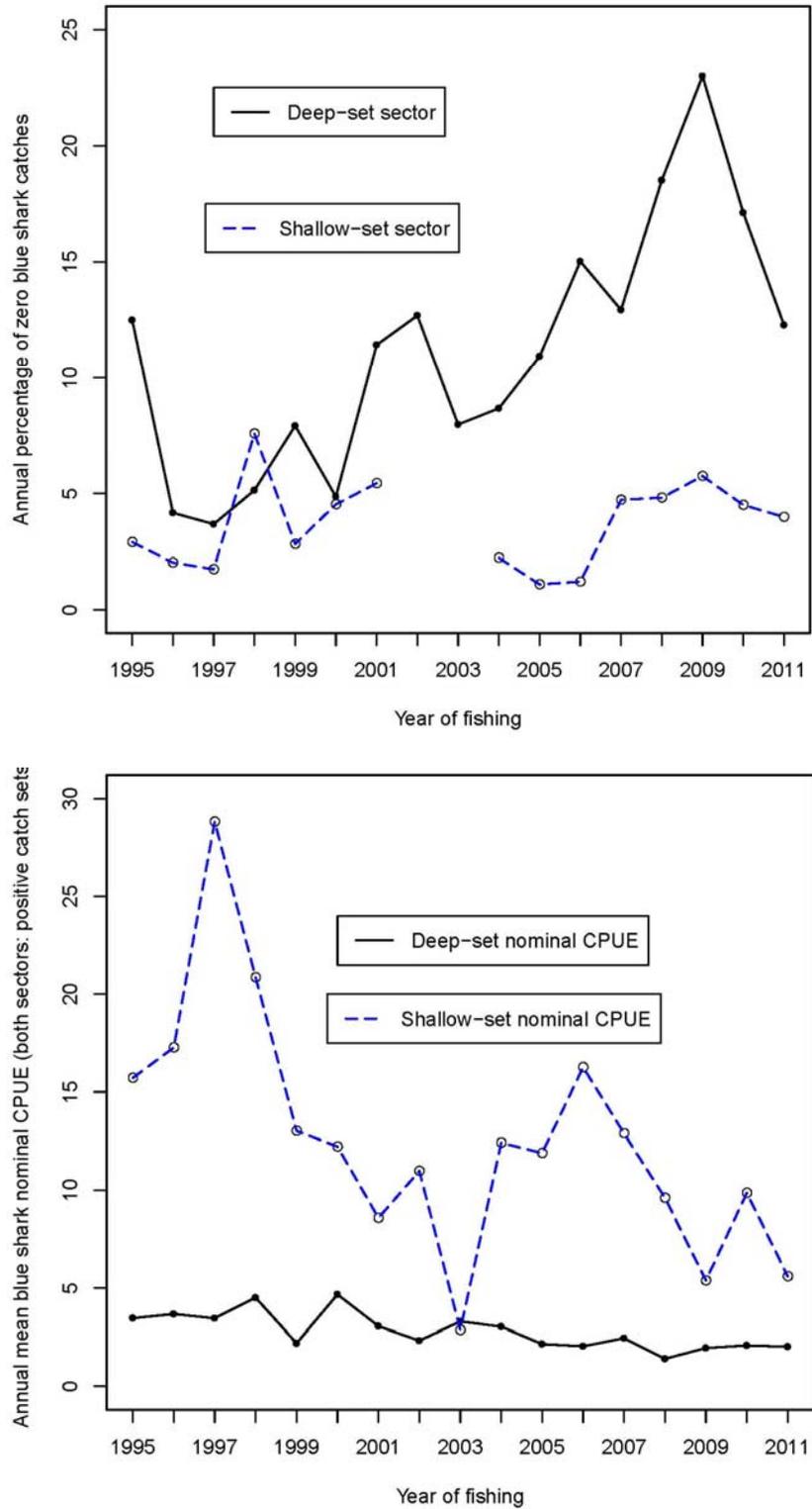


Figure 4. Relative abundance indices obtained from the GLM annual coefficients for blue shark by sector in the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.

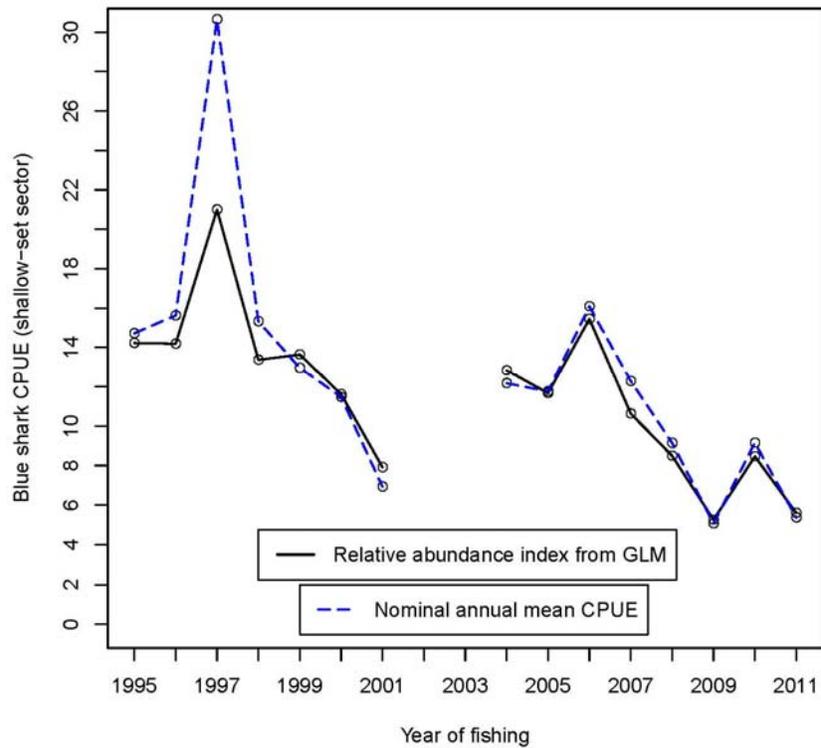
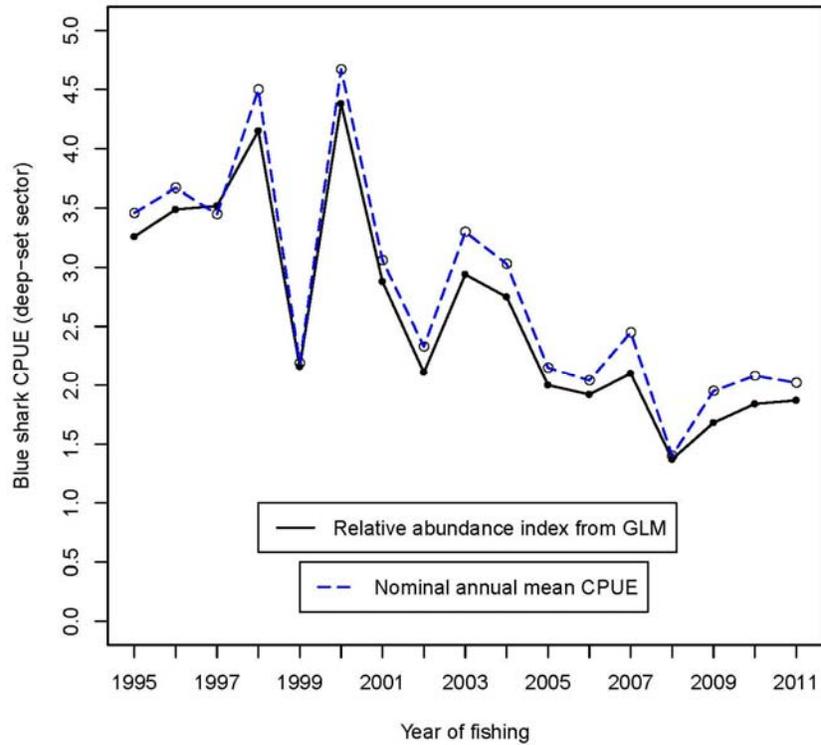


Figure 5. Standardized and nominal CPUE for blue shark by sectors, during quarters and in regions of typically high abundance.

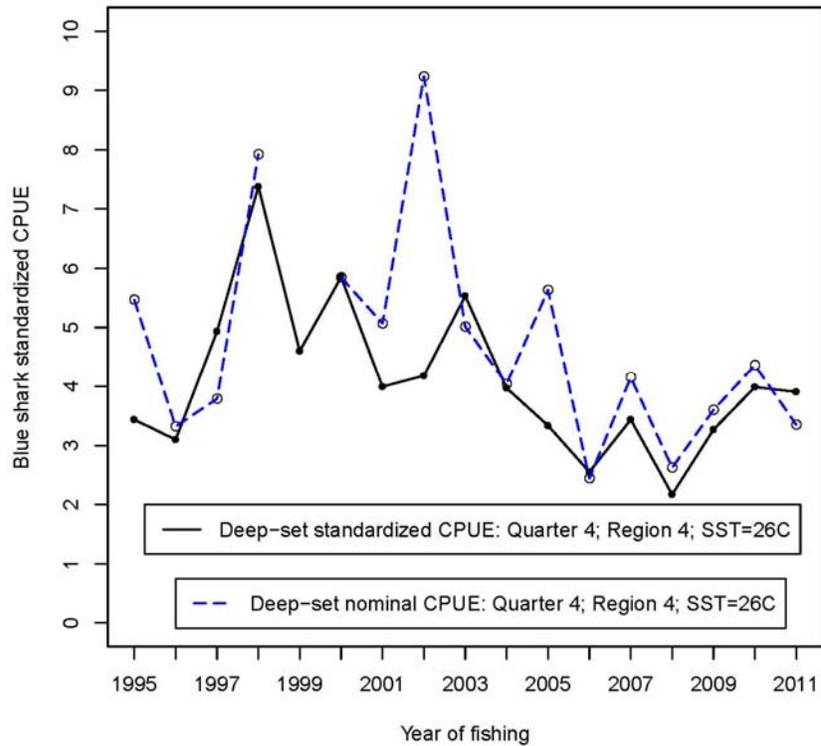
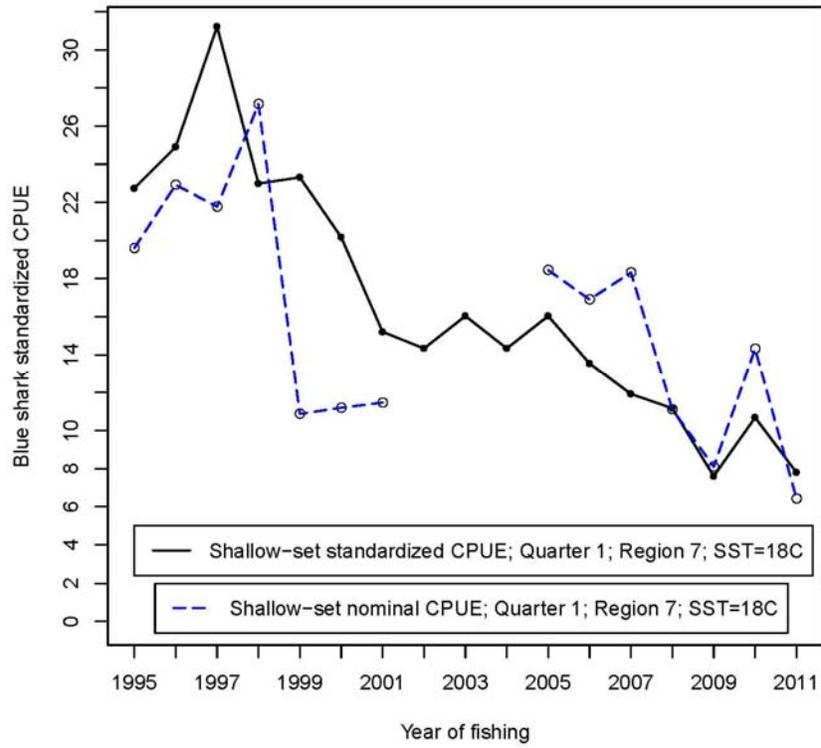


Figure 6. Size frequency distributions (total length, cm) for blue sharks by fishery sectors and sexes from 1995 through 2011.

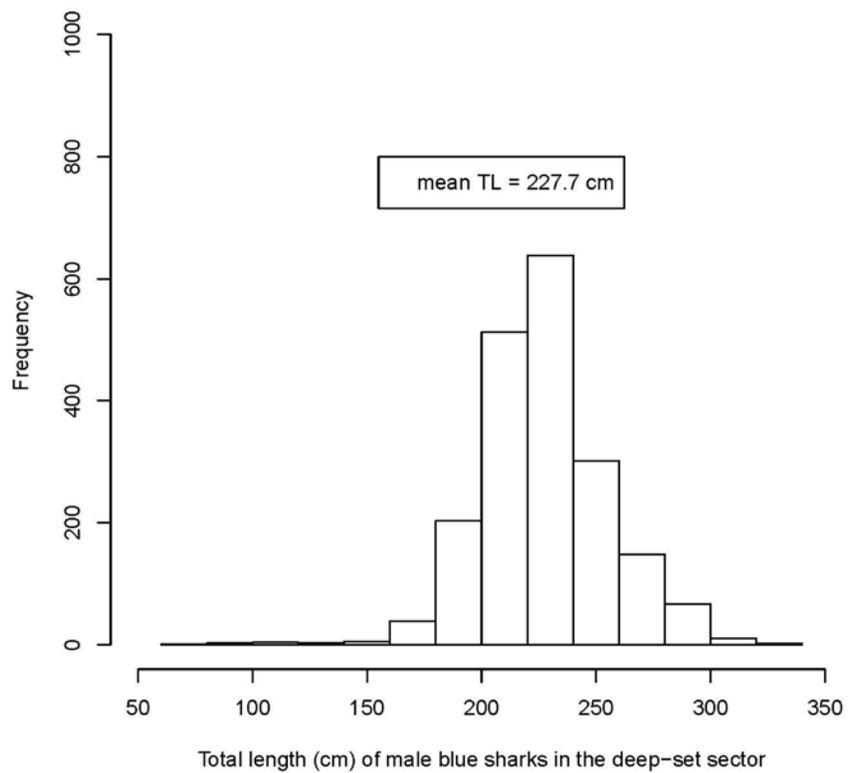
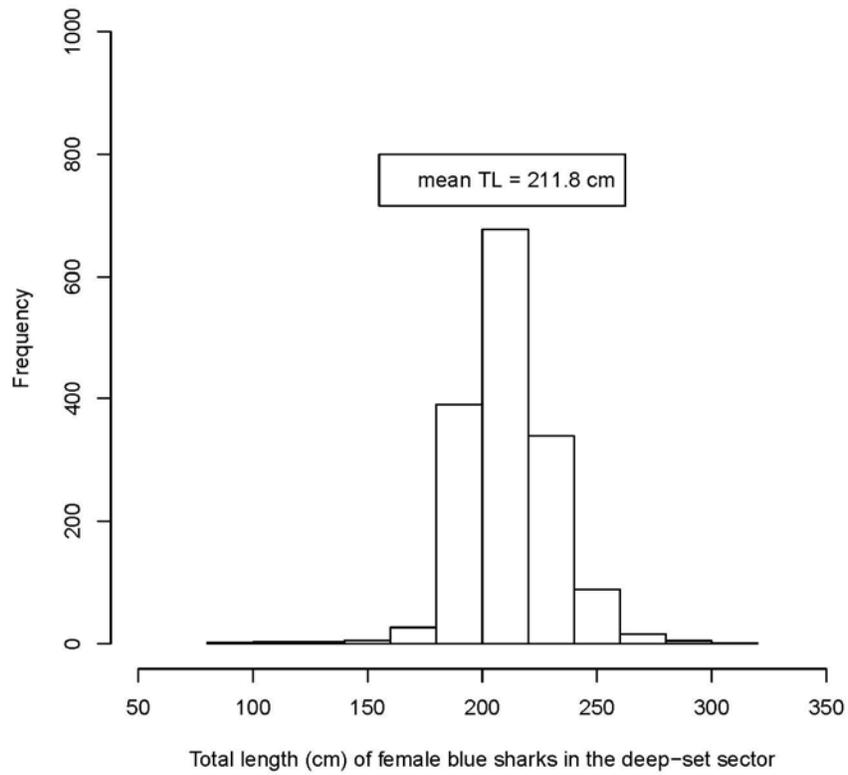


Figure 6, continued.

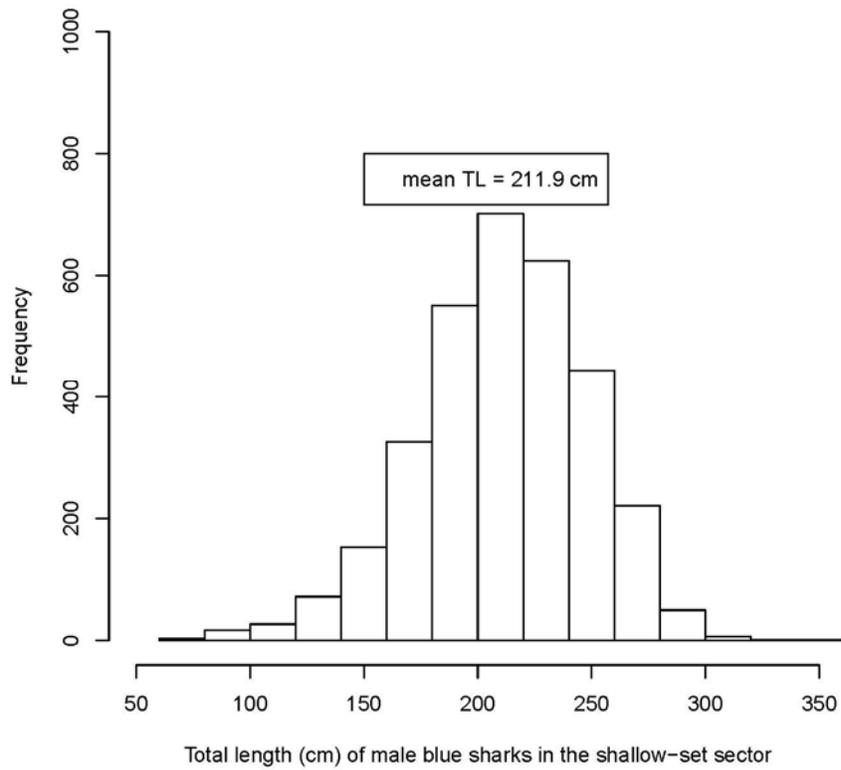
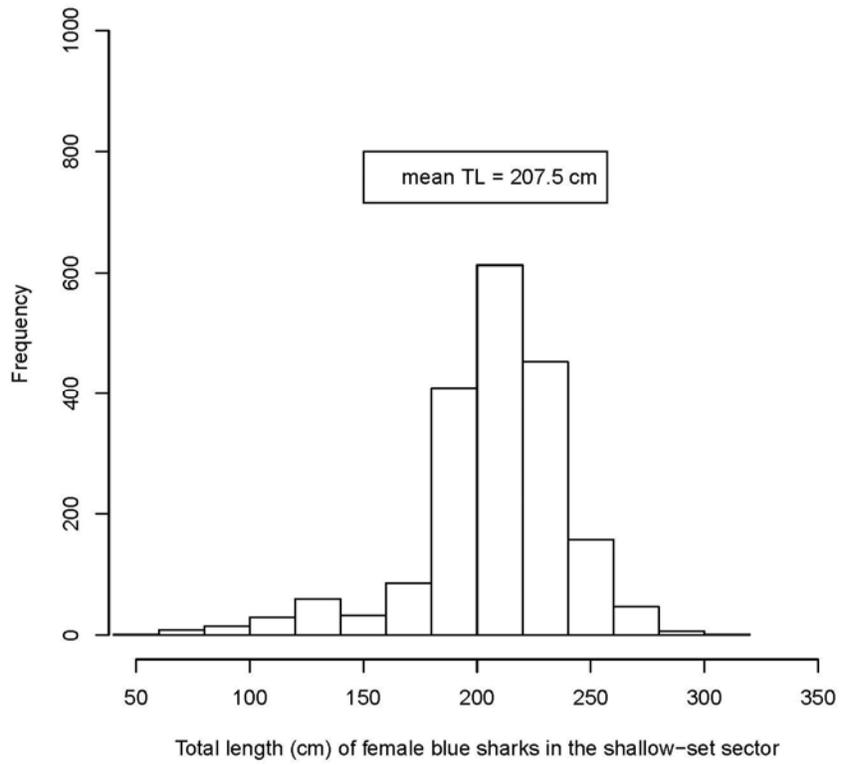


Figure 7. Size frequency distributions (fork length, cm) for blue sharks by fishery sectors and sexes from 1995 through 2011.

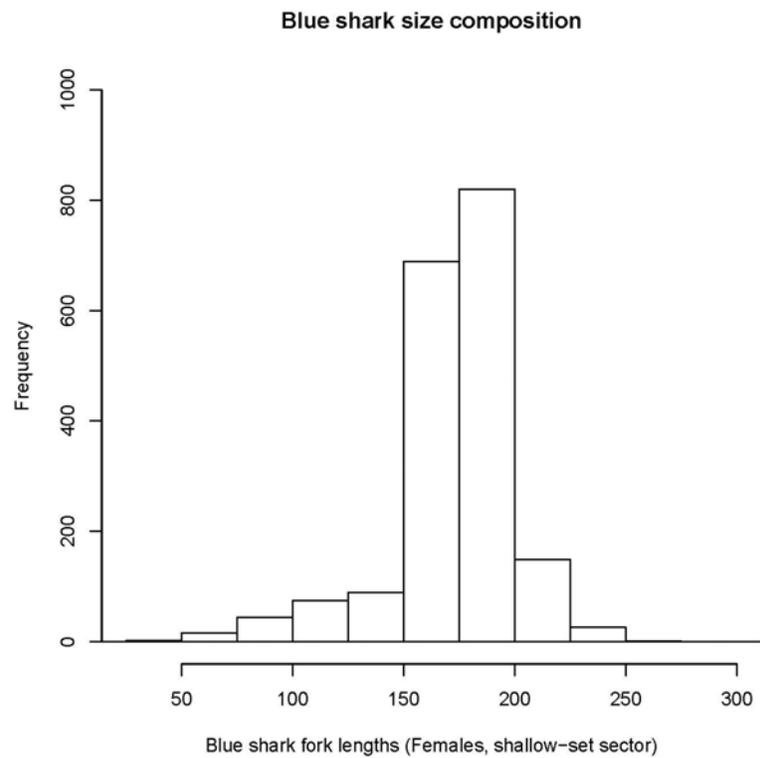
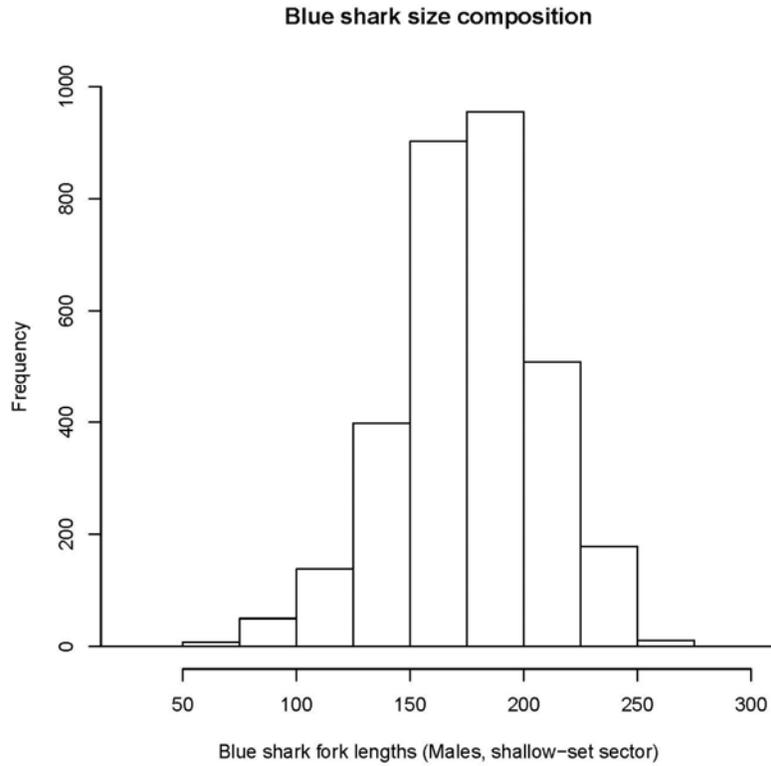


Figure 7, continued.

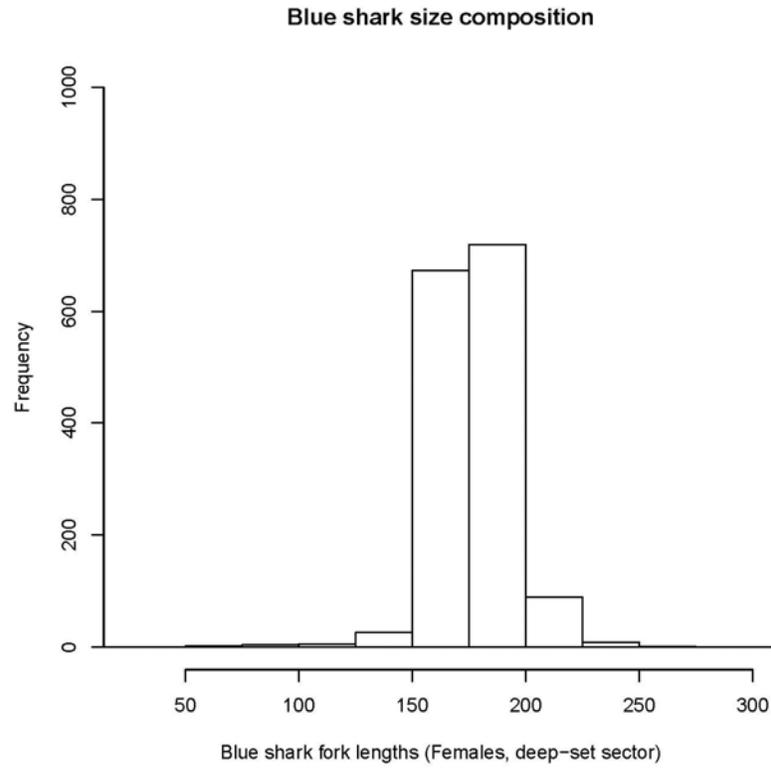
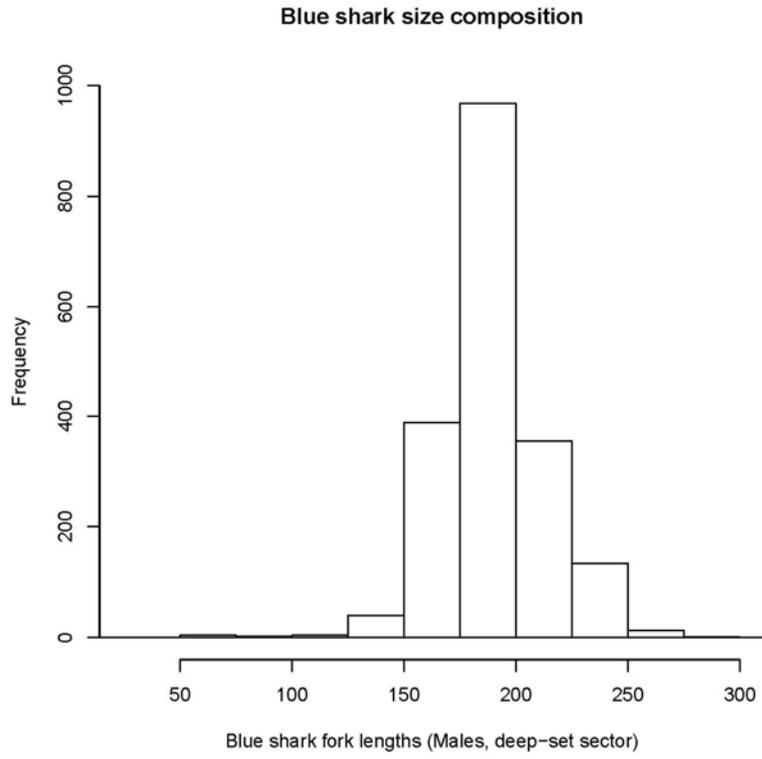


Figure 8. Annual mean blue shark total lengths by sexes in the deep-set sector in Regions 5 and 6 from 1995 through 2011.

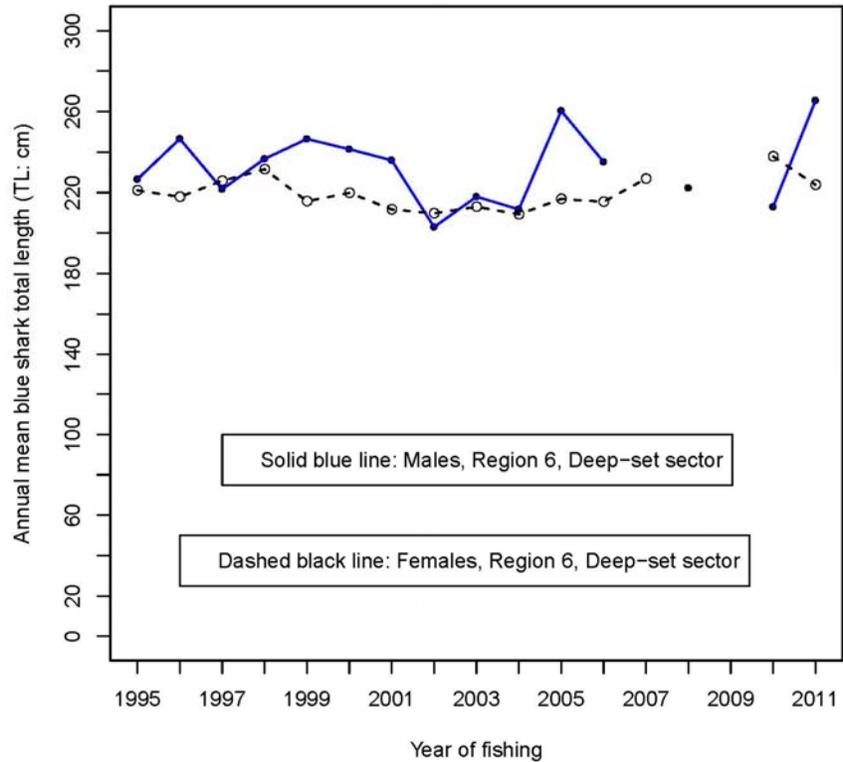
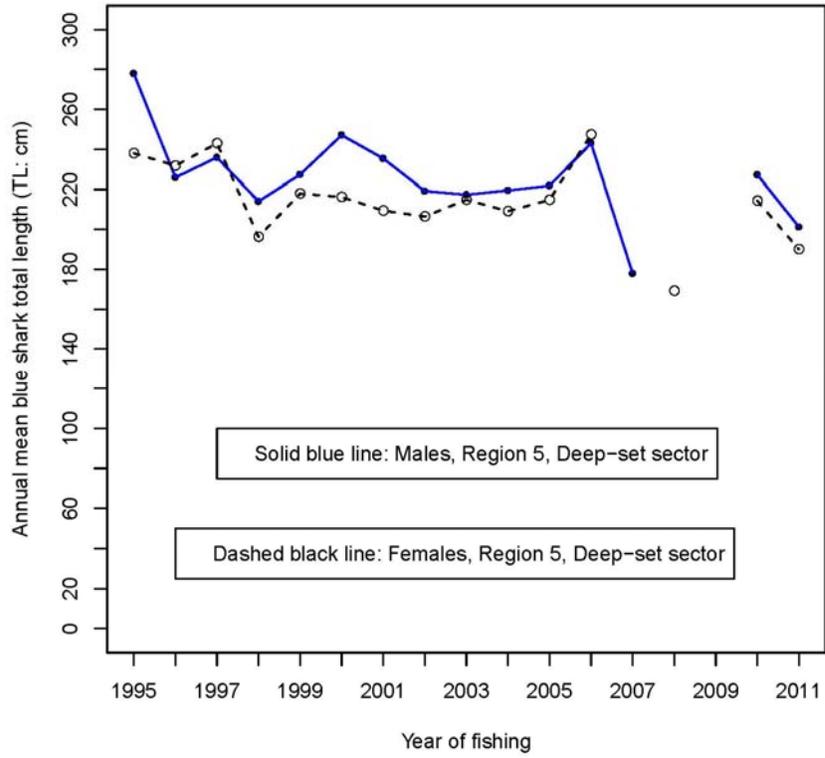
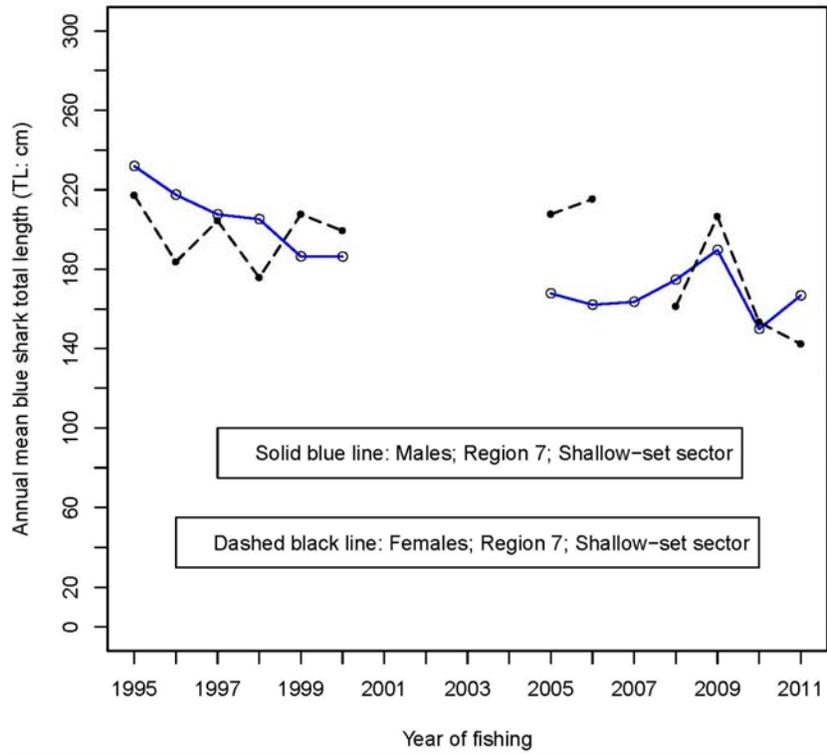


Figure 9. Annual mean blue shark total lengths by sexes in the shallow-set sector in Region 7 from 1995 through 2011.



## **APPENDIX I**

### **Residuals Plots and Synopses of Residuals**

Figure A1. Plots of residuals on fitted values (first plot: eight large fitted values not shown), the normal probability plot (second plot), the histogram of residuals (third plot), and the annual mean residuals from the lognormal GLM (fourth plot) for the deep-set sector from 1995 through 2011.

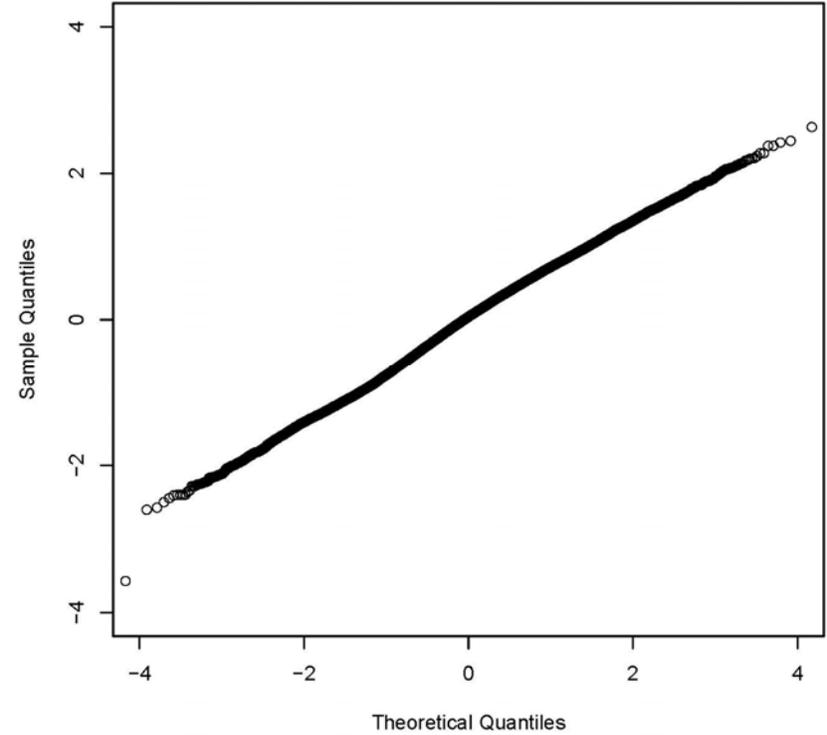
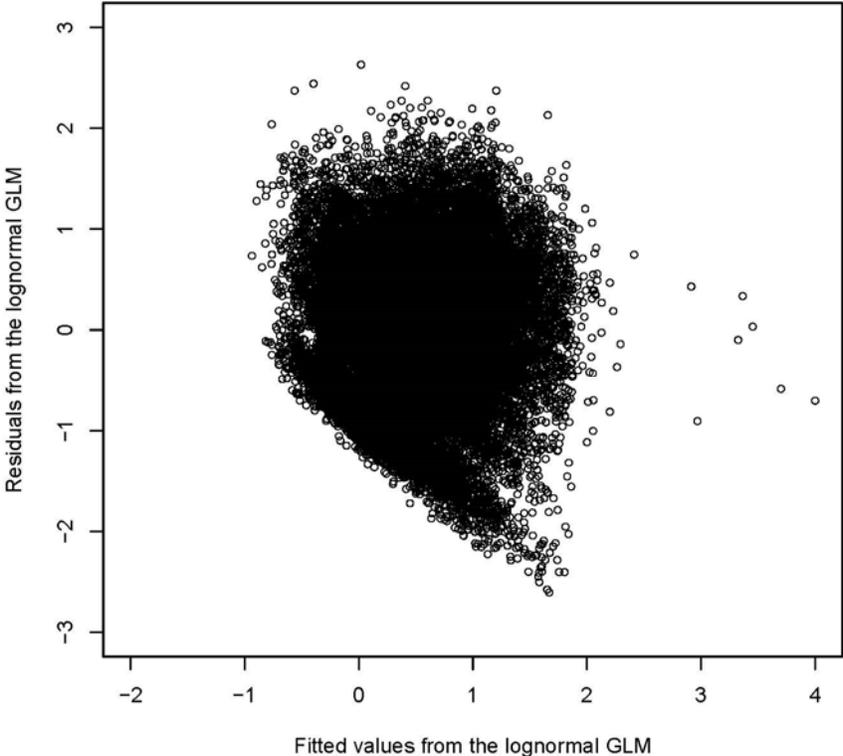


Figure A1, continued.

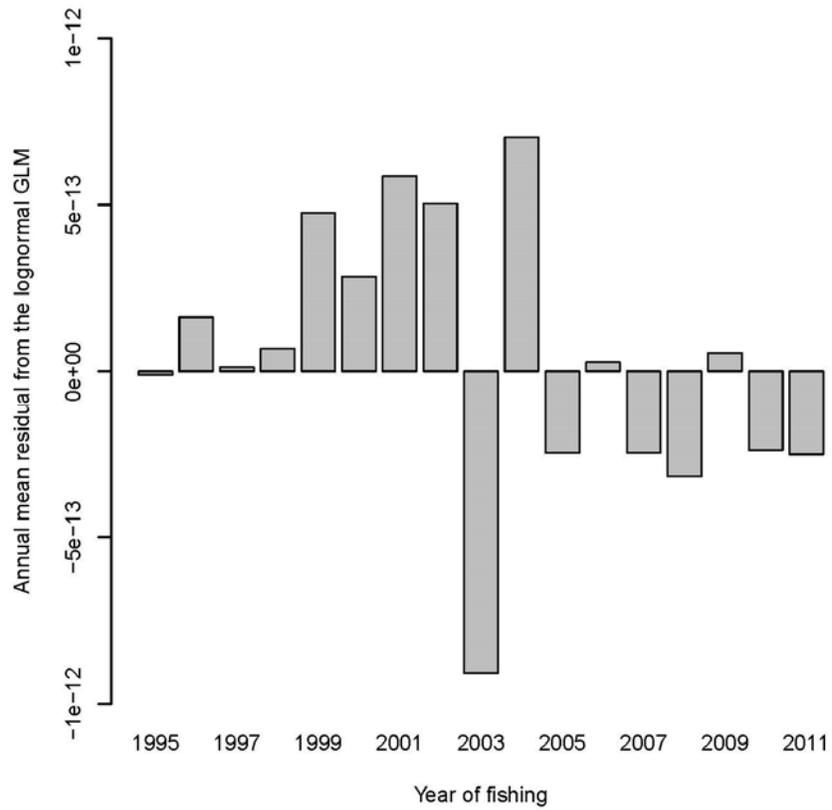
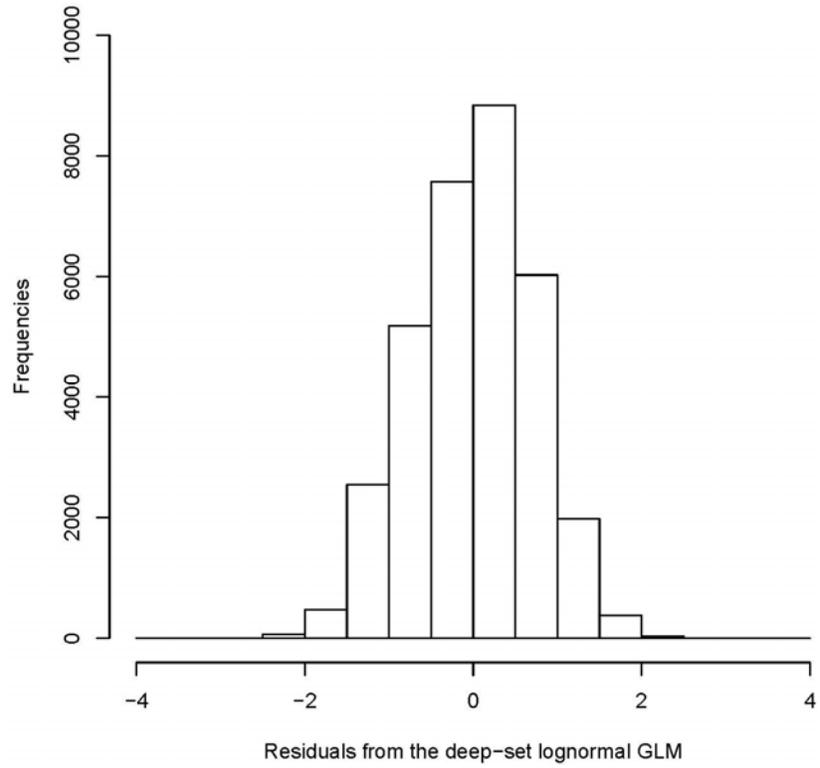


Figure A2. Plots of mean standardized residuals on the values of the factor variables in the binomial GLM of the delta lognormal analysis for the deep-set sector from 1995 through 2011.

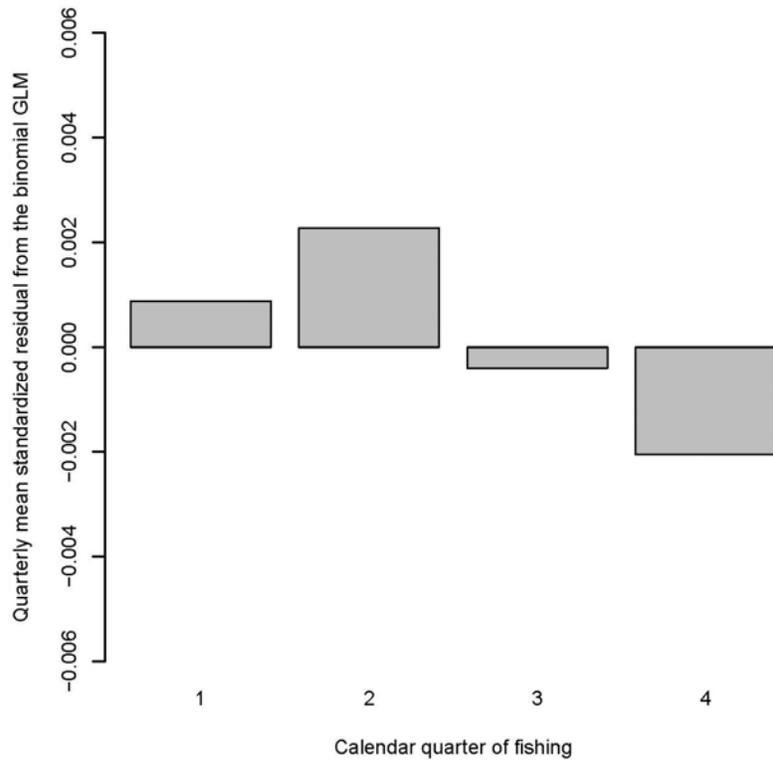
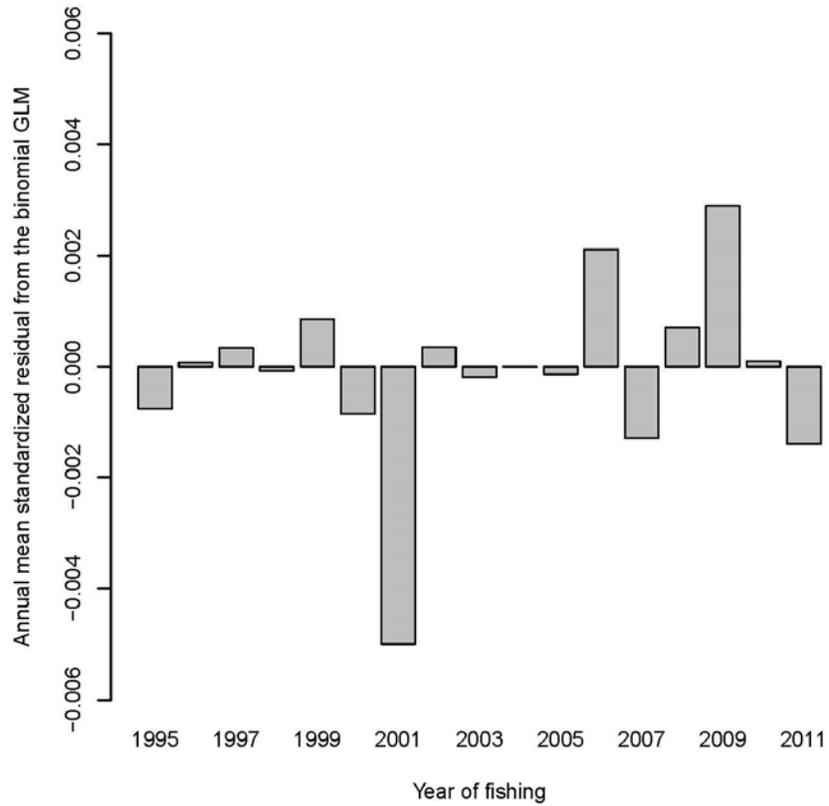
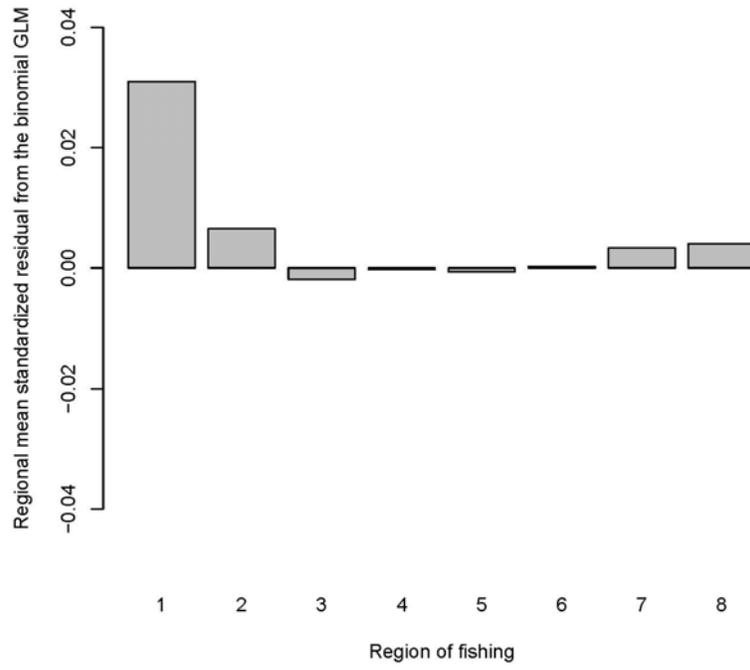


Figure A2, continued.



### Synopsis of Delta Lognormal Residuals: Deep-set Sector Lognormal GLM

The plot of residuals on fitted values from the lognormal GLM exhibited relatively uniform spread throughout most of the range of the fitted values. A cluster of 85 negative residuals ( $\leq -2$ ) near the predicted values of 1–2 consisted primarily (83.5%) of values associated with longline sets in the third and fourth quarters of several years in Regions 4 and 6.

The Q-Q plot of the residuals from the lognormal GLM was approximately linear.

The histogram of the residuals from the lognormal GLM was approximately symmetrical and centered near zero.

The annual mean residuals from the lognormal GLM from 1995–2002 were all positive whereas five of the seven annual mean residuals from 2005–2011 were negative.

### Synopsis of Delta Lognormal Residuals: Deep-set Sector Binomial GLM

There was no obvious trend in the annual mean standardized residuals from the binomial GLM. The largest was from 2001. The main perturbation to this sector at that time was the shark finning prohibition implemented in the preceding year. These analyses provided no information regarding any possible effect of the ban on either catches or fishing behavior.

The quarterly mean standardized residuals in the first two quarters were positive whereas those from the latter two quarters were negative.

The regional mean standardized residual from Region 1 was positive and more than four times greater than the absolute values of all other regional mean standardized residuals.

Figure A3. Plots of residuals on fitted values (first plot), the normal probability plot (second plot), the histogram of residuals (third plot), and the annual mean residuals from the lognormal GLM (fourth plot) for the shallow-set sector from 1995 through 2011.

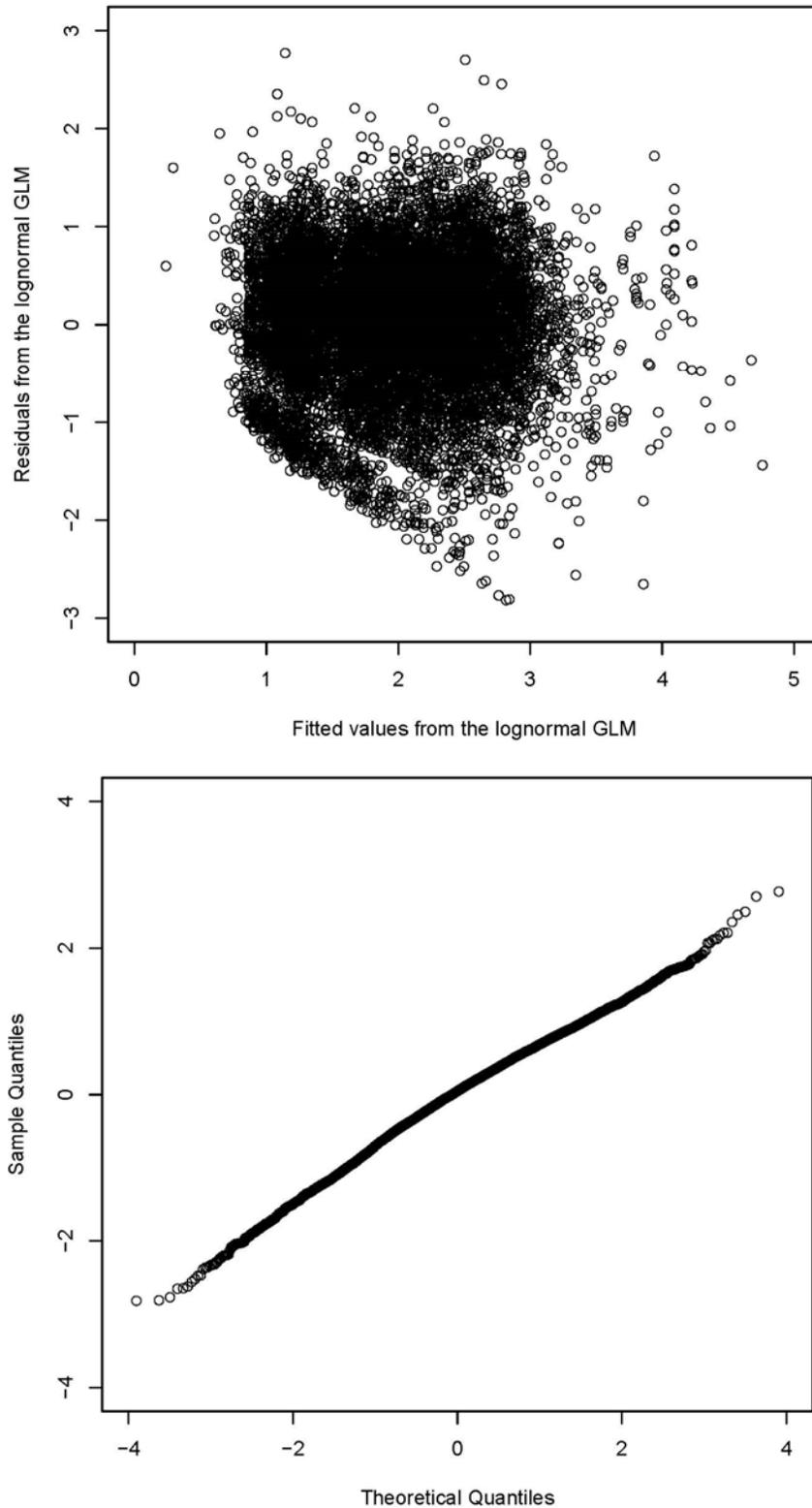


Figure A3, continued.

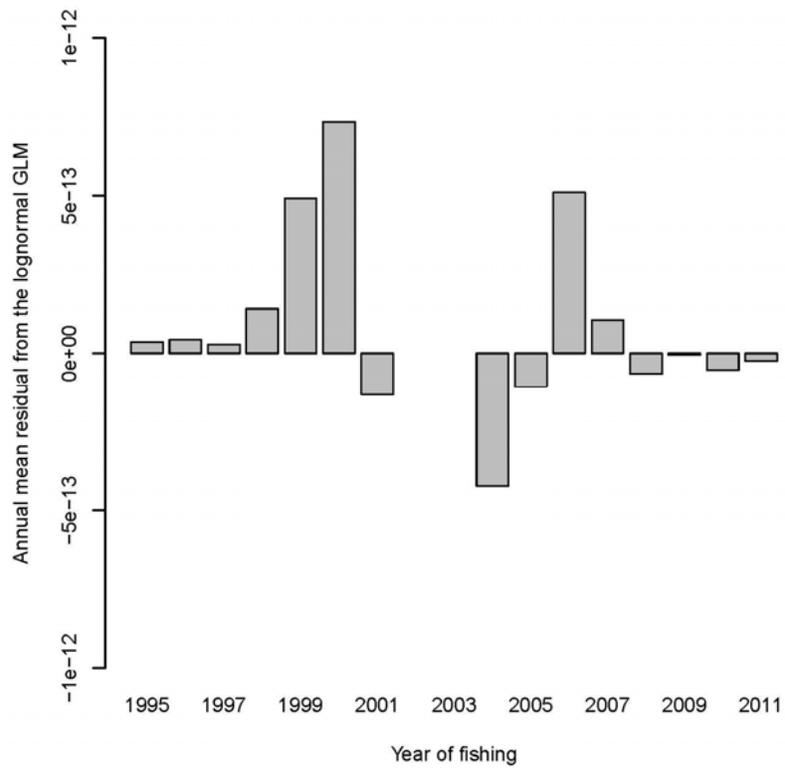
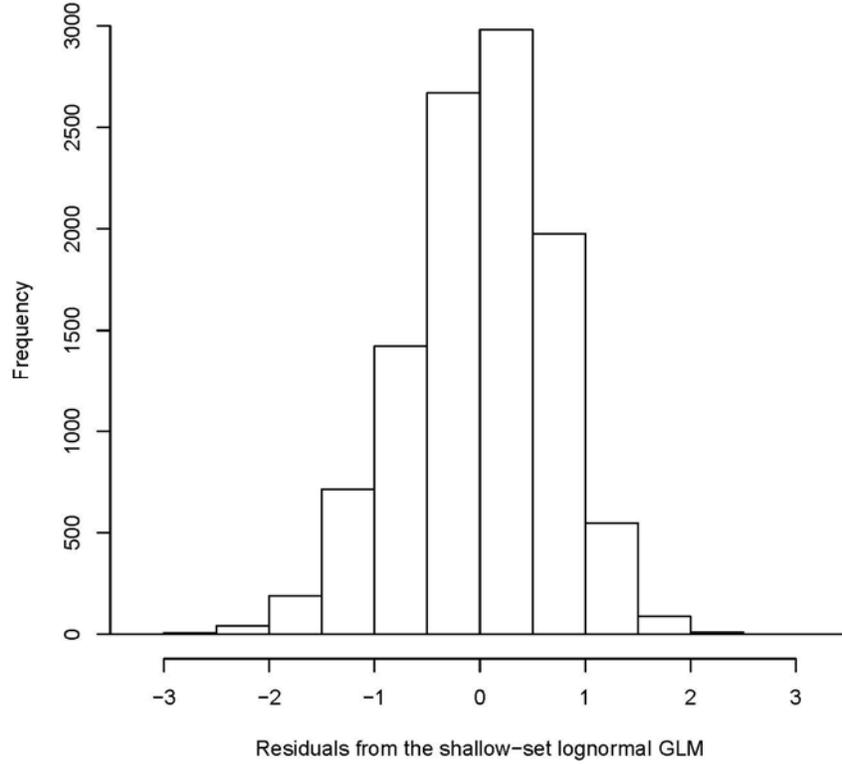


Figure A4. Plots of mean standardized residuals on the values of the factor variables in the binomial GLM of the delta lognormal analysis for the shallow-set sector from 1995 through 2011.

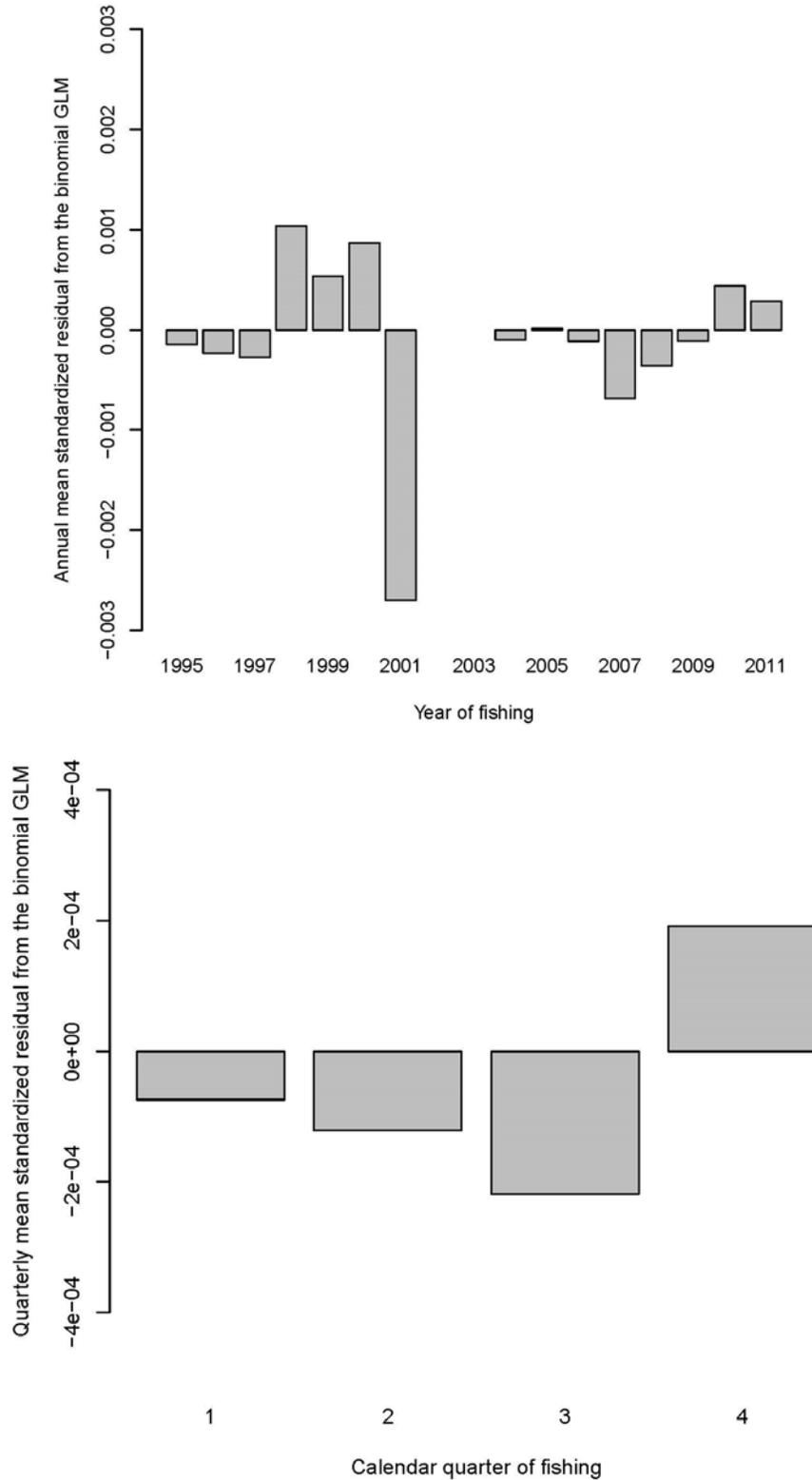
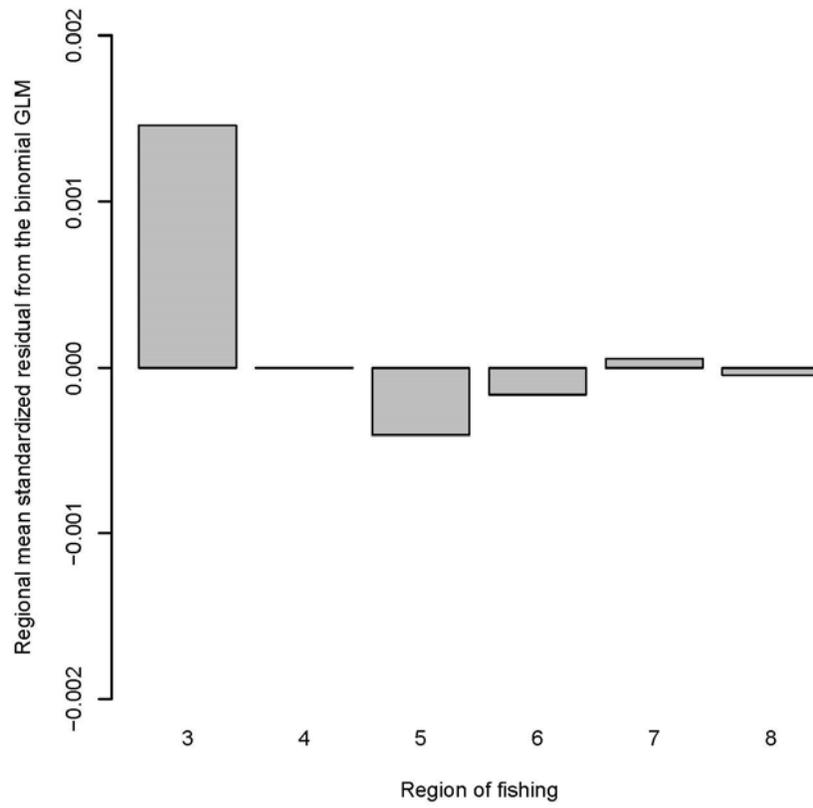


Figure A4, continued.



### Synopsis of Delta Lognormal Residuals: Shallow-set Sector Lognormal GLM

The plot of residuals on fitted values from the lognormal GLM exhibited relatively uniform spread throughout most of the range of the fitted values. The exception was a cluster of relatively large negative residuals (i.e.,  $\leq -2$ ) near the predicted values of 2 to 3. Of these 48 residuals, 33 (68.8%) were from the first quarters of 2005 through 2010.

Effort in this region increased after the re-opening of this sector. In 1995 through 2000, sets in this region and quarter constituted 2.6% to 24.7% of the total annual shallow-set effort. In 2004 through 2010, sets in this region and quarter constituted 37.0% to 81.6% of the total annual shallow-set effort.

The Q-Q plot of the residuals from the lognormal GLM was approximately linear.

The histogram of the residuals from the lognormal GLM was approximately symmetrical and centered near zero.

The annual mean residuals from the lognormal GLM, were very small, but were all positive from 1995 through 2000 and all negative from 2008 through 2011.

### Synopsis of Delta Lognormal Residuals: Shallow-set Sector Binomial GLM

There was no obvious trend in the annual mean standardized residuals from the binomial GLM. The largest mean value was from 2001, a partial fishing year during which the sector closure was implemented. The absolute value of this annual mean standardized residual was more than double those of all other years.

The quarterly mean standardized residuals in the first three quarters were negative whereas that from the fourth quarter was positive.

The mean standardized residual from Region 3 was positive and more than three times the absolute value of all others.

# **Responses to Questions about Blue Shark Catch Statistics and Criticism of a CPUE Standardization**

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August 2012

## **Introduction**

The Working Paper “Catch Statistics, Length Data and Standardized CPUE for Blue Shark *Prionace glauca* taken by Longline Fisheries based in Hawaii and California” by William A. Walsh and Steven L.H. Teo, was submitted and presented to the ISC Sharks Working Group in April 2012 (ISC/12/SHARKWG-1/02). This WP was criticized on one main point. One clarification and re-expression of size measurements were also sought. Because the latter are simpler concerns, they are addressed first herein.

## **Clarification to the Blue Shark WP**

### Post-release mortality

The clarification sought by the WG was related to post-release mortality of blue sharks. Two published papers relevant to this topic are available for this fishery.

Detailed results, including mortality attributable to finning, capture stress, or onboard handling, computed with observer data from two periods (1995–2000; 2004–2006) in the shallow-set and deep-set fisheries, are presented in Walsh et al. (2009). These authors documented that most (> 90%) blue sharks not subjected to finning survive capture and release. Thus, in the absence of finning, blue shark removals by this fishery should be minimized. It is recognized that the Walsh et al. (2009) results only provided the proportions of sharks that were dead or alive at release and as such, do not represent estimates of post-release survival per se.

Musyl et al. (2011) also presented results that indicate blue sharks suffer low rates of post-release mortality in the Hawaii-based pelagic longline fishery. A study conducted with pop-up satellite archival tags (PSATs) yielded a 6.3% post-release mortality rate, which was very close to the estimates of mortality at release from Walsh et al. (2009).

The longline fishery in the Northwest Atlantic off Canada is apparently characterized by higher mortality of caught blue sharks. A PSAT study (Campana et al. 2009) conducted there yielded an estimate of 18.9% post-release mortality. This difference in mortality is probably related to the handling procedures typical of the two fisheries (M.K. Musyl, personal communication).

The summary report suggested that post-release mortality estimates, which may need to be region- or fishery-specific, should be generated. If the WG were to choose a multiple (e.g., 2X, 5X, 10X) for the observed mortality at release, it should be possible to make a reasonable estimate of removals that is close to or moderately greater than the actual rate, rather than an unrealistically high estimate predicated upon the assumption that capture is invariably fatal to blue sharks.

Recommendation: In my opinion, a 5X multiplier would seem reasonable for the Hawaii-based longline fishery, which has been described as one of the world's most "shark friendly" (S.C. Clarke, personal communication). If this value were accepted for use in the stock assessment, the corresponding post-release mortality rate for Hawaii would be approximately 25%. A 2X multiplier (i.e., ca. 10% postrelease mortality) may not be justifiable because the PSAT sample size ( $N=17$ ; Musyl et al. 2011) was small, reflecting the tag cost.

### **Size Unit Conversion for Blue Sharks**

Conversion of size data to precaudal lengths

The WP presented blue shark measurements as total lengths (TL) in tabular form and in histograms, as requested at the previous meeting in La Jolla, CA, in November 2011. Because observers in this fishery usually measure fork length, a bivariate conversion regression was computed from a total of 7594 sharks that were measured for both TL and fork length (FL). Therefore, when TL was not measured, FL was converted to TL with the regression

$$Y = 10.678 + 1.138X$$

where  $Y = \text{TL (cm)}$  and  $X = \text{FL (cm)}$ .

The WG decided that TL and FL were not the most appropriate blue shark size measurements for use in an assessment, and recommended precaudal length (PCL) instead. The regression proposed by the WG was

$$\text{PCL} = 0.894(\text{FL}) + 2.547, N = 497, R^2 = 0.98, \text{ size range} = 98\text{-}243 \text{ cm PCL.}$$

The corresponding regression fitted to observer data from Hawaii over a greater size range is  $Y = 0.89294X + 3.00125$ ,  $N = 587$ ,  $R^2 = 0.915$ , size range = 18-246 cm PCL,

where  $Y = \text{PCL}$  and  $X$  is FL. The two regression coefficients are identical to the third decimal place, both coefficients of determination (0.915, 0.98) are very high, and the difference between intercepts would correspond to a 0.5 cm difference in PCL at birth.

Recommendation: These regressions can be used interchangeably. For a 200 cm FL shark, the two regressions yield estimates of PCL that differ by 0.2%.

### **Response to Criticism of the CPUE Standardization**

The Sharks WG inquired as to whether there has been a change(s) in targeting that would affect blue shark CPUE. Sharks have never been targeted in this fishery, so the question is irrelevant.

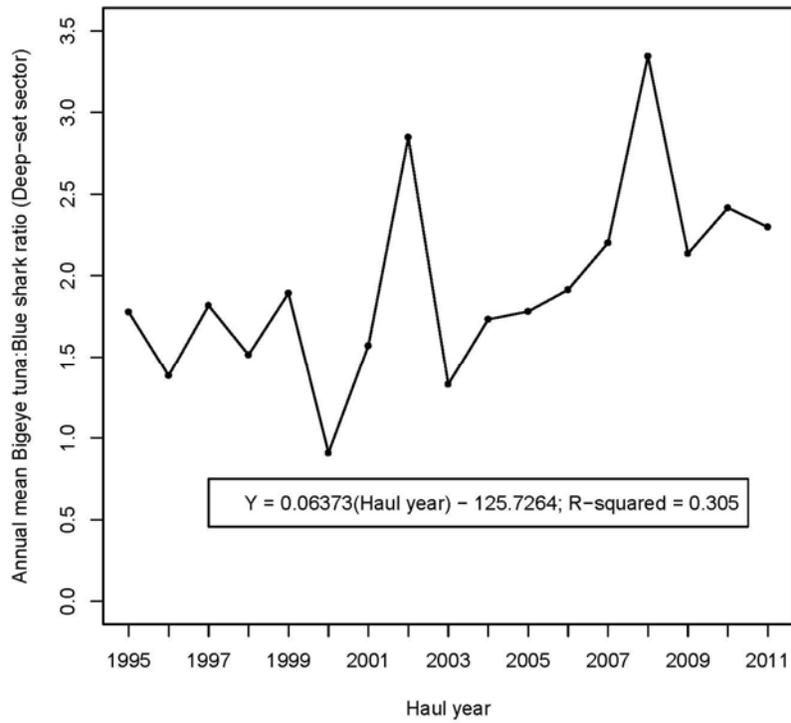
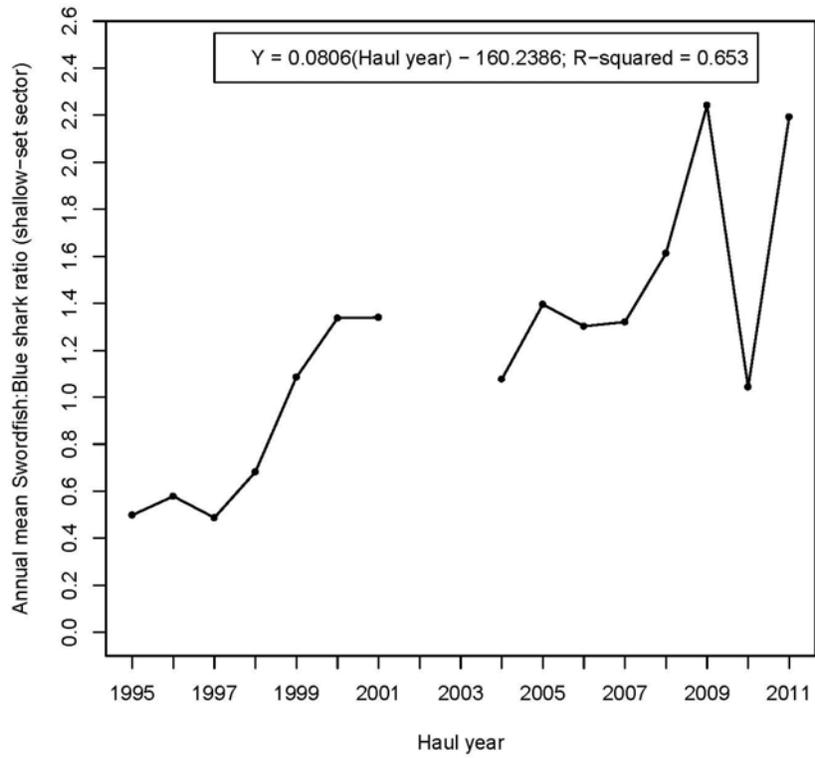
Figure 1 presents plots of the annual mean ratios of target species catch rates to blue shark catch rates in the two sectors of the Hawaii-based pelagic longline fishery. The noteworthy result is that both ratios follow an increasing trend, as indicated by statistically significant, positive regression coefficients, but the ratios during the period spanning the finning prohibition (2001) appear roughly stable. Thus, values from 1999–2007 for swordfish (although 2002 and 2003 are not plotted because of the sector closure) and from 1995–2006 for bigeye tuna (except for a low and high years in 2000 and 2002, respectively) did not provide any clear indications of an effect of the finning prohibition on the target species to blue shark ratios.

The Sharks WG wished to know if inclusion of other covariates in the generalized linear model used to standardize CPUE would increase precision or alter the temporal trend in relative abundance. Attempts to include other continuous variables (e.g., vessel length as a proxy for fishing power; begin-set time as an indicator of whether the gear deployment proceeded normally; soak time as an indicator of whether the duration was typical, etc.) did not yield reductions in the residual deviance, AIC, or BIC sufficient to warrant inclusion in the model. The request to include a factor distinguishing between the years before and after the finning prohibition was inappropriate because haul years and periods were confounded.

The principal concern with the Hawaii longline data is with the unobserved catch data, which are negatively biased because of under- and non-reporting. This concern has been met by including an upward correction for the catch on an annual basis, which was estimated by identifying negative outliers with regression techniques and substituting catches predicted by a generalized linear model.

Recommendation: The CPUE standardization model and index of relative abundance presented by Walsh and Teo (2012) should be used in their present form.

Figure 1. Annual mean ratios of the mean catches per set of target species (upper : swordfish; lower: bigeye tuna) and blue sharks.



### Literature Cited

Campana, S.E., W. Joyce, and M.J. Manning. 2009. Bycatch and discard mortality in commercially-caught blue sharks *Prionace glauca* assessed using archival satellite pop-up tags. *Marine Ecology Progress Series* 387:241–253.

Musyl, M.K., R.W. Brill, D.S. Curran, N.M. Fragoso, L.M. McNaughton, A. Nielsen, B.S. Kikkawa, and C.D. Moyes. 2011. Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. *Fishery Bulletin* 109:341–368.

Walsh, W.A., K.A. Bigelow, and K.L. Sender. 2009. Decreases in shark catches and mortality in the Hawaii-based longline fishery as documented by fishery observers. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 1:270–282.

**Blue Shark Catch Rates in the Hawaii-based Pelagic Longline Fishery in 2000–2012:  
A Re-evaluation of Observer Catch Data and Standardizations for both Fishery Sectors**

**William A. Walsh**

**Gerard T. DiNardo**

**January 2014**

## Introduction

This paper provides the exact R scripts and tests used to re-evaluate blue shark catches since 2000 in this fishery. Full details are provided. Results include the data preparation, model fitting, plots of nominal and standardized catch rates by fishery sector, tables summarizing the precision of the standardized catch rates, and a plot of the annual indices of relative abundance from both sectors. This section presupposes familiarity with R commands.

## Blue Shark CPUE Standardization

This file presents the results of a blue shark CPUE standardization using catch and operational data gathered by the PIROP observer program from January 2000 through December 2012. The analyses are computed by fishery sector. All work was computed in R version 3.0 for Windows.

### Preparation of the data frames

```
> BS_data<-read.table("Swordfish_CPUE_Data.txt",sep=" ")
```

```
dim(BS_data) [1]
55671 53
```

Set type totals

```
> table(BS_data$settype1)
```

```
[1] 1 2
43157 12514
```

Set type 1=Deep; set type 2=Shallow

This data frame includes 1995-2012.

### **Deep-set sector, 2000-2012:**

```
> BS_DS_data<-BS_data[BS_data$Haulyr>1999 & BS_GD_data$Haulyr<2013 &
BS_GD_data$settype1==1,]
```

```
> dim(BS_DS_data) [1]
41908 53
```

### **Shallow-set sector, 2000-2012:**

```
BS_SS_data<-BS_data[BS_data$Haulyr>1999 & BS_data$Haulyr<2013 &
BS_data$$settype1==2,]
```

```
> dim(BS_SS_data) [1]
11173 53
```

## Descriptive statistics

This section presents nominal catch rate summaries by year and fishing region for deep sector. The fishing regions correspond to the eight regions in Brodziak and Walsh (CJFAS; Dec.2013).

Deep-set sector: Annual totals, annual mean catches per set, and annual mean nominal CPUE

```
tapply(BS_DS_data$Blueshark,BS_DS_data$Haulyr,sum)
```

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
8475	13097	12797	18581	20961	12731	11950	16364	9891	11779	12734	14566	12586

```
> tapply(BS_DS_data$Blueshark,BS_DS_data$Haulyr,mean)
```

2000	2001	2002	2003	2004	2005	2006	2007	2008
8.746130	4.993138	3.739626	5.947823	5.546705	3.859048	3.639963	4.635694	2.543327
2009	2010	2011	2012					
3.355840	3.829774	4.168861	3.437859					

```
> tapply(BS_DS_data$BScpue,BS_DS_data$Haulyr,mean)
```

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
4.40183	2.67222	1.99397	2.97748	2.79378	1.92710	1.74304	2.13060	1.14422	1.50431
2010	2011	2012							
1.72523	1.77243	1.45280							

## Tabulation of catches in counts

```
table(BS_DS_data$BlueShark)
```

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
5716	7145	6406	5121	4064	3059	2219	1636	1271	1006	767	595	453	392	322	251	214	162			
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
146	146	122	110	87	66	67	49	45	41	37	22	25	17	21	26	10	8	11	6	3
39	40	41	42	43	44	45	46	48	49	50	54	57	61	62	63					
11	5	5	6	2	4	2	1	1	1	1	1	1	1	1	1					

Number of zero catches

```
dim(BS_DS_data)
```

```
[1] 41908 54
```

```
> 5716/41908
```

```
[1] 0.136394
```

Zero blue sharks were caught on 13.6% of the observed deep sets.

```
> junk<-BS_DS_data[BS_DS_data$BlueShark==0,]
```

```
> table(junk$Haulyr)
```

```
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
  44  305  424  250  323  357  495  461  721  808  563  425  540
```

**NOTE: The relatively high number in 2009 reflects activity in Region 1.**

Fishing regions

Catch totals

```
tapply(BS_DS_data$BlueShark,BS_DS_data$Region1,sum)
```

```
1 2 3 4 5 6 7 8
```

```
172 2419 28554 61510 43419 34320 3605 2513
```

Mean catches per set

```
> tapply(BS_DS_data$BlueShark,BS_DS_data$Region1,mean)
```

```
1 2 3 4 5 6 7 8
```

```
0.9717514 1.7945104 4.4386756 5.8928914 2.7720743 6.3169520 2.1888282 3.2678804
```

> Nominal CPUE

```
> tapply(BS_DS_data$BScpue,BS_DS_data$Region1,mean)
```

```
1 2 3 4 5 6 7 8
```

```
0.4683669 0.8613570 2.2234192 2.8058859 1.3056451 3.0234755 0.9637668 1.6083741
```

> Fishing Quarters

> Catch totals

> tapply(BS\_DS\_data\$BlueShark,BS\_data\$Quarter1,sum)

1 2 3 4

26224 32004 44445 73839

> Mean catches per set

> tapply(BS\_DS\_data\$BlueShark,BS\_DS\_data\$Quarter1,mean)

1 2 3 4

2.933333 3.322329 4.243365 5.741311

> Mean nominal CPUE

> tapply(BS\_DS\_data\$BScpue,BS\_DS\_data\$Quarter1,mean)

1 2 3 4

1.440306 1.588336 2.041593 2.719516

> Other Factor Variables

> Bait

> tapply(BS\_DS\_data\$BlueShark,BS\_DS\_data\$Bait1,mean)

1 2 3 4 5 6 7

5.444444 2.000000 4.044577 4.059480 4.493800 5.001312 4.354626

> Hook Types

> tapply(BS\_DS\_data\$BlueShark,BS\_DS\_data\$HookType1,mean)

1 2 3 4 5 6 7

5.041595 5.641830 3.751945 4.246835 4.032374 4.504587 3.830203

> Leader Materials

> tapply(BS\_DS\_data\$BlueShark,BS\_DS\_data\$LdrMatl1,mean)

1 2 3

3.604327 4.270940 3.808362

## Model Summary

```
> summary(BS_DS_NB_GLM_1)
```

Call:

```
glm.nb(formula = BlueShark ~ Haulyr1 + Quarter1 + Region1 + Bait1 +  
HookType1 + LdrMat1 + Quarter1:Region1 + SST + Hkpfl + Soaktime +  
offset(log(Hooks)), data = BS_DS_data, init.theta = 2.603890082, link = log)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-3.3202	-0.9154	-0.2375	0.4309	6.9411

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	-12.958096	0.281767	-45.989	< 2e-16 ***
Haulyr12001	-0.100257	0.029416	-3.408	0.000654 ***
Haulyr12002	-0.391736	0.029167	-13.431	< 2e-16 ***
Haulyr12003	-0.166817	0.029755	-5.606	2.07e-08 ***
Haulyr12004	-0.402088	0.030062	-13.375	< 2e-16 ***
Haulyr12005	-0.454416	0.034247	-13.269	< 2e-16 ***
Haulyr12006	-0.757794	0.034725	-21.823	< 2e-16 ***
Haulyr12007	-0.648604	0.032933	-19.695	< 2e-16 ***
Haulyr12008	-0.831375	0.035466	-23.441	< 2e-16 ***
Haulyr12009	-0.839207	0.035627	-23.555	< 2e-16 ***
Haulyr12010	-0.562858	0.035949	-15.657	< 2e-16 ***
Haulyr12011	-0.639896	0.036103	-17.724	< 2e-16 ***
Haulyr12012	-0.739895	0.036401	-20.326	< 2e-16 ***
Quarter12	0.079895	0.278216	0.287	0.773984
Quarter13	-0.428815	0.260156	-1.648	0.099291 .

Quarter14	1.056936	0.305982	3.454	0.000552	***
Region12	0.840042	0.218627	3.842	0.000122	***
Region13	1.588274	0.216287	7.343	2.08e-13	***
Region14	1.611603	0.215800	7.468	8.14e-14	***
Region15	1.430203	0.216905	6.594	4.29e-11	***
Region16	2.289560	0.216644	10.568	< 2e-16	***
Region17	3.659121	0.309409	11.826	< 2e-16	***
Region18	5.075476	0.263520	19.260	< 2e-16	***
Bait12	-0.416661	0.711028	-0.586	0.557877	
Bait13	-0.587873	0.115190	-5.104	3.33e-07	***
Bait14	-0.629282	0.120738	-5.212	1.87e-07	***
Bait15	-0.561841	0.115801	-4.852	1.22e-06	***
Bait16	-0.583708	0.116430	-5.013	5.35e-07	***
Bait17	-0.534826	0.116433	-4.593	4.36e-06	***
HookType12	0.111814	0.031419	3.559	0.000373	***
HookType13	-0.015067	0.018308	-0.823	0.410503	
HookType14	0.164515	0.065416	2.515	0.011907	*
HookType15	0.019037	0.039114	0.487	0.626465	
HookType16	0.108662	0.079542	1.366	0.171908	
HookType17	-0.004188	0.021428	-0.195	0.845036	
LdrMatl12	0.216433	0.015875	13.633	< 2e-16	***
LdrMatl13	-0.011685	0.053484	-0.218	0.827061	
SST	0.223580	0.004897	45.657	< 2e-16	***
Hkpfl	-0.019039	0.001519	-12.536	< 2e-16	***
Soaktime	0.030344	0.001849	16.412	< 2e-16	***
Quarter12:Region12	-0.476616	0.285390	-1.670	0.094910	.
Quarter13:Region12	-0.661022	0.270926	-2.440	0.014693	*

Quarter14:Region12 -2.254501 0.320386 -7.037 1.97e-12 \*\*\*  
 Quarter12:Region13 -0.173021 0.279681 -0.619 0.536155  
 Quarter13:Region13 1.090879 0.261714 4.168 3.07e-05 \*\*\*  
 Quarter14:Region13 -0.565125 0.307109 -1.840 0.065747 .  
 Quarter12:Region14 0.046636 0.278924 0.167 0.867213  
 Quarter13:Region14 1.259089 0.260982 4.824 1.40e-06 \*\*\*  
 Quarter14:Region14 -0.372118 0.306804 -1.213 0.225173  
 Quarter12:Region15 0.136137 0.279761 0.487 0.626529  
 Quarter13:Region15 0.396297 0.261149 1.518 0.129138  
 Quarter14:Region15 -0.841568 0.306918 -2.742 0.006107 \*\*  
 Quarter12:Region16 -0.473198 0.280244 -1.689 0.091312 .  
 Quarter13:Region16 -0.216201 0.262896 -0.822 0.410860  
 Quarter14:Region16 -0.885875 0.307036 -2.885 0.003911 \*\*  
 Quarter12:Region17 -1.867599 0.368815 -5.064 4.11e-07 \*\*\*  
 Quarter13:Region17 -1.907003 0.341428 -5.585 2.33e-08 \*\*\*  
 Quarter14:Region17 -3.488913 0.394746 -8.838 < 2e-16 \*\*\*  
 Quarter12:Region18 -2.987088 0.325001 -9.191 < 2e-16 \*\*\*  
 Quarter13:Region18 -3.121797 0.301524 -10.353 < 2e-16 \*\*\*  
 Quarter14:Region18 -5.925388 0.376398 -15.742 < 2e-16 \*\*\*

(Dispersion parameter for Negative Binomial(2.6039) family taken to be 1)

Null deviance: 73036 on 41907 degrees of freedom

Residual deviance: 46060 on 41847 degrees of freedom

AIC: 193523

Theta: 2.6039 Std. Err.: 0.0321 2 x log-likelihood: -193398.7240

Pseudocoefficient of determination ( $pseudo-R^2$ ) = (73036.12-46060.11)/73036.12

[1] 0.3693517

This negative binomial GLM explains 36.9% of the null deviance of blue shark catches per observed deep set.

Figure X. Standardized and nominal annual mean catches per observed deep set, 2000-2012, in the Hawaii-based pelagic longline fishery.

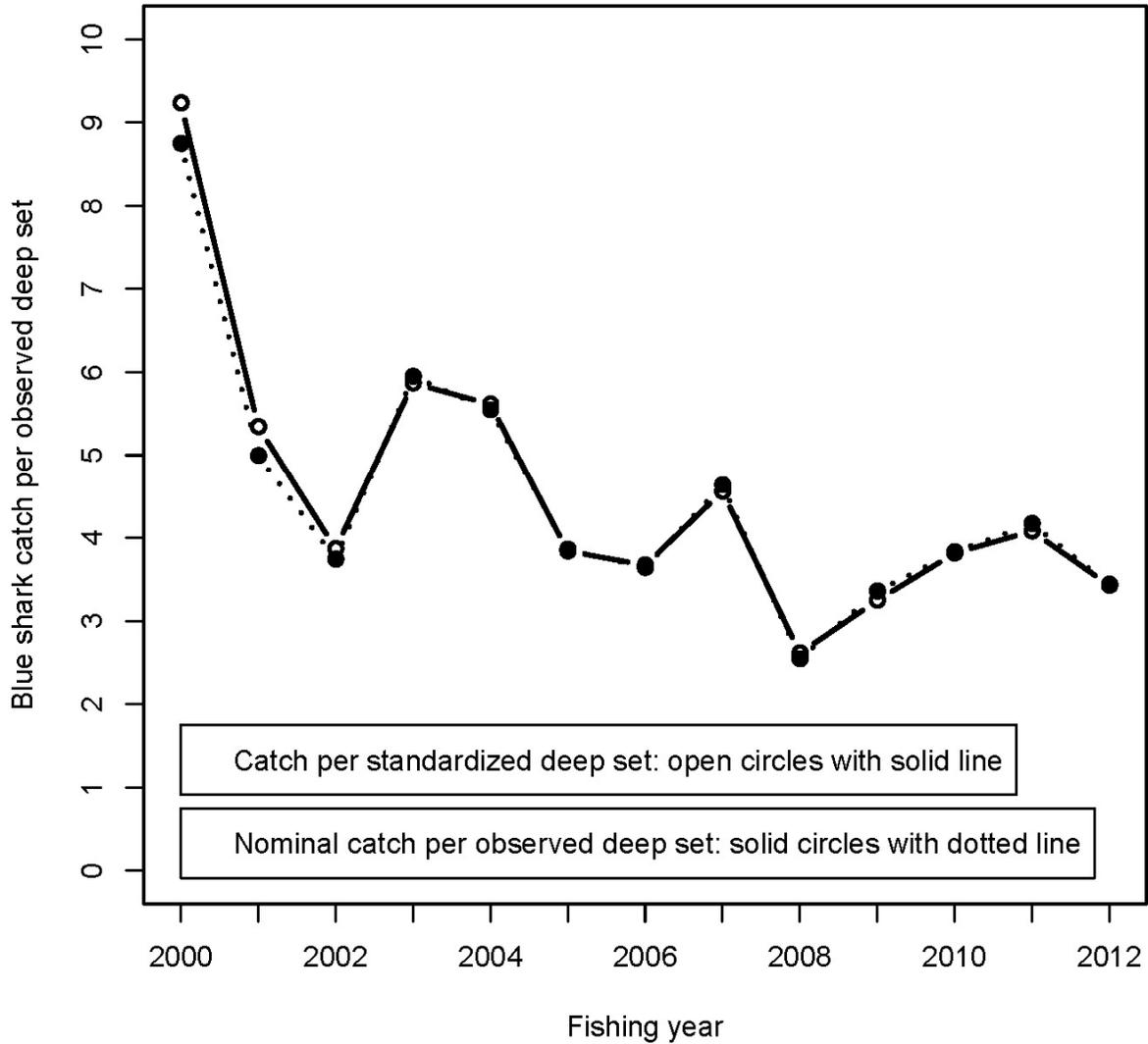


Figure X. 1.7%

### Histogram of Pearson residuals

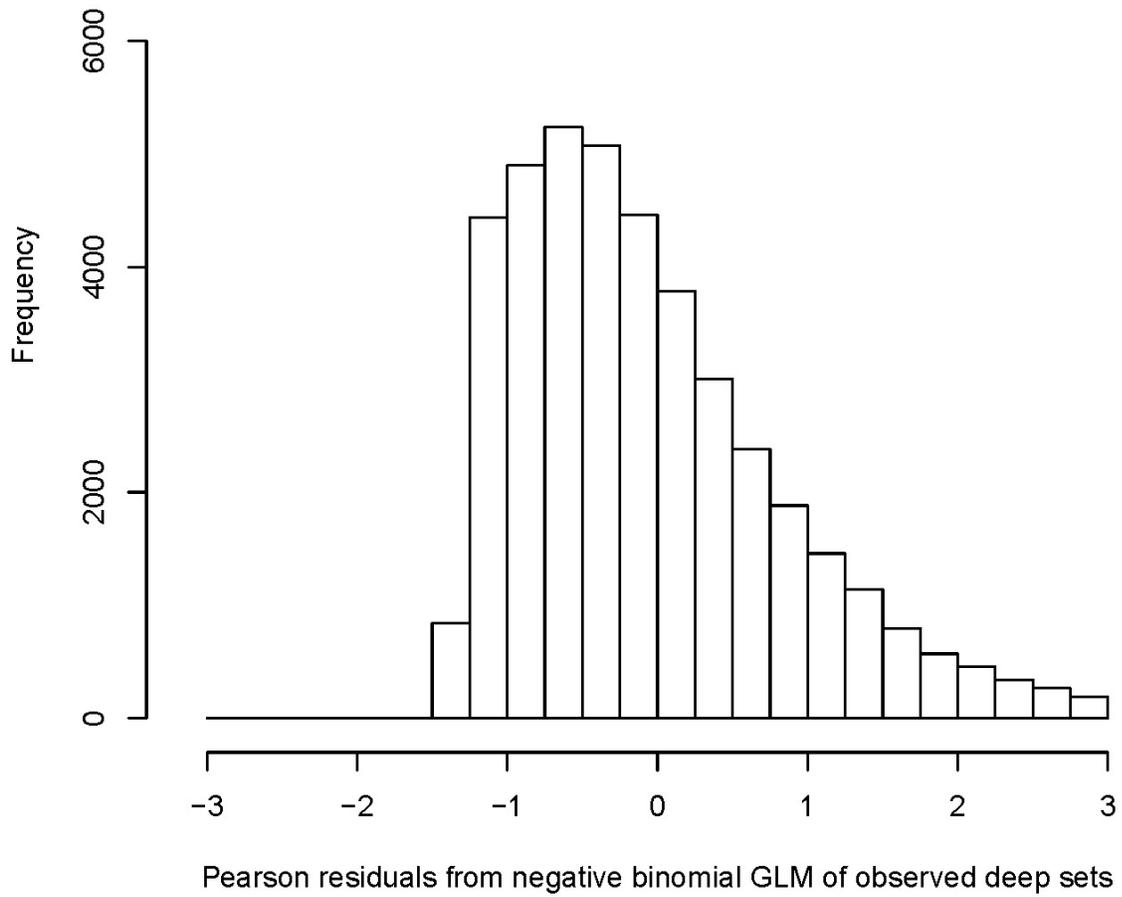


Table X. Standardized CPUE (blue shark/standard set) in the deep-set sector of the Hawaii-based pelagic longline fishery. The table entries for each fishing year include the mean catch per standard set with its variance and standard deviation, the coefficient of variation, and sample size.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Mean CPUE	9.07	5.15	3.79	5.97	5.50	3.89	3.63	4.61	2.58	3.36	3.81	4.17	3.44
Variance	27.07	9.04	6.33	15.22	8.45	5.42	4.64	10.24	2.21	9.36	6.14	8.75	4.69
Standard deviation	5.20	3.01	2.52	3.90	2.91	2.33	2.15	3.20	1.49	3.06	2.48	2.96	2.16
CV	0.57	0.58	0.66	0.65	0.53	0.60	0.59	0.69	0.58	0.91	0.65	0.71	0.63
N	969	2623	3422	3124	3779	3299	3283	3530	3889	3510	3325	3494	3661

## Shallow-set Sector Analyses

The procedures described above were also used to generate these results. For that reason, preparatory stages are not repeated. The initial data frame (BS\_GD\_SS\_data) was summarized. Name simplified: BS\_SS\_data).

```
> table(BS_SS_data$Haulyr)
1995 1996 1997 1998 1999 2000 2001 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
 277  334  282  272  176  353  146   4  135 1640  821 1566 1474 1635 1560  928  911
>
> BS_SS_data1<-BS_SS_data[BS_SS_data$Haulyr>1999,]
> dim(BS_SS_data1)
[1] 11173  53
>
> table(BS_SS_data1$Haulyr)
2000 2001 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
 353  146   4   135 1640  821 1566 1474 1635 1560  928  911
>
> BS_SS_data2<-BS_SS_data1[BS_SS_data1$Haulyr<2001 | BS_SS_data1$Haulyr>2004,]
> dim(BS_SS_data2)
[1] 10888  53
> This removed 285 sets from 2001-2004 during the closure and subsequent partial year.
```

### Table of observed shallow sets per year.

```
> table(BS_SS_data2$Haulyr)
2000 2005 2006 2007 2008 2009 2010 2011 2012
 353 1640  821 1566 1474 1635 1560  928  911
```

### Descriptive catch statistics on observed shallow sets.

Annual sums

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Haulyr,sum)
2000 2005 2006 2007 2008 2009 2010 2011 2012
3073 15575 10282 16239 12010 7764 14703 5039 3886
```

> Annual mean per set

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Haulyr,mean)
2000 2005 2006 2007 2008 2009 2010 2011 2012
8.705382 9.496951 12.523752 10.369732 8.147897 4.748624 9.425000 5.429957 4.265642
```

> Annual mean nominal CPUE

```
> BS_SS_data2$BScpue<-1000*(BS_SS_data2$BlueShark/BS_SS_data2$Hooks)
> tapply(BS_SS_data2$BScpue,BS_SS_data2$Haulyr,mean)
2000 2005 2006 2007 2008 2009 2010 2011 2012
11.664823 11.769637 16.066471 12.276330 9.157700 5.069549 9.962339 5.369817 4.041678
```

>Table of observed catches per shallow set .

```
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
453 774 1152 1125 1016 949 815 614 540 442 407 345 217 238 209 184 167 128 102 111
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
90 79 86 69 55 44 45 39 35 39 23 26 22 25 22 19 20 12 12 13
40 41 42 43 44 45 46 47 48 49 50 51 52 53 55 56 57 59 60 61 62
9 4 11 5 4 11 6 3 7 3 5 1 4 6 2 7 4 6 2 3 2
63 65 68 70 71 72 76 77 81 92 108 112 129 131 133 134 242 268 359
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

### Proportions of zero catches

```
> 453/10888
```

```
[1] 0.04160544
```

There were 4.16% zero catches on observed shallow sets from 2000 through 2012.

### Annual zero catch percentages

```
> junk<-BS_SS_data2[BS_SS_data2$BlueShark==0,]
> dim(junk)
[1] 453 54
```

### Zero catch sets per year

```
> table(junk$Haulyr)
2000 2005 2006 2007 2008 2009 2010 2011 2012
  16  18  10  74  71  94  70  37  63
> zerorate<-table(junk$Haulyr)
> annsets<-table(BS_SS_data2$Haulyr)
> annsets
2000 2005 2006 2007 2008 2009 2010 2011 2012
353 1640 821 1566 1474 1635 1560 928 911
> zerorate
2000 2005 2006 2007 2008 2009 2010 2011 2012
  16  18  10  74  71  94  70  37  63
> 100*(zerorate/annsets)
  2000    2005    2006    2007    2008    2009    2010    2011    2012
4.532578 1.097561 1.218027 4.725415 4.816825 5.749235 4.487179 3.987069 6.915477
> Zero catch rates ranged from 1.1% to 6.9% between 2000 and 2012.
```

## Effects of other factor variables

### Quarterly

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Quarter1,mean)
```

```
  1      2      3      4
```

```
10.438593 4.698975 8.820565 9.482673
```

```
>
```

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Quarter1,sum)
```

```
  1      2      3      4
```

```
57287 19247 4375 7662
```

```
>
```

```
> tapply(BS_SS_data2$BScpue,BS_SS_data2$Quarter1,mean)
```

```
  1      2      3      4
```

```
12.050047 5.202988 10.045197 11.638922
```

### Regional

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Region1,mean)
```

```
  3      4      5      6      7      8
```

```
11.944444 10.400000 4.369880 4.928887 10.861898 9.532609
```

```
>
```

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Region1,sum)
```

```
  3      4      5      6      7      8
```

```
215 364 6935 14486 52539 14032
```

```
>
```

```
> tapply(BS_SS_data2$BScpue,BS_SS_data2$Region1,mean)
```

```
  3      4      5      6      7      8
```

```
12.746746 12.785394 4.845572 5.388411 12.705489 10.984319
```

**> Bait types**

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Bait1,mean)
```

```
  1      2      3      4      5      6      7
8.954023 8.010989 4.889610 8.118604 11.090226 3.615385 10.450000
```

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$Bait1,sum)
```

```
  1    2    3    4    5    6    7
2337 729 753 82347 1475 94 836
```

```
> tapply(BS_SS_data2$BScpue,BS_SS_data2$Bait1,mean)
```

```
  1      2      3      4      5      6      7
12.106398 10.424492 5.780686 9.255970 13.232171 4.696549 13.310535
```

**> Leader materials**

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$LdrMatl1,mean)
```

```
  1      2
8.129200 8.657895
```

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$LdrMatl1,sum)
```

```
  1    2
87584 987
```

```
> tapply(BS_SS_data2$BScpue,BS_SS_data2$LdrMatl1,mean)
```

```
  1      2
9.358807 8.745406
```

**> Hook types**

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$HookType1,mean)
```

```
 1      2      4      5      6      7
```

```
7.000000 8.710227 17.750000 11.395522 12.201699 7.869583
```

```
> tapply(BS_SS_data2$BlueShark,BS_SS_data2$HookType1,sum)
```

```
 1  2  4  5  6  7
```

```
7 3066 142 1527 5747 78082
```

```
> tapply(BS_SS_data2$BScpue,BS_SS_data2$HookType1,mean)
```

```
 1      2      4      5      6      7
```

```
9.283820 11.671587 26.532326 14.184514 14.701199 8.937092
```

## GLM fitting

Negative binomial GLM : Shallow-set sector (2000-2012; 2001-2004 deleted due to closure)

```
> BS_SS_NegBin_GLM<-glm.nb(BlueShark ~ Haulyr1 + Quarter1 + Region1 + Bait1 +  
LdrMatl1 + SST + Soaktime +offset(log(Hooks)), data =BS_SS_data2,link=log)
```

```
> summary(BS_SS_NegBin_GLM)
```

```
Call: glm.nb(formula = BlueShark ~ Haulyr1 + Quarter1 + Region1 + Bait1 + LdrMatl1 + SST +  
Soaktime + offset(log(Hooks)), data = BS_SS_data2, link = log, init.theta = 2.127929513, link =  
log)
```

Deviance Residuals:

```
  Min      1Q  Median      3Q      Max  
-2.9588 -0.8837 -0.2857  0.3850  7.3183
```

```
>Estimated Coefficients
```

```
Coefficients: Estimate Std. Error z value Pr(>|z|)
```

(Intercept) -2.444419 0.240670 -10.157 < 2e-16 \*\*\*  
 Haulyr12005 0.178739 0.807347 0.221 0.82479  
 Haulyr12006 0.023796 0.807761 0.029 0.97650  
 Haulyr12007 -0.093357 0.807434 -0.116 0.90795  
 Haulyr12008 -0.329833 0.807428 -0.408 0.68291  
 Haulyr12009 -0.743644 0.807483 -0.921 0.35708  
 Haulyr12010 -0.179954 0.807259 -0.223 0.82360  
 Haulyr12011 -0.692059 0.807589 -0.857 0.39148  
 Haulyr12012 -0.916397 0.807605 -1.135 0.25650  
 Quarter12 -0.056869 0.027755 -2.049 0.04047 \*  
 Quarter13 0.353906 0.052035 6.801 1.04e-11 \*\*\*  
 Quarter14 -0.089791 0.030382 -2.955 0.00312 \*\*  
 Region14 -0.105018 0.227529 -0.462 0.64440  
 Region15 -0.997359 0.182759 -5.457 4.84e-08 \*\*\*  
 Region16 -0.938386 0.182679 -5.137 2.79e-07 \*\*\*  
 Region17 -0.553671 0.184714 -2.997 0.00272 \*\*  
 Region18 -0.513934 0.184716 -2.782 0.00540 \*\*  
 Bait12 -0.382878 0.098209 -3.899 9.67e-05 \*\*\*  
 Bait13 -0.520661 0.804872 -0.647 0.51771  
 Bait14 -0.160084 0.807798 -0.198 0.84291  
 Bait15 0.286816 0.810584 0.354 0.72346  
 Bait16 -0.749609 0.825509 -0.908 0.36385  
 Bait17 -0.103116 0.812350 -0.127 0.89899  
 LdrMatl12 -0.195435 0.077125 -2.534 0.01128 \*  
 SST -0.081352 0.005502 -14.786 < 2e-16 \*\*\*  
 Soaktime 0.021423 0.003464 6.184 6.26e-10 \*\*\*

(Dispersion parameter for Negative Binomial(2.1279) family taken to be 1)

Null deviance: 17716 on 10887 degrees of freedom

Residual deviance: 11672 on 10862 degrees of freedom

AIC: 64440

Number of Fisher Scoring iterations: 1

Theta: 2.1279 Std. Err.: 0.0373 2 x log-likelihood: -64386.4210

> pseudo-R squared:

```
(BS_SS_NegBin_GLM>null.deviance-BS_SS_NegBin_GLM$deviance)/
```

```
BS_SS_NegBin_GLM>null.deviance
```

```
[1] 0.3411593
```

> This negative binomial GLM explains 34.1% of the null deviance of blue shark catches per standardized shallow set.

```
> NB_SS_null<-glm.nb(BlueShark~1+offset(log(Hooks)),data=BS_SS_data2)
```

```
> AIC(NB_SS_null)
```

```
[1] 69195.84
```

```
> AIC(BS_SS_NegBin_GLM)
```

```
[1] 64440.42
```

```
> (69195.84-64440.42)/69195.84
```

```
[1] 0.06872407
```

> This negative binomial GLM AIC corresponds to 6.87% of the null model AIC.

Figure Z. Standardized and nominal annual mean catches per observed shallow set, 2000-2012, in the Hawaii-based pelagic longline fishery. No data are plotted for 2001-2004 because the sector was closed all or part of those years.

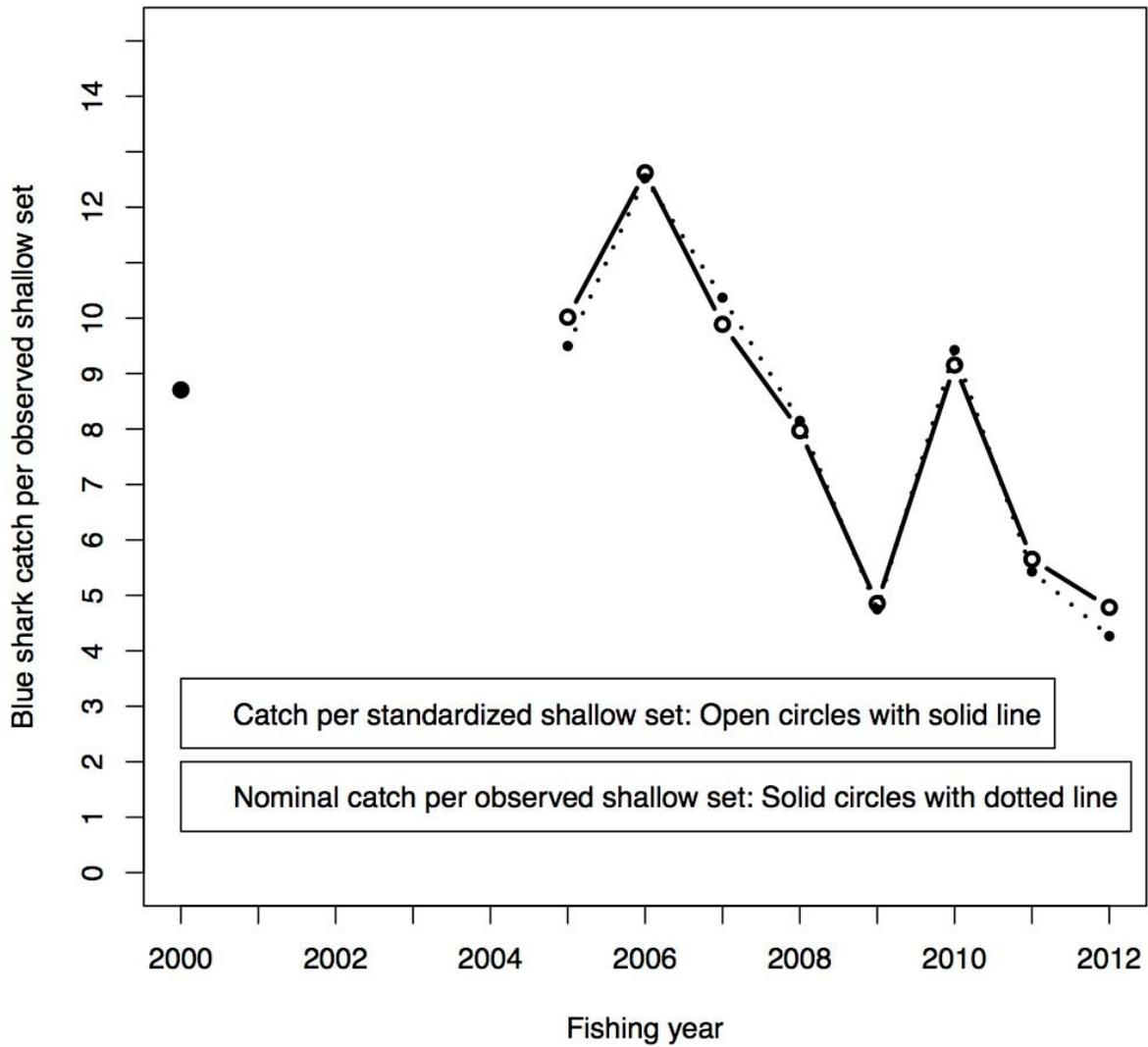


Figure ZZ. 2.0%

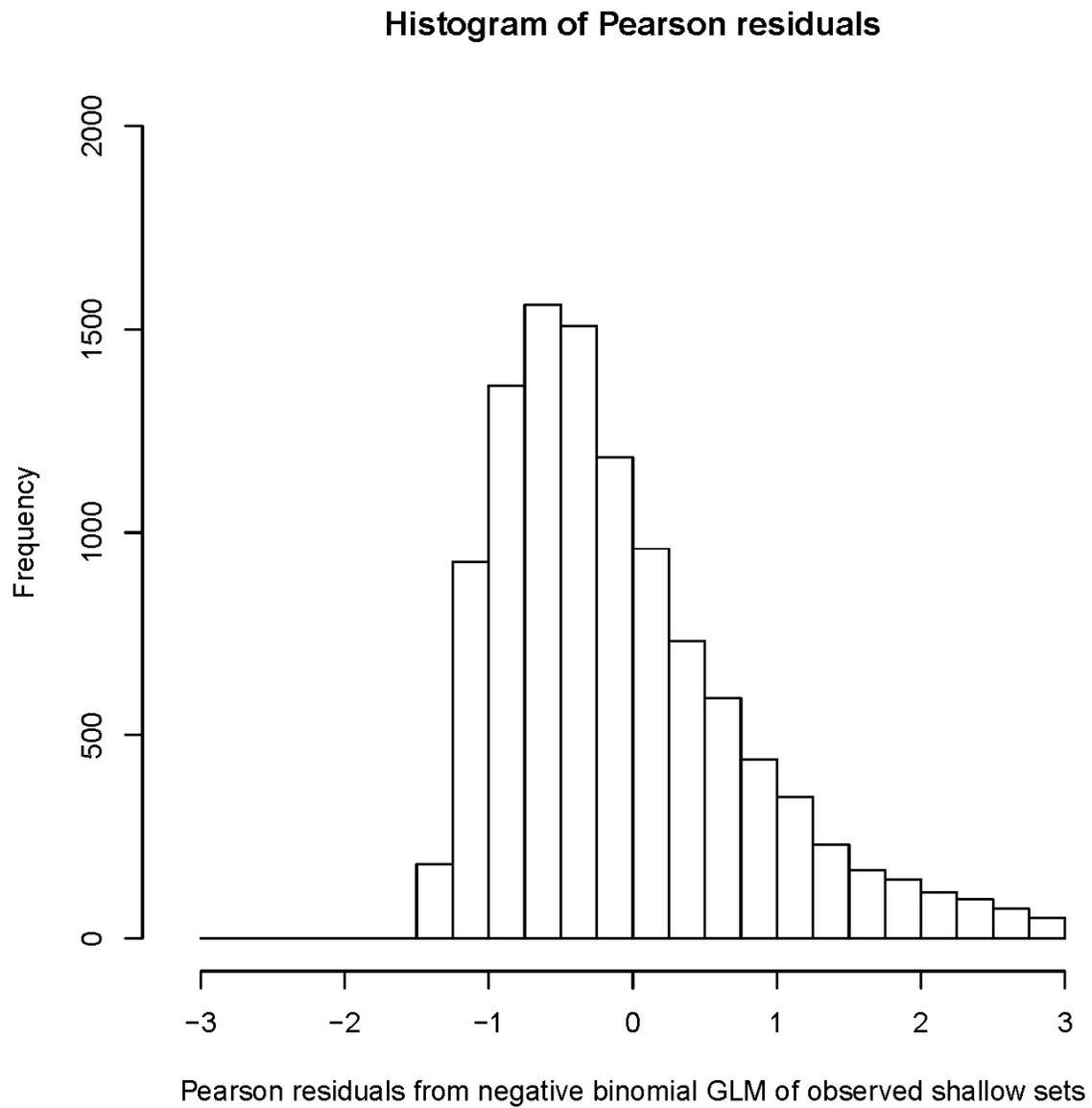
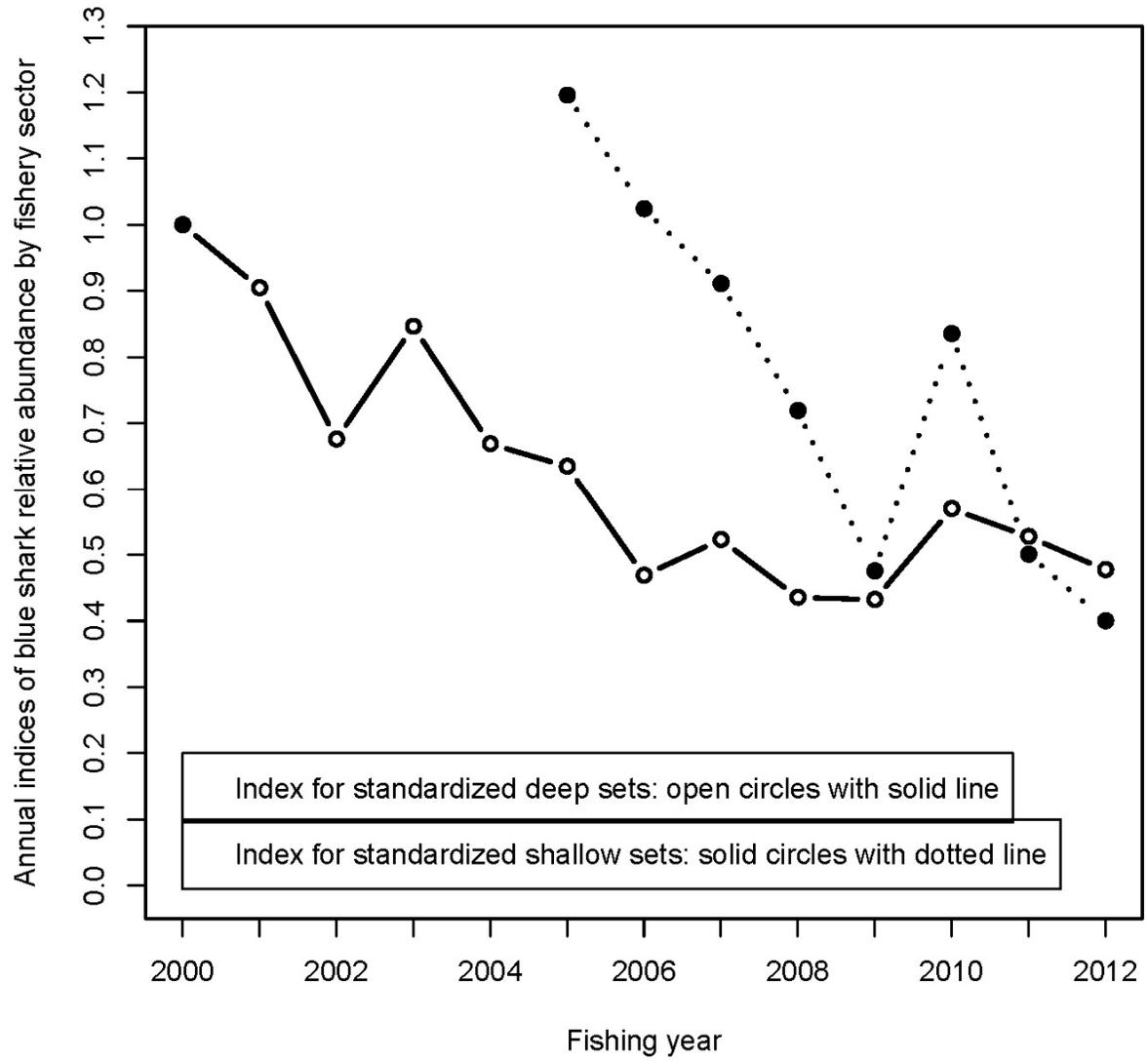


Figure XXX. Annual indices of blue shark relative abundance in the two sectors of the Hawaii-based pelagic longline fishery, 2000-2012.



## **Synopsis**

The re-evaluation and plots of standardized and nominal blue shark catch rates in this fishery from 2000 through 2012 did not lead to new conclusions. These results do not engender new conclusions or a more optimistic population scenario than previous work.

Table N. Standardized CPUE (blue shark/standard set) in the shallow-set sector of the Hawaii-based pelagic longline fishery. The table entries for each fishing year include the mean catch per standard set with its variance and standard deviation, the coefficient of variation, sample size, the standard error of the mean, and the coefficient of variation of the mean. No data are provided for 2001-2004 because the sector was closed all or part of those years.

Year	2000	2005	2006	2007	2008	2009	2010	2011	2012
Mean CPUE	8.71	10.01	12.62	9.89	7.97	4.86	9.15	5.65	4.78
Variance	12.72	24.77	9.09	16.33	8.22	4.01	16.82	5.51	4.12
Standard deviation	3.57	4.98	3.02	4.04	2.87	2.00	4.10	2.35	2.03
CV	0.41	0.50	0.24	0.41	0.36	0.41	0.45	0.42	0.42
N	353	1640	821	1566	1474	1635	1560	928	911
SEM	0.189	0.123	0.105	0.102	0.075	0.049	0.104	0.077	0.067
CV of mean CPUE	2.2%	1.2%	0.8%	1.0%	0.9%	1.0%	1.1%	1.4%	1.4%

## **Addendum to a Negative Binomial GLM Catch Rate Standardization for Blue Shark**

**William A. Walsh**

**Gerard T. DiNardo**

**May 2014**

A recent document (“Blue shark catch rates in the Hawaii-based pelagic longline fishery in 2000–2012: A re-evaluation of observer catch data and standardizations for both fishery sectors” by W.A. Walsh and G.T. DiNardo) provided catch rate analyses for blue shark in the Hawaii longline fishery. The study period was 2000–2012. This interval was chosen because the 1995–1999 observer coverage rate in this fishery was low (ca. 5%), whereas coverage rose to about 10% in 2000, has consistently remained around 20% in the deep-set sector since 2001, and has been 100% in the shallow-set sector since 2004.

This document presents a histogram of the GLM residuals and plots of the residuals on the scale of the linear predictor from the shallow-set sector analysis. There are no obvious patterns that would appear troubling. Hence, there is no basis to change conclusions from prior work.

This document also presents summary tables with CPUE standardization results by fishery sector. The tables provide annual mean catches per standard set, variances, standard deviations, sample sizes, standard errors of the means, and the coefficients of variation of the means.

Figure 1. Histogram of Pearson residuals from a negative binomial GLM of blue shark catch rates in the Hawaii-based pelagic longline fishery.

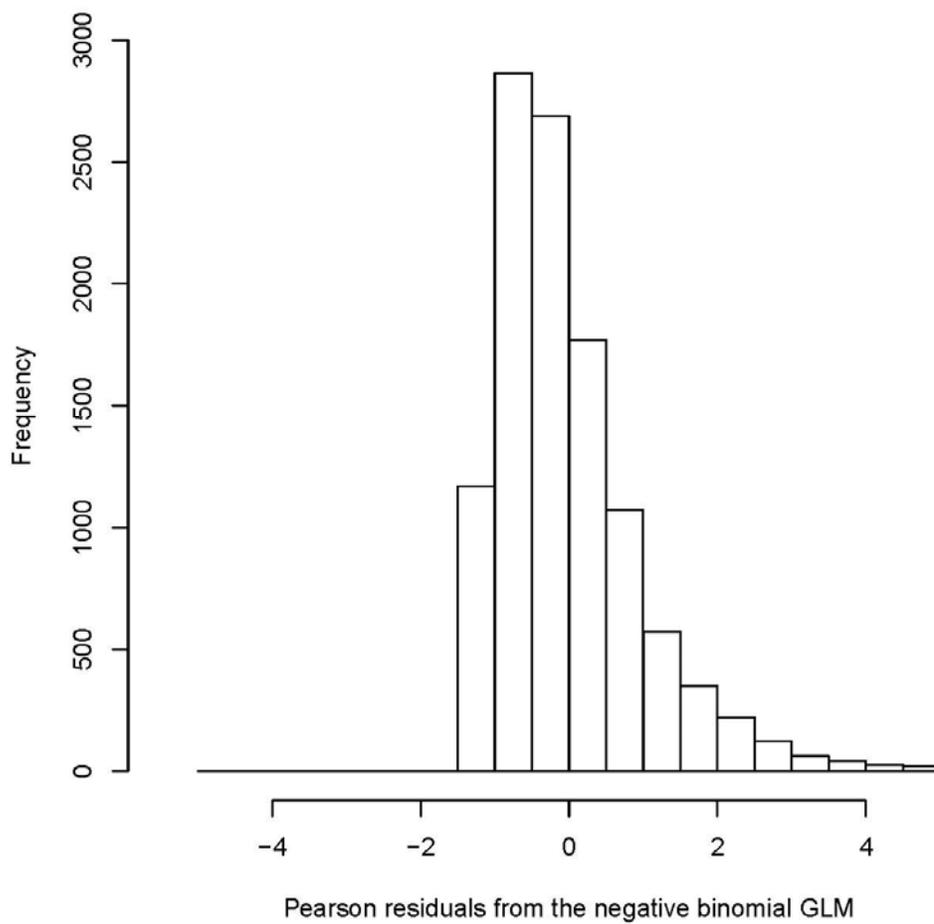


Figure 2A. Plot of Pearson residuals from a negative binomial GLM of blue shark catch rates in the Hawaii-based pelagic longline fishery in relation to the year of fishing.

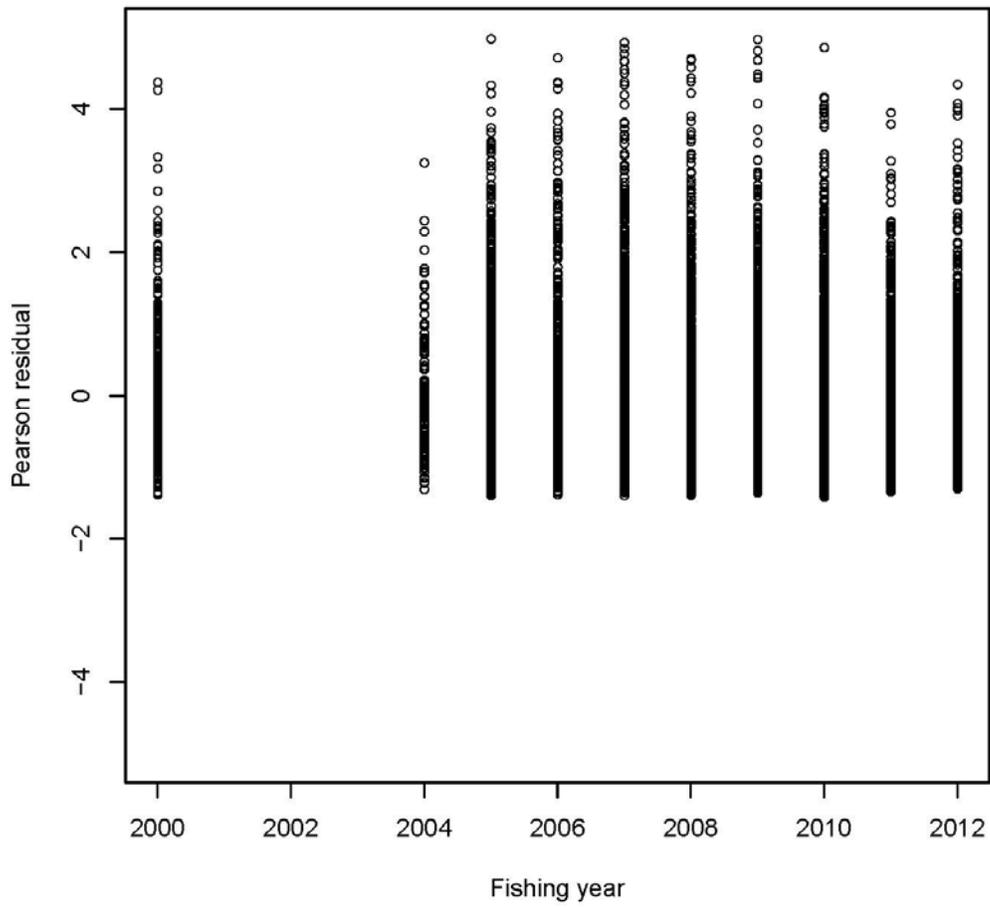


Figure 2B. Plot of Pearson residuals from a negative binomial GLM of blue shark catch rates in the Hawaii-based pelagic longline fishery in relation to the fishing quarter.

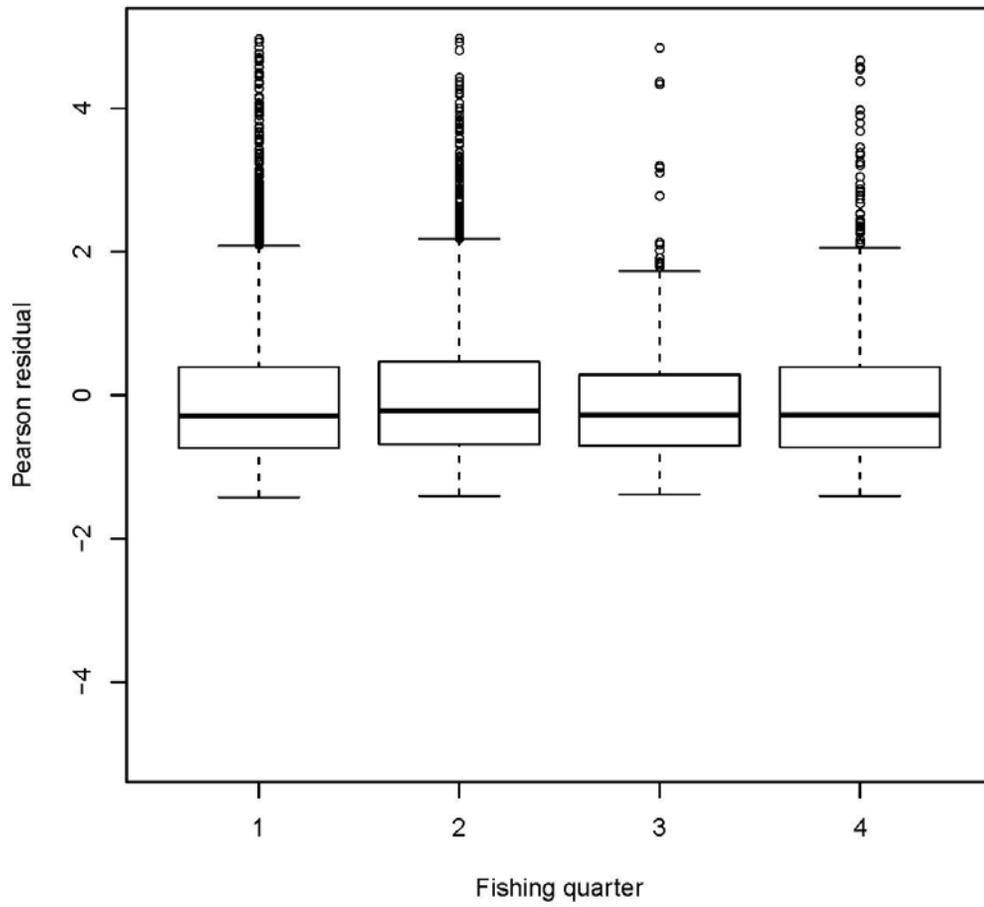


Figure 2C. Plot of Pearson residuals from a negative binomial GLM of blue shark catch rates in the Hawaii-based pelagic longline fishery in relation to the fishing region.

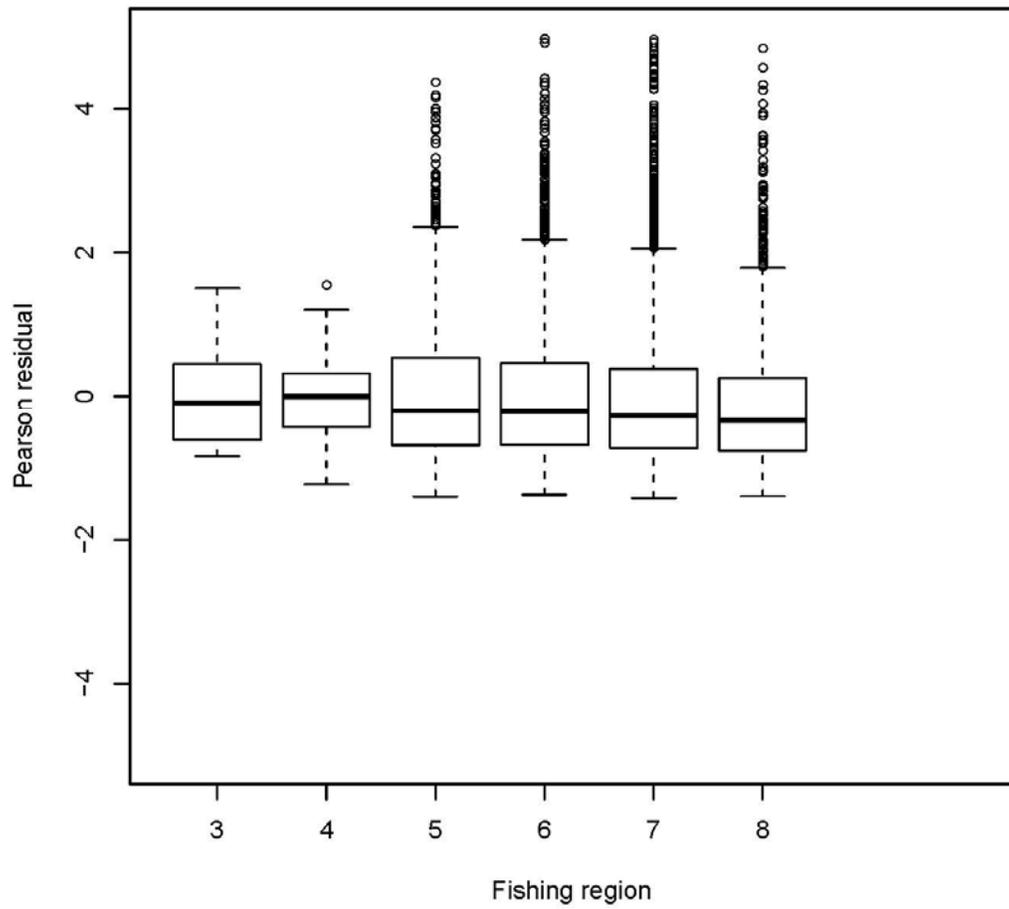


Figure 2D. Plot of Pearson residuals from a negative binomial GLM of blue shark catch rates in the Hawaii-based pelagic longline fishery in relation to the sea surface temperature ( $^{\circ}\text{C}$ ).

