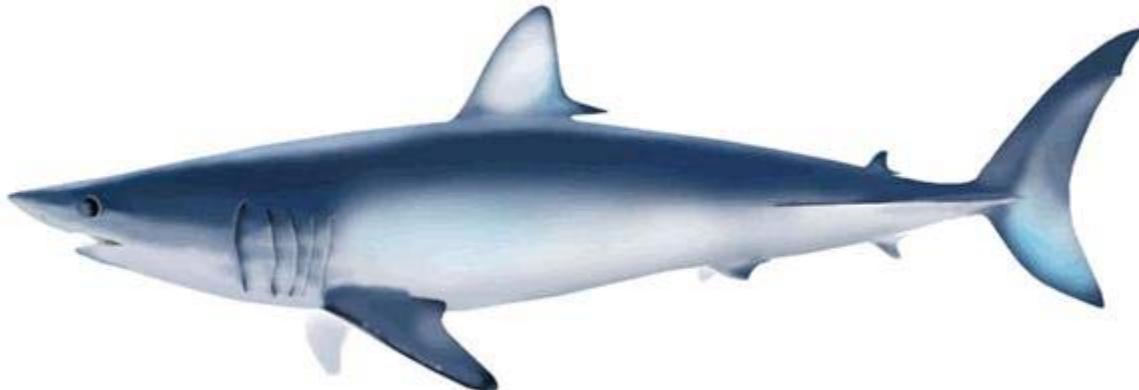


**Catch Statistics, Length Data and Standardized CPUE for Blue Shark *Prionace glauca*  
taken by Longline Fisheries based in Hawaii and California<sup>1</sup>**

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## Abstract

This working paper (WP) updates previously reported compilations of catch, dead removals, length distributions, catch per unit effort (CPUE) standardizations and other information for blue shark *Prionace glauca* from US Pacific longline fisheries based in Hawaii and California. The objective of this WP is to provide inputs for a north Pacific blue shark stock assessment to be conducted by the ISC Sharks Working Group in 2013. The blue shark catch and total dead removals in waters near Hawaii from 1975 through 2011 were estimated using fishery observer data and self-reported data from mandatory commercial logbooks. Candidate indices of relative abundance were developed by standardizing the CPUE using 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. In addition, the estimated dead removals from the California pelagic longline fishery during 1991–2004 are included. The estimated dead removals from experimental longline fisheries in the Southern California Bight are reported in Document ISC/13/SHARKWG-1/02.

## Introduction

This working paper (WP) updates the compilations of catches, dead removals, catch per unit effort (CPUE) standardizations, sex ratios and total length distributions for blue shark *Prionace glauca* in US Pacific longline fisheries, previously reported by Walsh and Teo (2012). The main sources of data are commercial logbooks and observer reports from the Hawaii-based pelagic longline fishery, but logbook and observer 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, dead removals, 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 2013. The period to be assessed is 1971–2011.

## 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 and dead removals from Hawaii

Blue shark catches by the Hawaiian longline fishery were assumed to be negligible during 1971–1976 due to the decline in the fishery during the 1950s and 60s (Boggs and Ito 1993). The catches from 1976 to 1990 were estimated using the method of Boggs and Ito (1993), which was used to estimate catches of other pelagic fish caught by the Hawaii longline fishery prior to 1991. The Boggs and Ito (1993) method is simply a linear interpolation between the 0 fish caught in 1975 to the 65481 fish caught in 1991. The Hawaii catch data from 1991–1994 are taken from the PIFSC longline logbook reports. Which 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 logbook data that 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). However, the decision was made in this study to use less stringent criteria for the logbook data evaluations to increase the chances of removing inaccuracies to the greatest possible extent because error patterns and the occurrence of underreporting have been thoroughly documented.

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.

Total dead removals are one of the key data inputs for the upcoming stock assessment. The total number of dead removals is the sum of the number landed or finned and the number of dead discards. The number of released sharks (live, dead, or in unknown condition) was estimated by using the annual mean rates reported by observers for 1995-2011. 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. Due to the prohibition of shark finning in 2001, the observed blue shark discard rate was >99% since 2003. Therefore, we assumed that the 100% of blue sharks were discarded from 2003. Prior to 1995, we assumed that 48.9% of blue sharks were discarded (average of 1995 to 2000). The blue shark dead discard percentage reported by observers was used to estimate the number of blue sharks that did not survive after release. Walsh et al. (2009) reported the blue shark dead discard percentage for the Hawaii shallow-set (8.5%: 1995-2000; and 5.7%: 2004-2006) and deep-set longline fisheries (6.1%: 1995-2000; and 4.0%: 2004-2006). These rates are highly similar to another study using popup tags to determine the post-release mortality of blue sharks in the shallow-set fishery (5.9%; Musyl et al. 2011). For this working paper, the blue shark dead discard percentage for years prior to 2001 was assumed to be the same as the average dead discard rate for shallow-set and deep-set longline fisheries from 1995-2000 (7.3%) reported by Walsh et al. (2009). Similarly, we assumed that the dead discard percentage from 2001-2011 was 4.85% [average dead discard for 2004-2006 reported in Walsh et al. (2009)]. The number of dead discards was calculated by multiplying the catch with the proportion of dead discards for each year.

In order to convert these estimates from numbers of fish into round weight in metric tons, which is the input for the stock assessment, blue shark numbers were converted to weight with the following relationships:

$$PCL_{cm} = 0.748 * TL_{cm} + 1.063$$

$$WT_{kg} = 0.0000042 * PCL_{cm}^{3.1635}$$

where  $PCL_{cm}$  is the precaudal length in cm,  $TL_{cm}$  is the total length in cm (assumed to be 215 cm),  $WT_{kg}$  is the round weight in kg. Based on this, the assumed average weight of each blue shark in the Hawaii longline fishery is 40.93 kg.

#### Compilation of catch and dead removals from California

Previously, Walsh and Teo (2012) reported estimated catches from both the California pelagic longline fishery and the California experimental longline fisheries in the Southern California Bight. However, we only report on the estimated catches of the California pelagic longline fishery in this document. The estimated catch from experimental longline fisheries in the Southern California Bight are reported in Document ISC/13/SHARKWG-1/02.

Catch and total dead removals from the California pelagic longline fishery were estimated from data collected from vessel logbooks and onboard observers. 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. 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 these data are confidential.

Similar to catch, the annual dead removals from this fishery were estimated by calculating the overall number of dead removals per unit effort (1000 hooks) from observer data and extrapolating that to the annual effort recorded in the logbooks. Based on the observed lengths, the average weight of blue shark caught by this fishery was 19.7 kg. This average weight was used to convert the annual number of dead removals to the annual weight of dead removals, which is the input data for the upcoming stock assessment.

## 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 (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: ≥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 ( $N = 23$  trips) and logbook records of blue shark catch were considered to be unreliable.

## 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,

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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.

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 average weight of blue sharks caught by this fishery was 19.7 kg.

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 and dead removals by Hawaii- and California-based vessels from 1975–2011. Blue shark catches and dead removals prior to 1975 can be assumed to be 0 mt. Estimated blue shark removals for the California-based pelagic longline fishery were relatively low, typically having <200 mt of blue shark removed from the population (2000 and 2001 being exceptions). The Hawaii data include estimates for

releases based on the observer data. These values demonstrate that total removals have 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 (data with 3 or less vessels are not shown due to data confidentiality) 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  $30^{\circ}\text{--}35^{\circ}\text{N}$  and  $155^{\circ}\text{--}160^{\circ}\text{W}$  in 2006. Catches in the nearby squares were lower, but CPUE was relatively uniform from  $30^{\circ}\text{--}35^{\circ}\text{N}$  and  $145^{\circ}\text{--}170^{\circ}\text{W}$ , 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  $35^{\circ}\text{--}40^{\circ}\text{N}$  and  $130^{\circ}\text{--}150^{\circ}\text{W}$ .

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  $30^{\circ}\text{N}$  were in the shallow-set sector, whereas all sets in tropical waters (equator to  $10^{\circ}\text{N}$ ) were in the deep-set sector. Most sets (87.6%) from  $10^{\circ}\text{--}30^{\circ}\text{N}$  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 final 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 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 CPUE 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 ( $\delta$ : 227.7 cm;  $\varphi$ : 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 ( $\delta$ : 211.9 cm;  $\varphi$ : 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 updates the compilations of catch, dead removals, relative abundance indices, length distributions and sex ratios for blue sharks taken by California and Hawaii-based (1975–2011) pelagic 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 and dead removals from the California-based fisheries are relatively uncertain, but are relatively low and unlikely to influence the assessment results appreciably. Only one vessel has been active in the California-based pelagic longline fishery since 2004 so its catches and dead removals are confidential. Therefore, we recommend assuming that the impact of the California-based pelagic longline fishery is negligible for 2005–2011 for the stock assessment.

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 and dead removals 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 contributes the catch, dead removals, and abundance indices from Hawaii- and California-based longline fisheries required for the ISC Sharks WG for the blue shark stock assessment.

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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 release (%)
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 catch and dead removals of blue sharks taken by Hawaii- and California-based longline fisheries in 1975–2011.

Year	Hawaii									California	Hawaii and California combined
	Catch observed trips (#fish)	Catch reliable unobserved trips (# fish)	Catch unreliable unobserved trips (# fish)	Total catch (# fish)	Number of releases	Number of dead releases	Number of landed or finned fish	Number of dead removals	Total dead removals (mt)		
1975	NA	NA	NA	0	0	0	0	0	0	0	0
1976	NA	NA	NA	4093	2000	299	2093	2392	97.9	0	97.9
1977	NA	NA	NA	8186	4000	598	4186	4784	195.8	0	195.8
1978	NA	NA	NA	12279	6000	896	6279	7175	293.7	0	293.7
1979	NA	NA	NA	16372	8000	1195	8372	9567	391.6	0	391.6
1980	NA	NA	NA	20465	10001	1494	10464	11958	489.5	0	489.5
1981	NA	NA	NA	24558	12001	1793	12557	14350	587.4	0	587.4
1982	NA	NA	NA	28651	14001	2092	14650	16742	685.3	0	685.3
1983	NA	NA	NA	32744	16001	2390	16743	19133	783.1	0	783.1
1984	NA	NA	NA	36837	18001	2689	18863	21525	881.1	0	881.1
1985	NA	NA	NA	40930	20001	2988	20929	23917	979.0	0	979.0
1986	NA	NA	NA	45023	22001	3287	23022	26309	1076.9	0	1076.9
1987	NA	NA	NA	49116	24001	3585	25115	28700	1174.7	0	1174.7
1988	NA	NA	NA	53209	26001	3884	27208	31092	1272.6	0	1272.6
1989	NA	NA	NA	57302	28002	4183	29300	33483	1370.5	0	1370.5
1990	NA	NA	NA	61395	30002	4482	31393	35875	1468.4	0	1468.4
1991	NA	65481	NA	65481	31998	4780	33483	38263	1566.2	1.6	1567.8
1992	NA	89292	NA	89292	43634	6518	45658	52176	2135.6	10.5	2146.1
1993	NA	150216	NA	150216	73406	10966	76810	87776	3592.8	2.2	3595.0

Year	Hawaii								California	Hawaii and California combined	
	Catch observed trips (#fish)	Catch reliable unobserved trips (# fish)	Catch unreliable unobserved trips (# fish)	Total catch (# fish)	Number of releases	Number of dead releases	Number of landed or finned fish	Number of dead removals	Total dead removals (mt)	Total dead removals (mt)	
1994	NA	110187	NA	110187	53845	8044	56342	64386	2635.4	7.1	2642.5
1995	5903	83279	21280	110462	71690	8064	38772	46836	1917.1	37.5	1954.6
1996	6914	73127	17550	97591	46258	7124	51333	58457	2392.7	82.7	2475.4
1997	7491	65059	17412	89962	27978	6567	61984	68551	2805.9	89.3	2895.2
1998	6509	84741	13829	105079	42452	7671	62627	70298	2877.4	109.9	2987.3
1999	3169	74853	17965	92818	33043	6776	59775	66551	2724.0	162.0	2886.0
2000	12144	59265	7112	78521	57948	5732	20573	26305	1076.7	238.7	1315.4
2001	14132	25297	1518	40947	39596	1986	1351	3337	136.6	213.7	350.3
2002	13161	26804	1570	41535	40704	2014	831	2845	116.5	139.3	255.8
2003	19119	42409	2545	64073	64073	3108	0	3108	127.2	127.9	255.1
2004	23458	41440	2072	66970	66970	3248	0	3248	132.9	54.1	187.0
2005	36621	30376	1519	68516	68516	3323	0	3323	136.0	NA	136.0
2006	23872	34752	1738	60362	60362	2928	0	2928	119.8	NA	119.8
2007	32623	32929	988	66540	66540	3227	0	3227	132.1	NA	132.1
2008	23141	29914	897	53952	53952	2617	0	2617	107.1	NA	107.1
2009	20405	27802	834	49041	49041	2378	0	2378	97.3	NA	97.3
2010	31082	27721	1022	59825	59825	2902	0	2902	118.8	NA	118.8
2011	22483	33330	1012	56825	56825	2756	0	2756	112.8	NA	112.8

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	$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	$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 $\times$ 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	$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	$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: ♂	Deep-set: ♂	Deep-set: ♂	Deep-set: ♂	Deep-set: ♂	Deep-set: ♂
203.3±12.6 $N = 3$	217.2±24.0 $N = 132$	224.2±29.4 $N = 370$	228.7±24.7 $N = 671$	226.8±27.9 $N = 215$	233.4±28.5 $N = 512$	251.9±24.7 $N = 7$	201.7±41.0 $N = 32$
Deep-set: ♀	Deep-set: ♀	Deep-set: ♀	Deep-set: ♀	Deep-set: ♀	Deep-set: ♀	Deep-set: ♀	Deep-set: ♀
206.0±5.7 $N = 2$	202.7±24.2 $N = 105$	208.0±15.9 $N = 416$	210.0±16.7 $N = 599$	219.7±25.5 $N = 189$	221.1±20.8 $N = 240$	199.6 $N = 1$	186.4±44.9 $N = 6$
Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂	Shallow-set: ♂
$N = 0$	$N = 0$	226.9±14.8 $N = 34$	212.5±16.4 $N = 19$	233.8±25.9 $N = 231$	215.7±32.4 $N = 1500$	194.4±41.7 $N = 672$	212.7±39.0 $N = 742$
Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀	Shallow-set: ♀
$N = 0$	$N = 0$	212.5±16.3 $N = 28$	212.0±19.1 $N = 21$	217.2±21.7 $N = 364$	216.6±23.6 $N = 852$	190.6±42.8 $N = 461$	188.1±36.3 $N = 194$

Table 8. Summary of blue shark sex ratios ( $\text{♂} : \text{♀}$ ) 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	$\geq 10^{\circ}\text{--}20^{\circ}\text{N}$ ; east of 160°W	$\geq 10^{\circ}\text{--}20^{\circ}\text{N}$ ; west of 160°W	$\geq 20^{\circ}\text{--}30^{\circ}\text{N}$ ; east of 160°W	$\geq 20^{\circ}\text{--}30^{\circ}\text{N}$ ; 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.

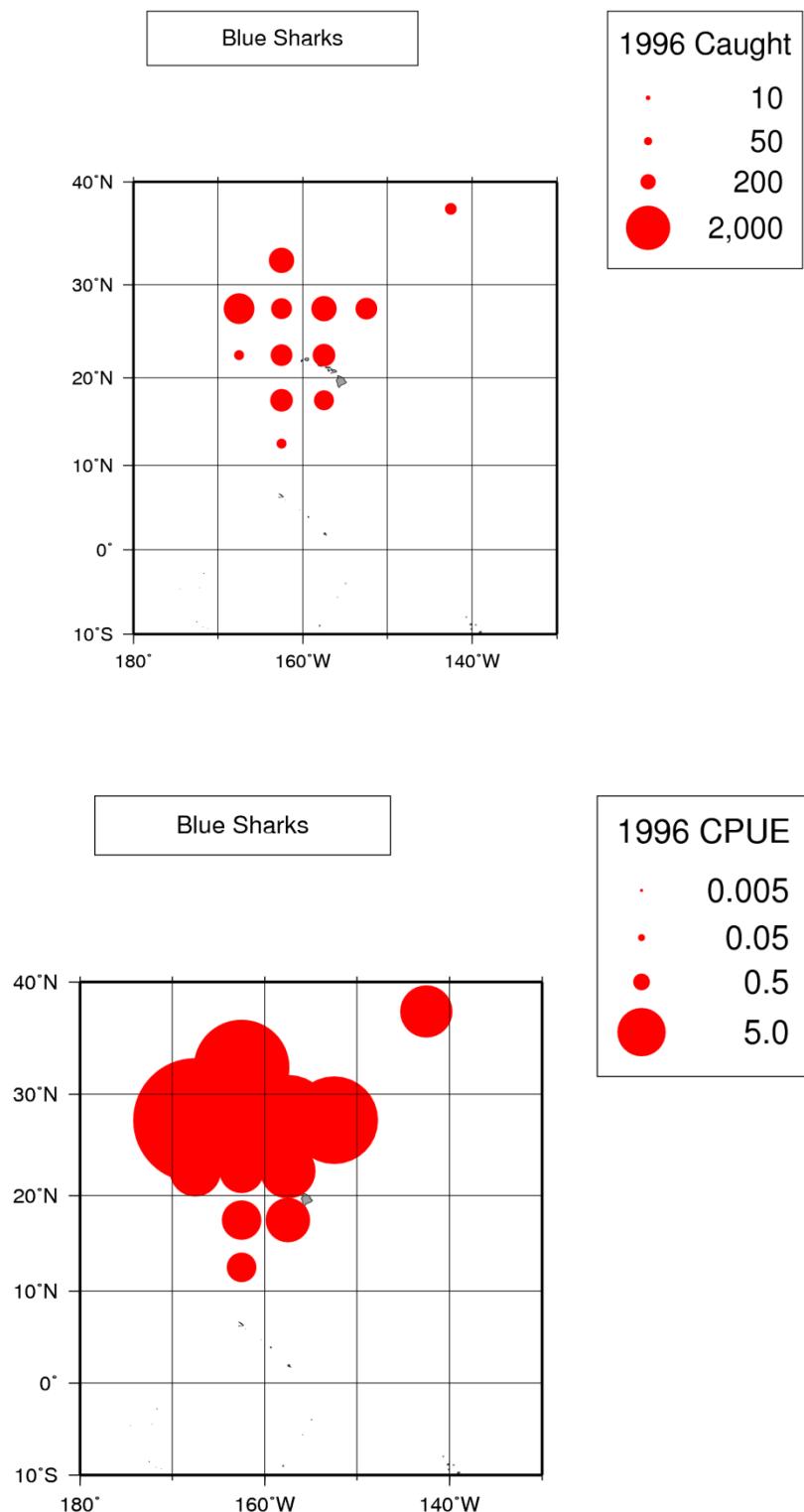


Figure 1, continued.

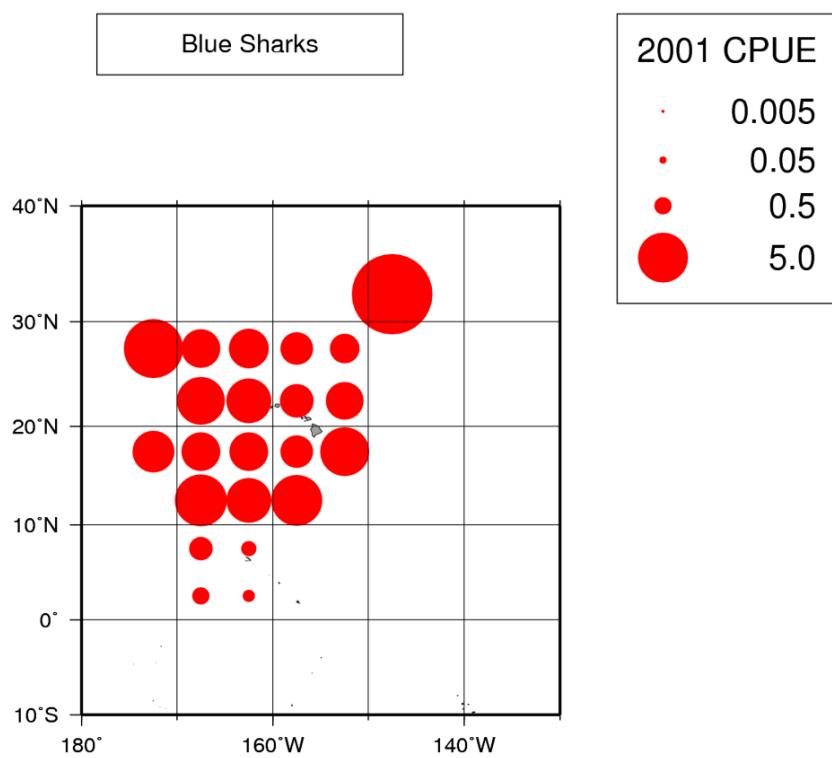
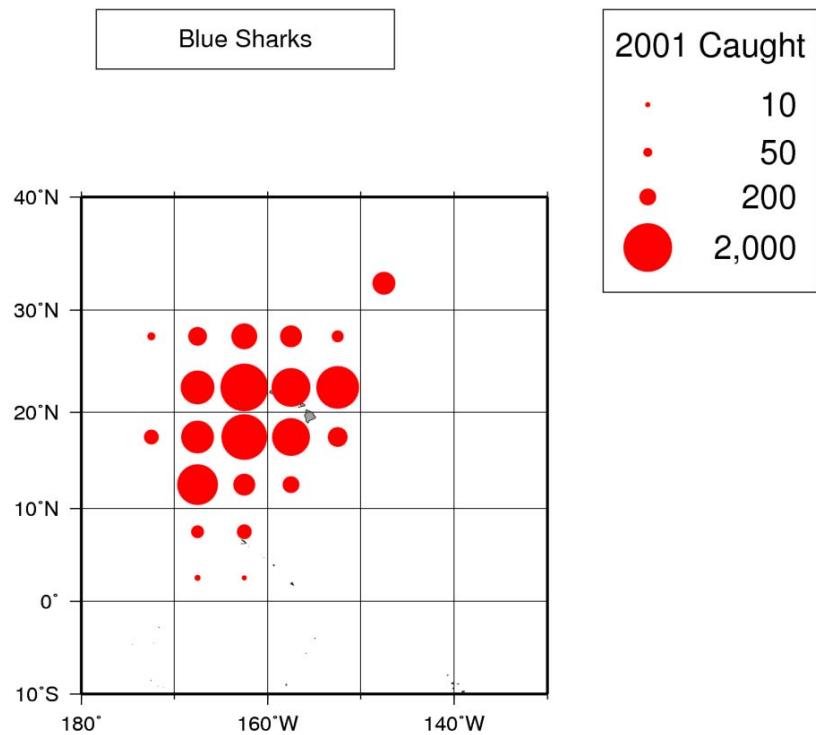


Figure 1, continued.

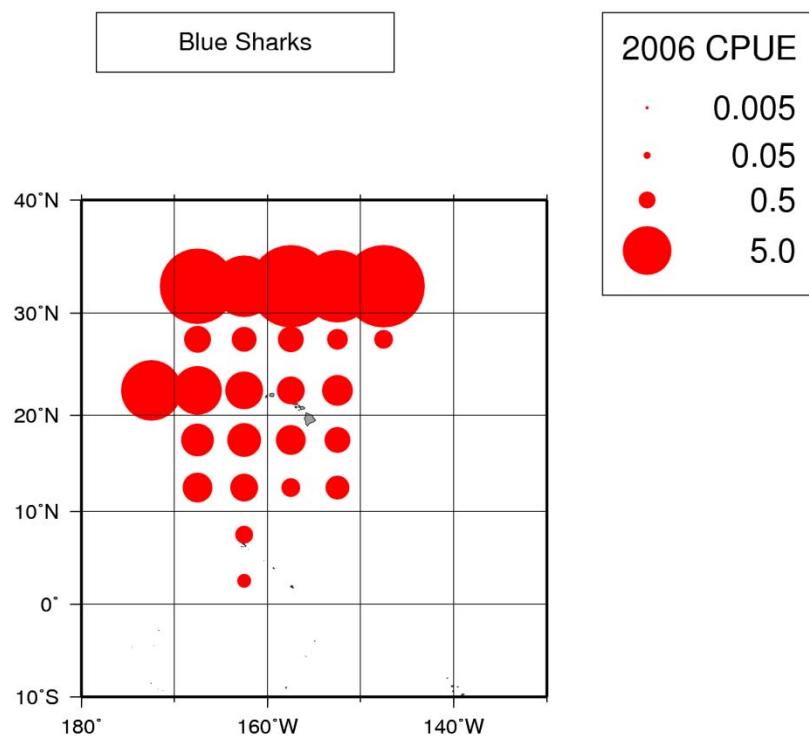
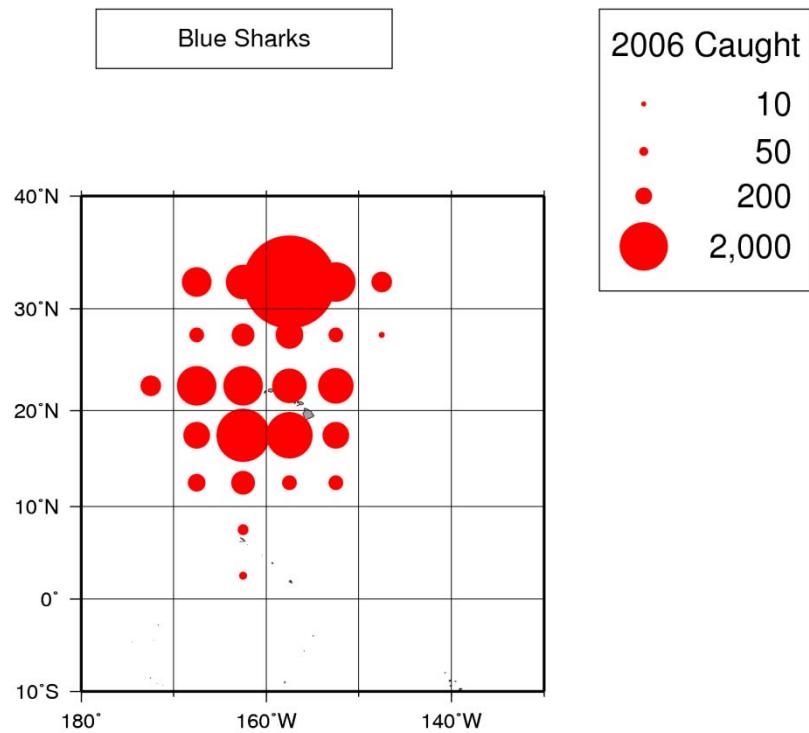


Figure 1, continued.

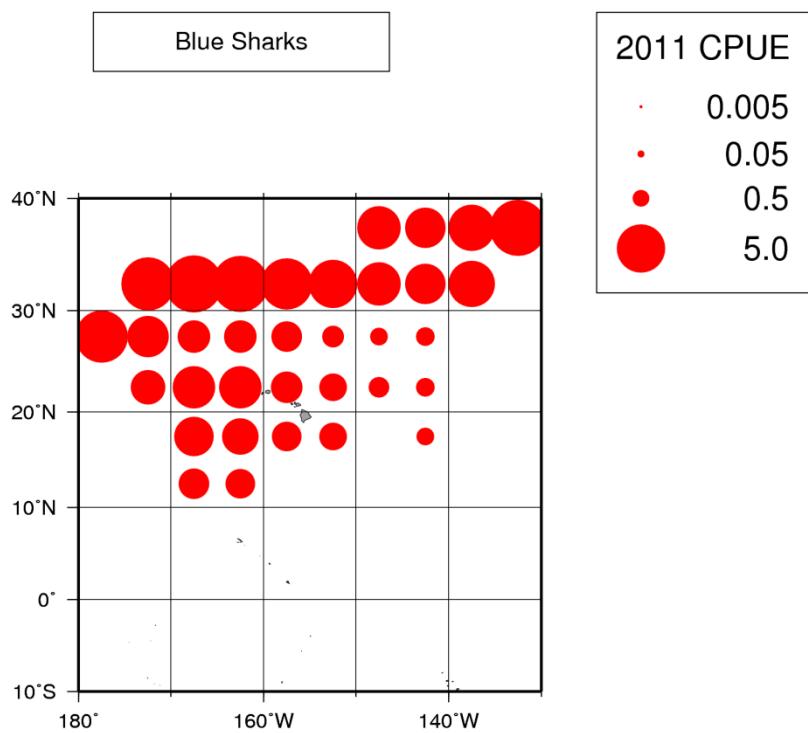
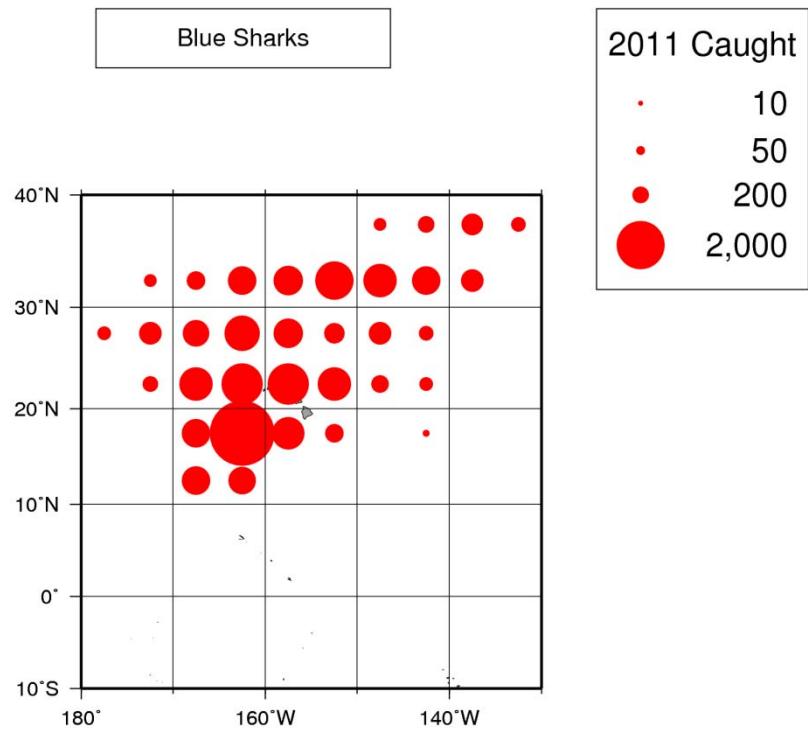
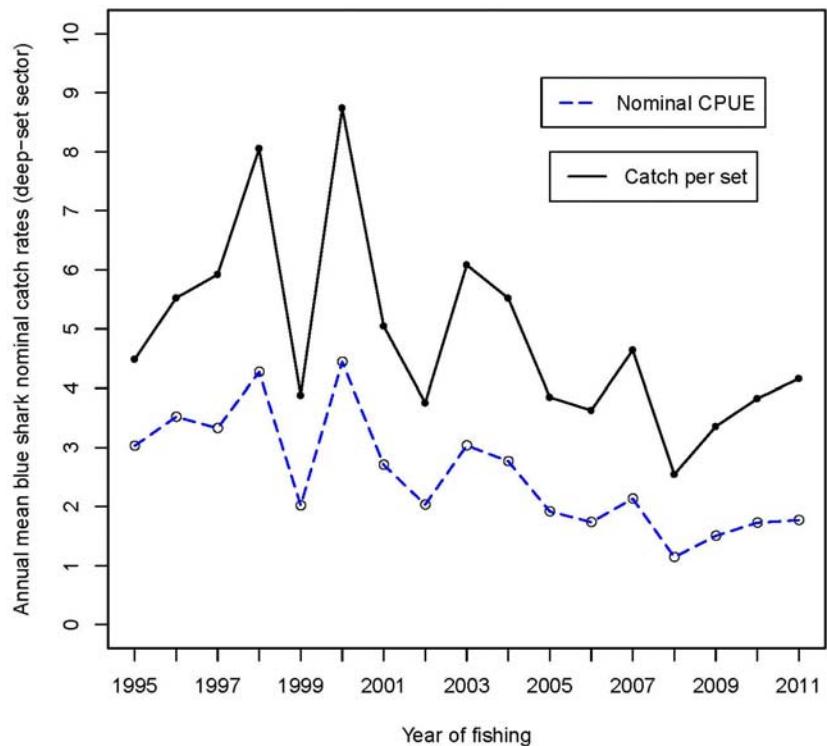


Figure 2. Annual mean blue shark nominal catch rates in the deep-set (upper) and shallow-set sectors (lower) of the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.



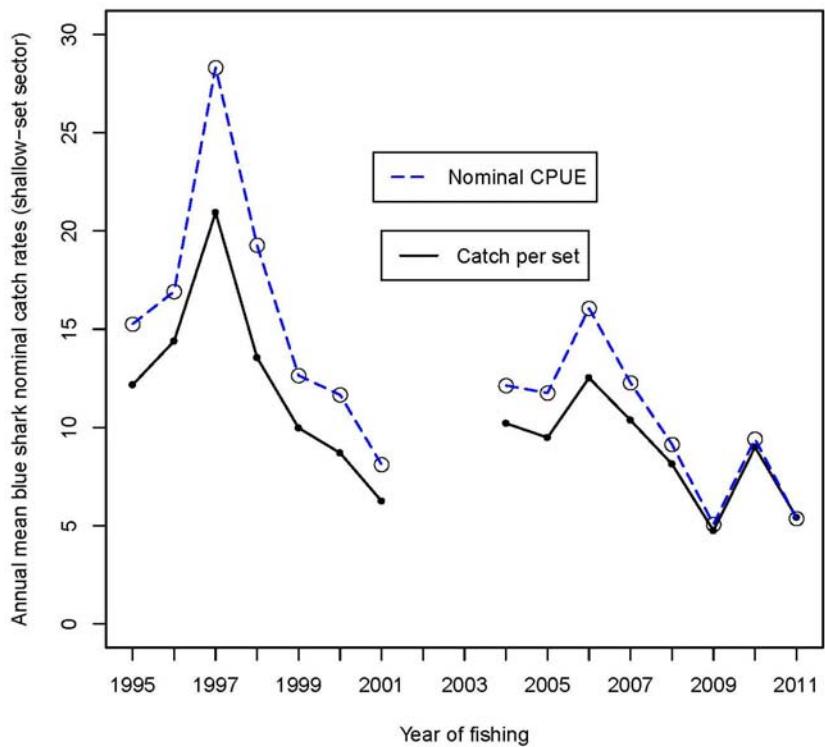
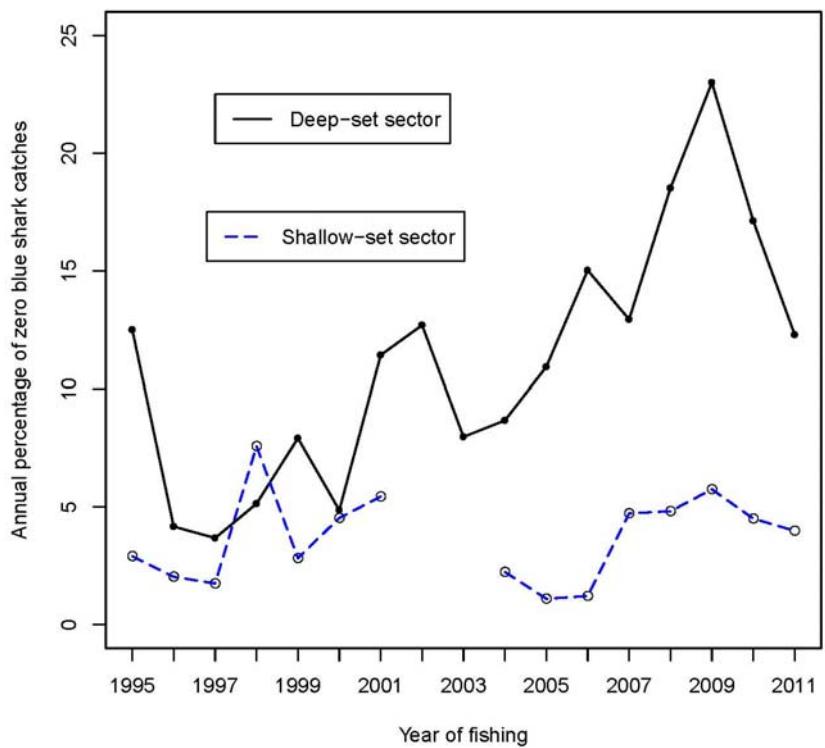


Figure 3. Annual percentages of zero catches (upper) and CPUE on sets with positive blue shark catches (lower) by sector in the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.



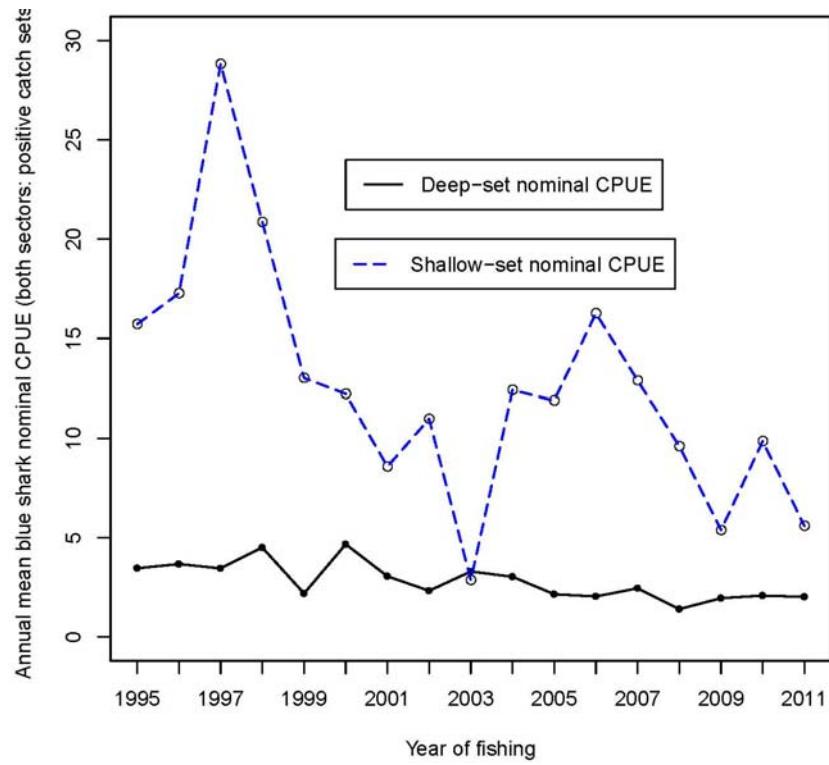
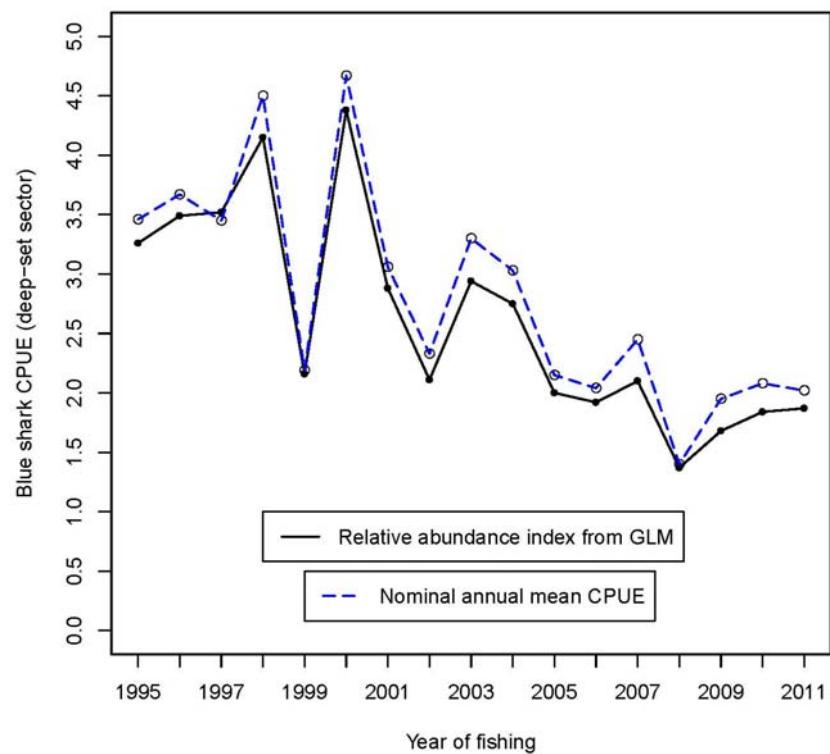


Figure 4. Relative abundance indices obtained from the GLM annual coefficients for blue shark by sector in the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.



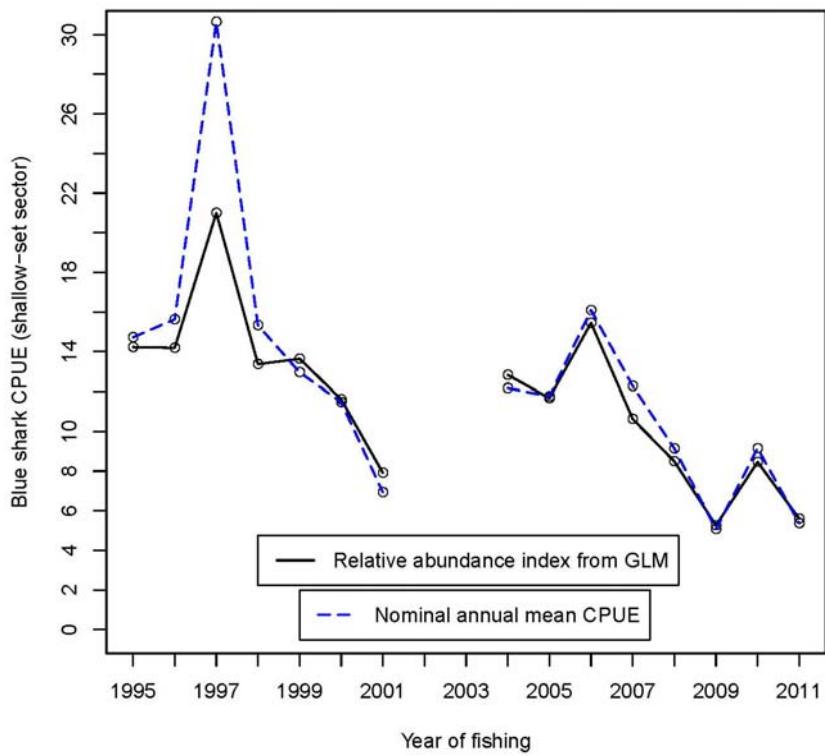
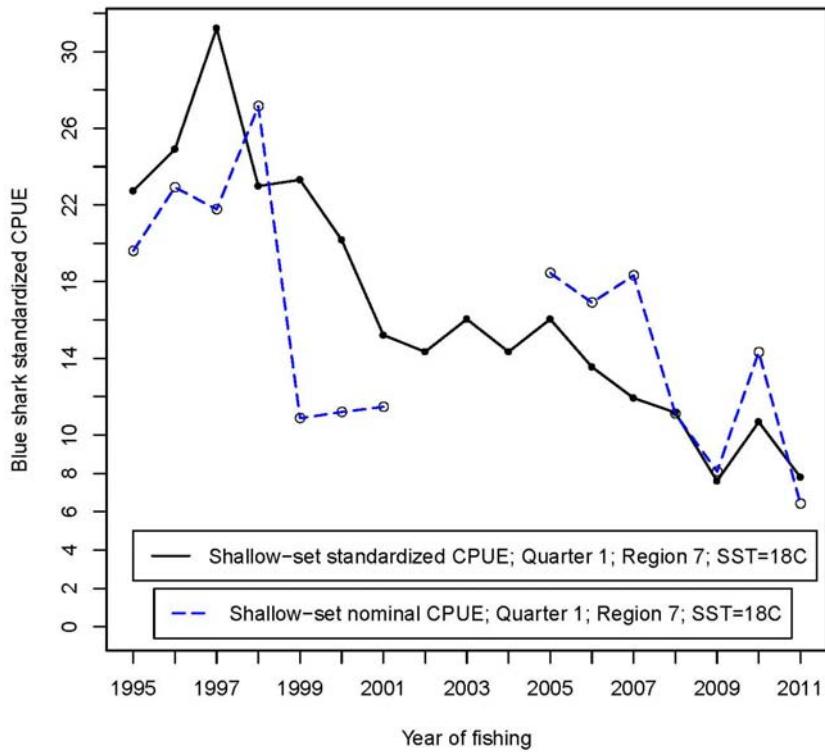


Figure 5. Standardized and nominal CPUE for blue shark by sectors, during quarters and in regions of typically high abundance.



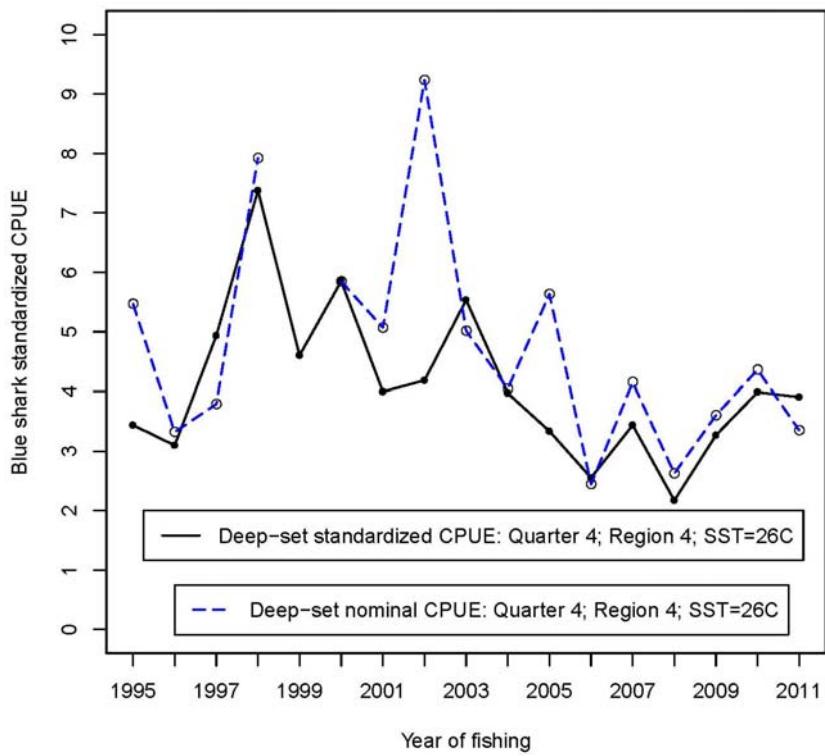
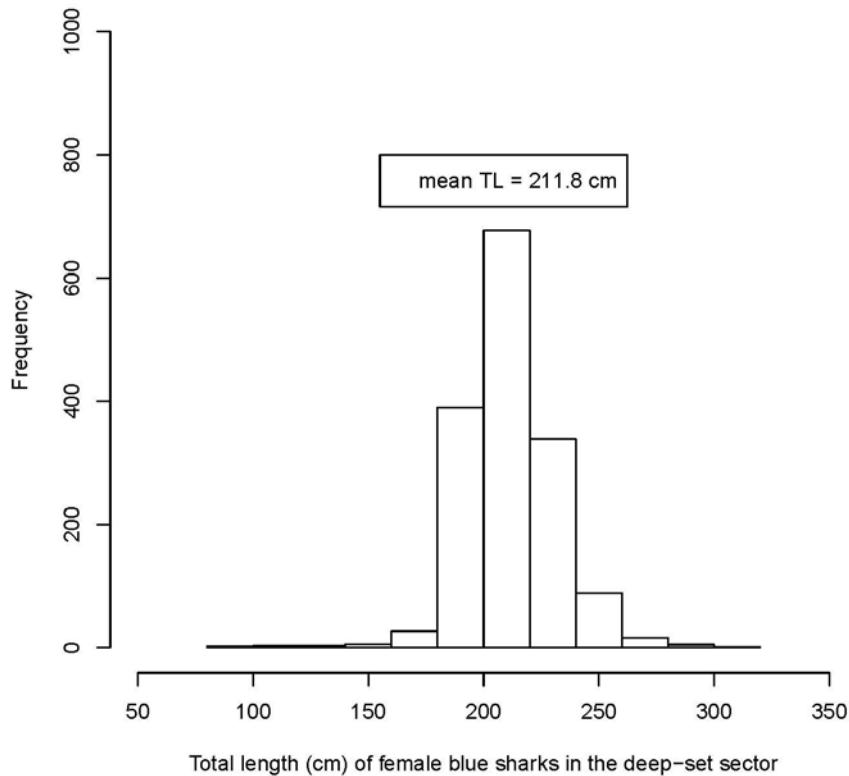


Figure 6. Size frequency distributions (total length, cm) for blue sharks by fishery sectors and sexes from 1995 through 2011.



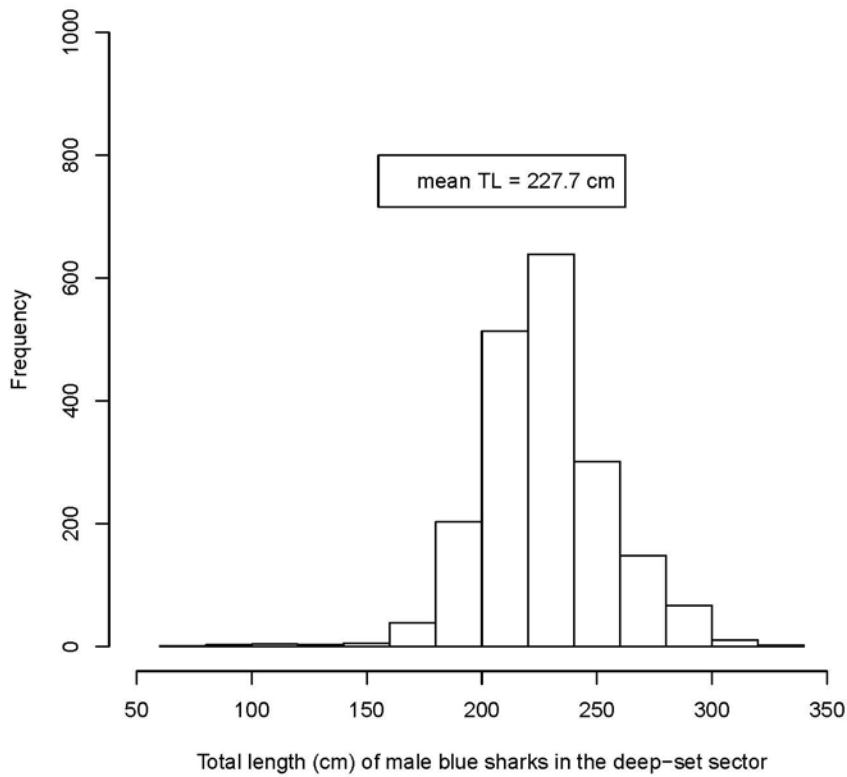
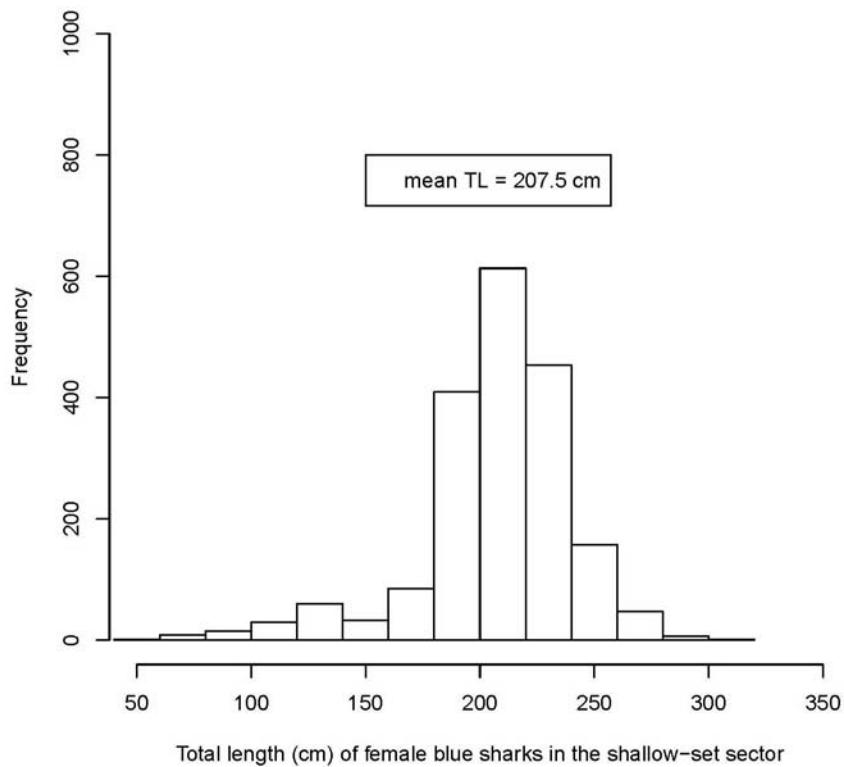


Figure 6, continued.



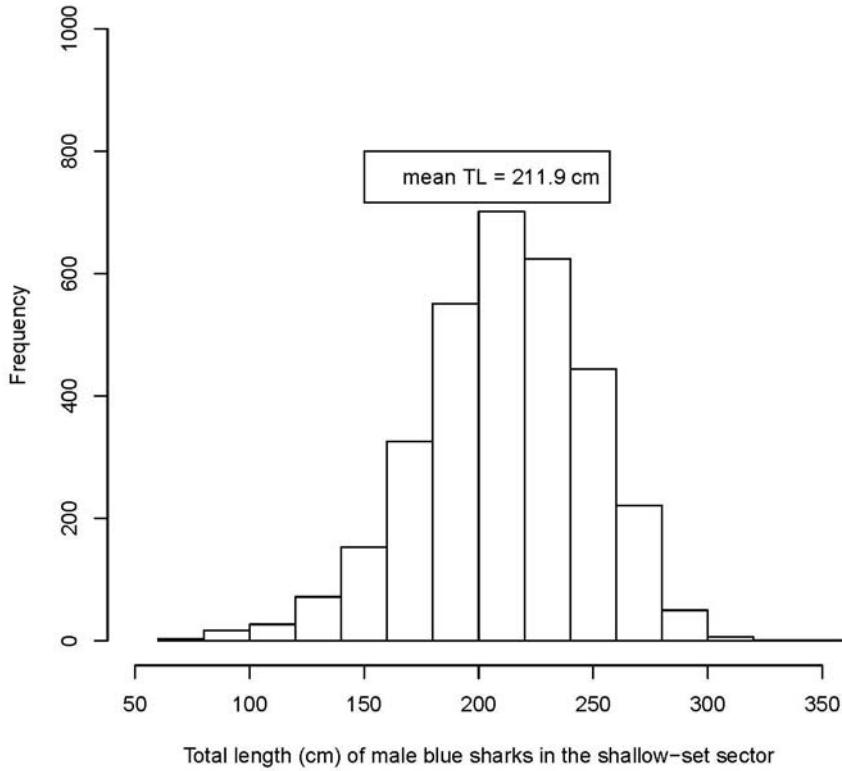
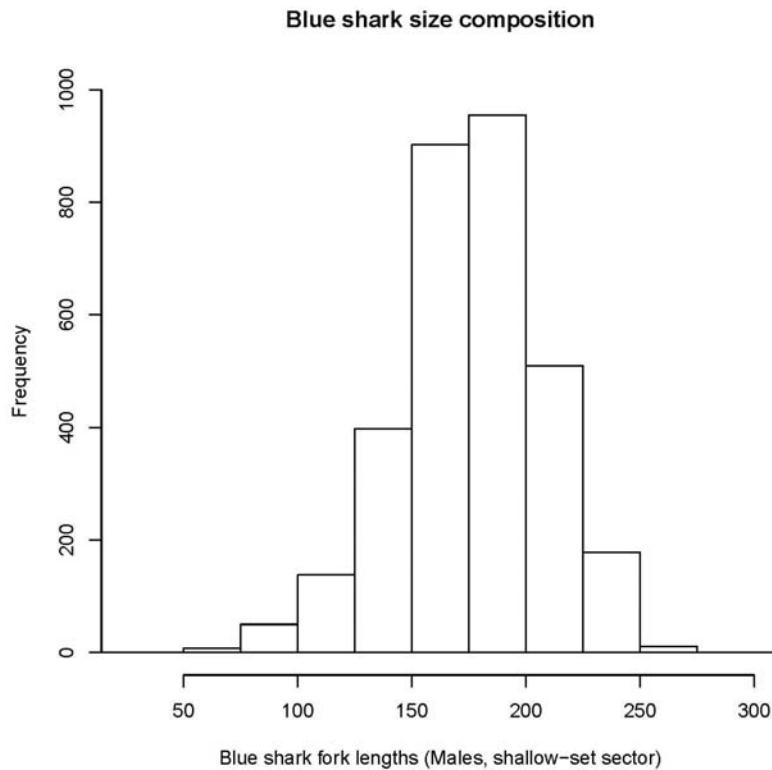


Figure 7. Size frequency distributions (fork length, cm) for blue sharks by fishery sectors and sexes from 1995 through 2011.



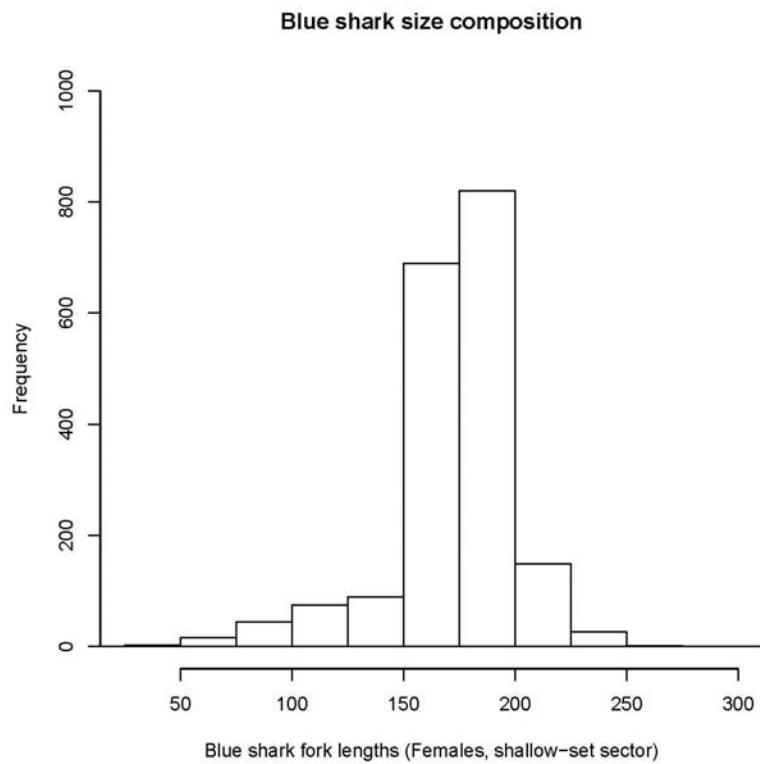
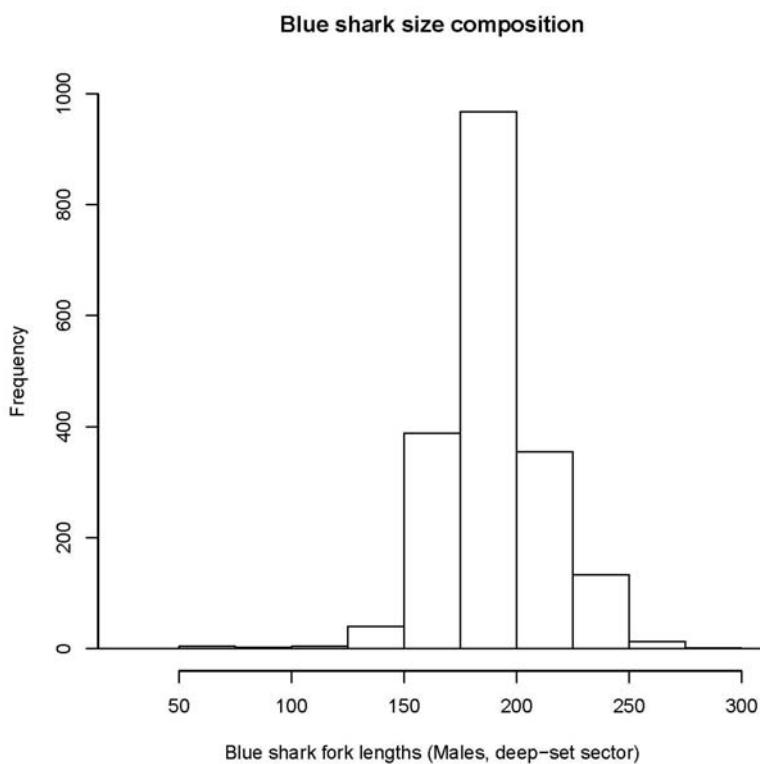


Figure 7, continued.



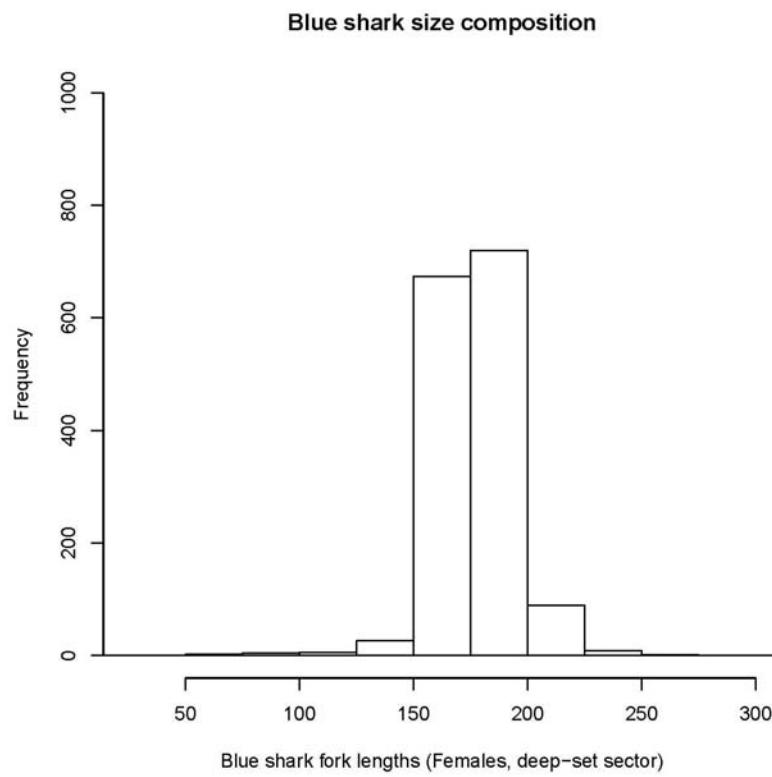
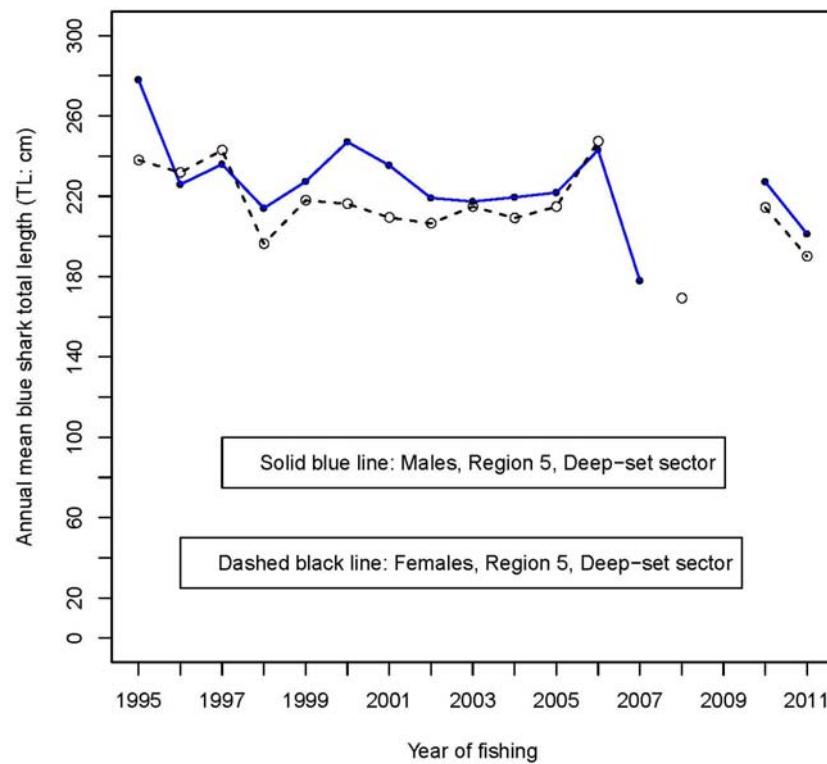


Figure 8. Annual mean blue shark total lengths by sexes in the deep-set sector in Regions 5 and 6 from 1995 through 2011.



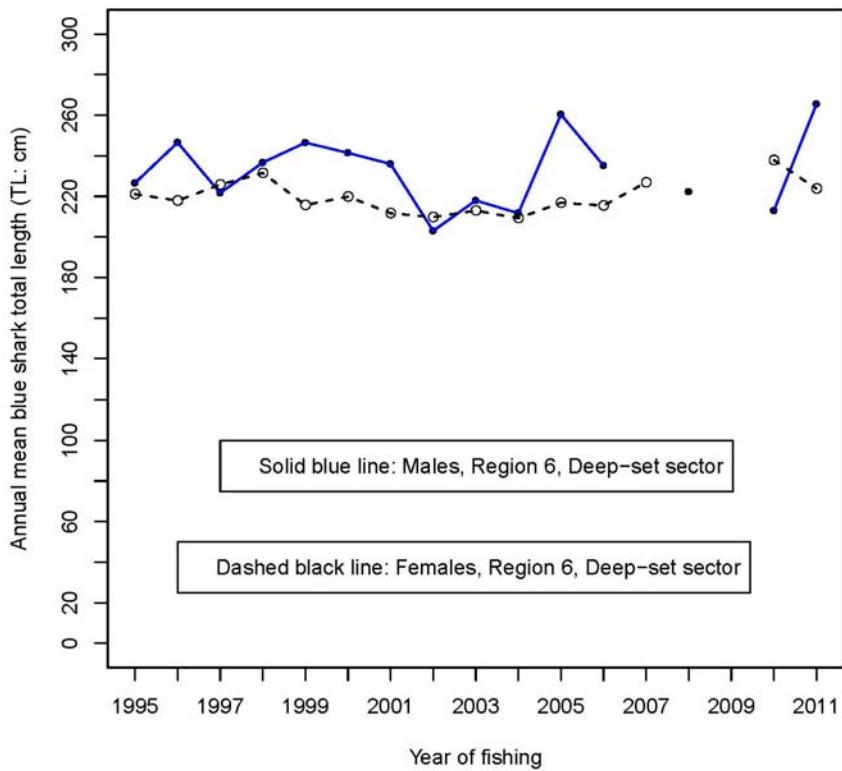
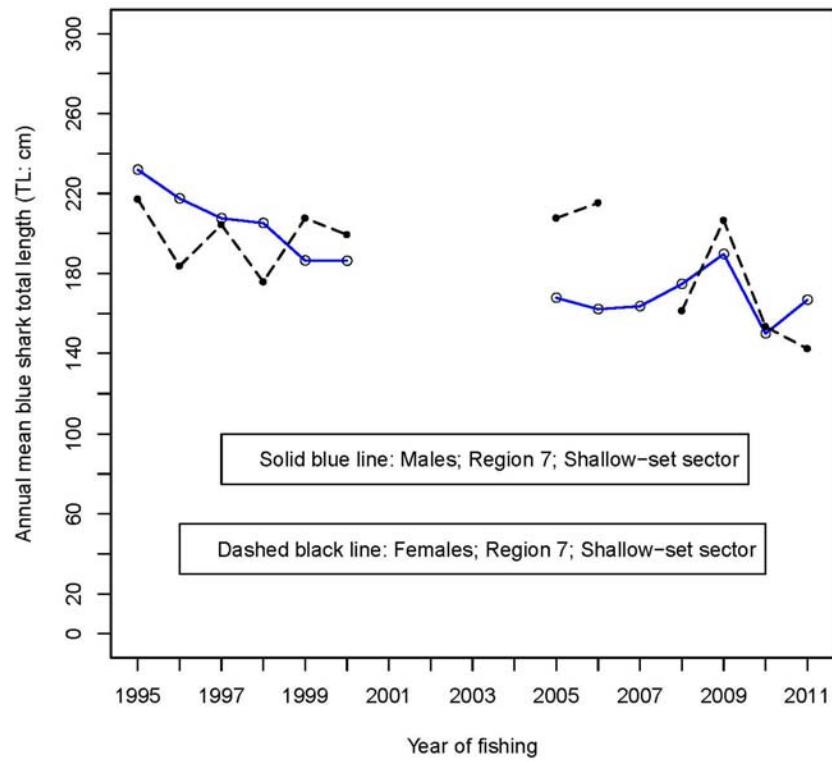


Figure 9. Annual mean blue shark total lengths by sexes in the shallow-set sector in Region 7 from 1995 through 2011.





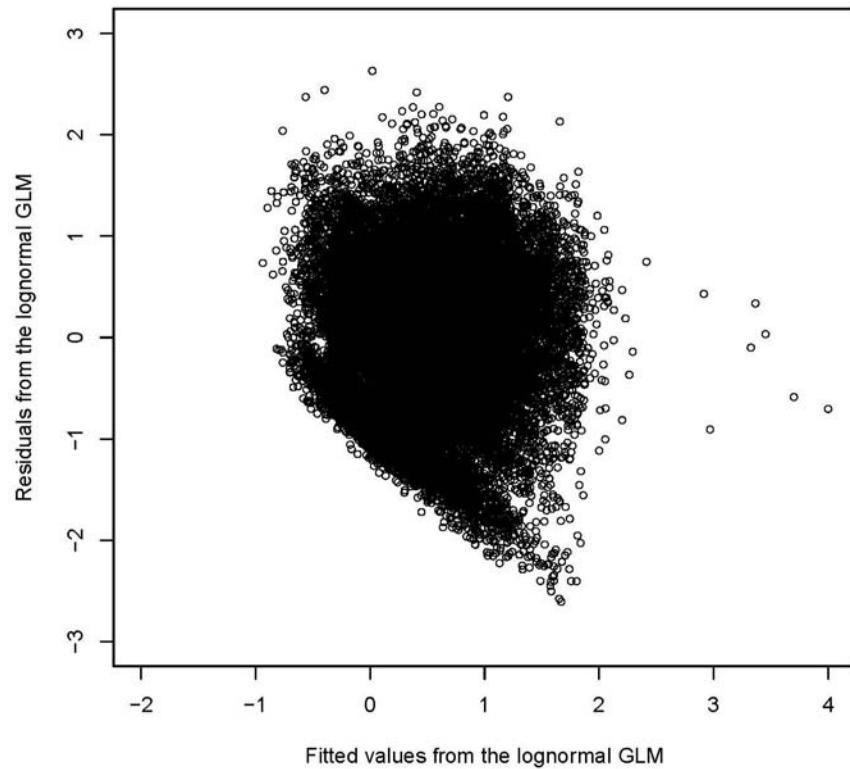
### **Acknowledgments**

The authors thank Karen Sender of the NOAA Pacific Islands Fisheries Science Center for preparation of the catch and CPUE maps, and Hui-Hua Lee of the NOAA Pacific Islands Fisheries Science Center for statistical advice and computing assistance.

## **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.



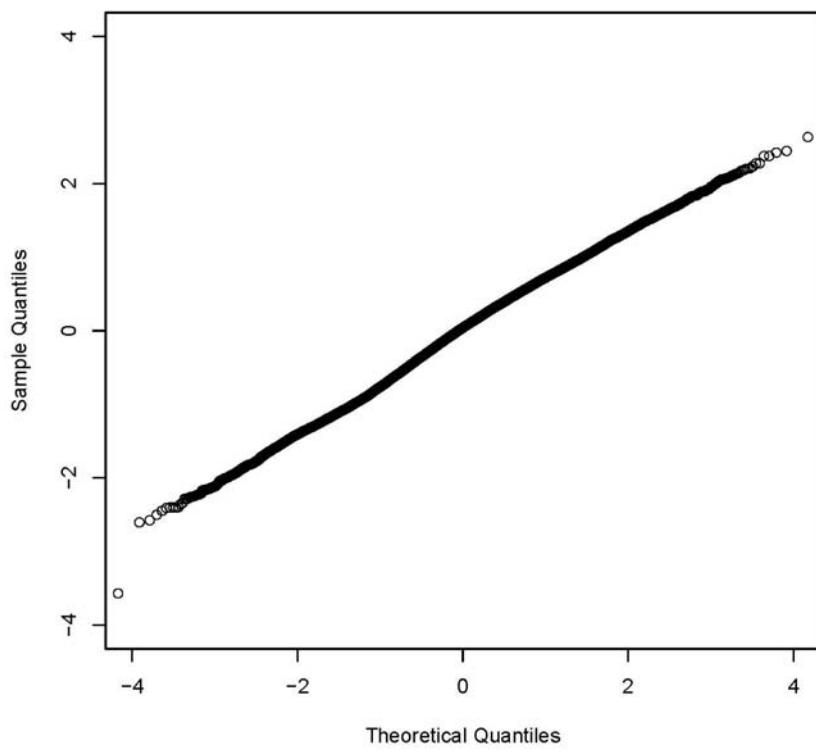
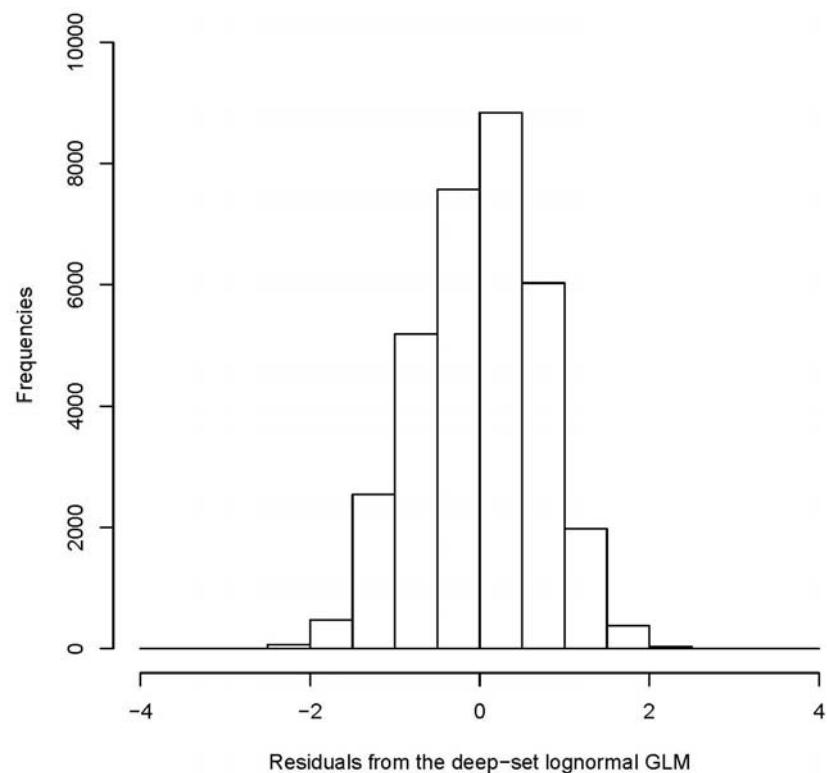


Figure A1, continued.



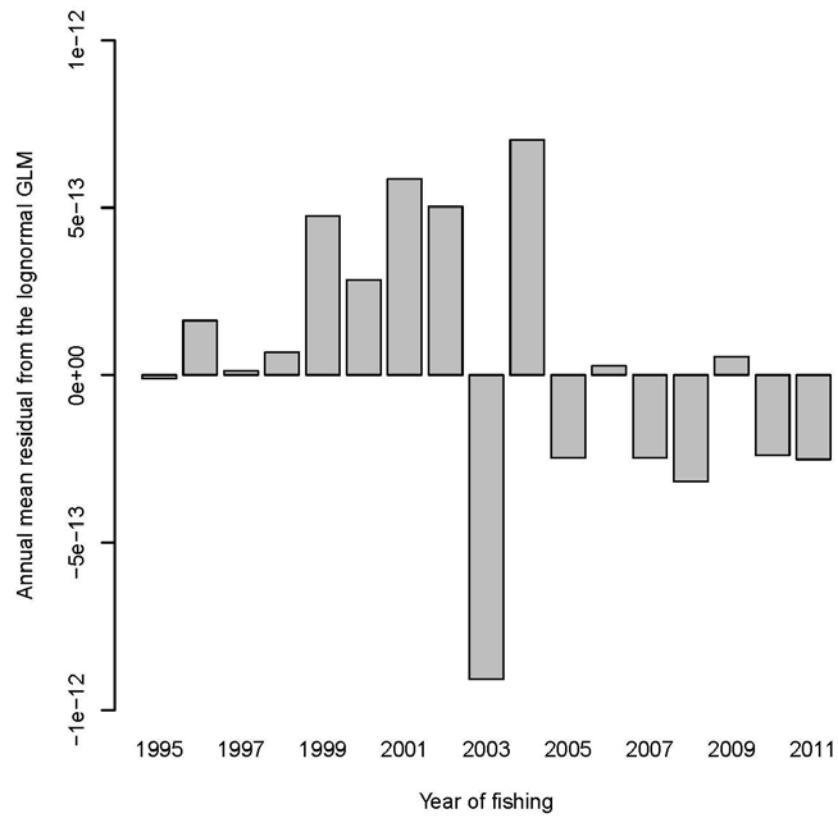
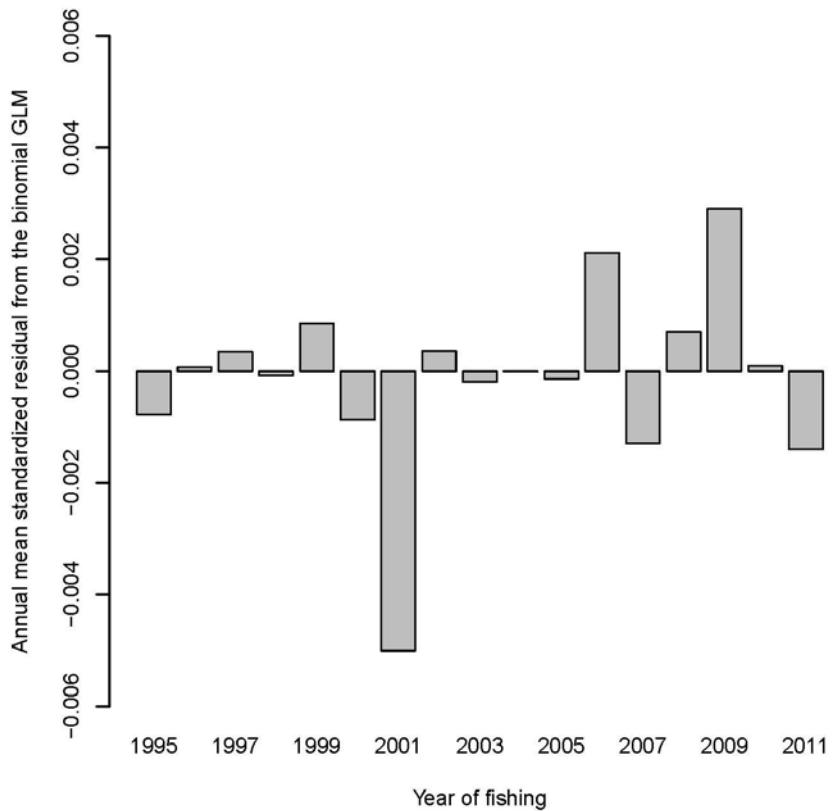


Figure A2. Plots of mean standardized residuals on the values of the factor variables in the binomial GLM of the delta lognormal analysis for the deep-set sector from 1995 through 2011.



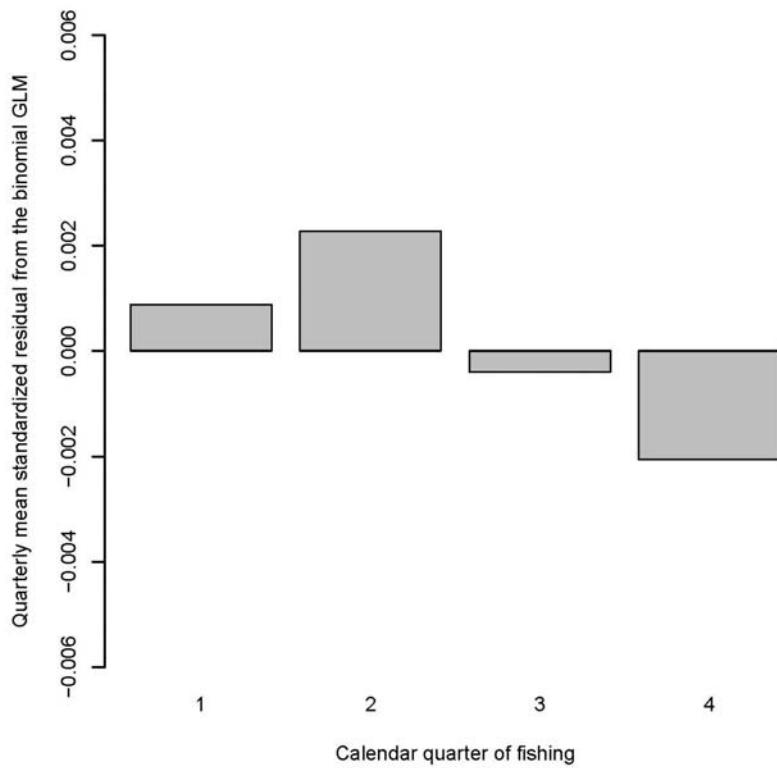
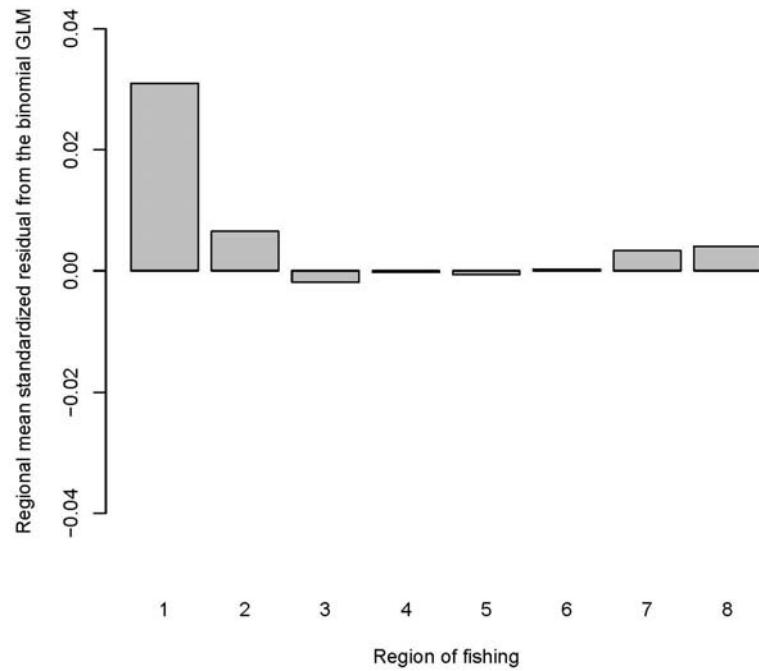


Figure A2, continued.



### 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.

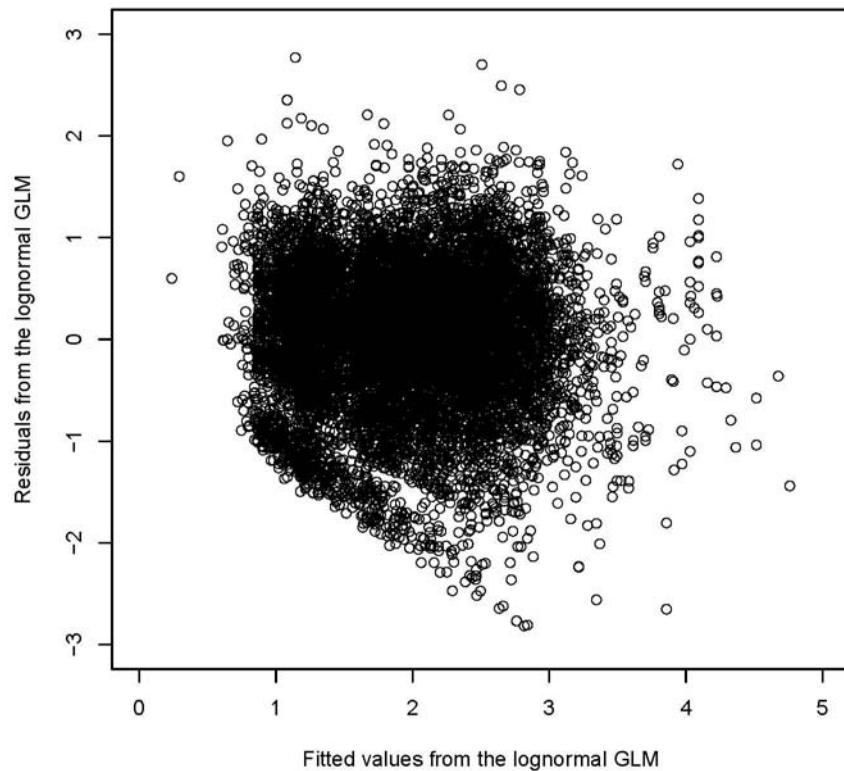
### Synopsis of Delta Lognormal Residuals: Deep-set Sector Binomial GLM

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.



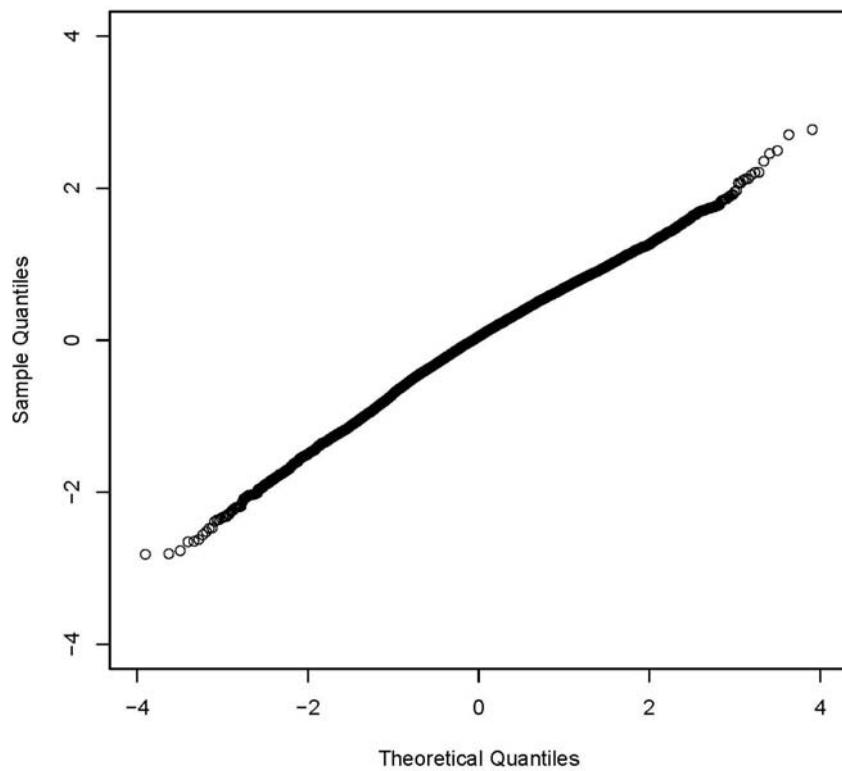
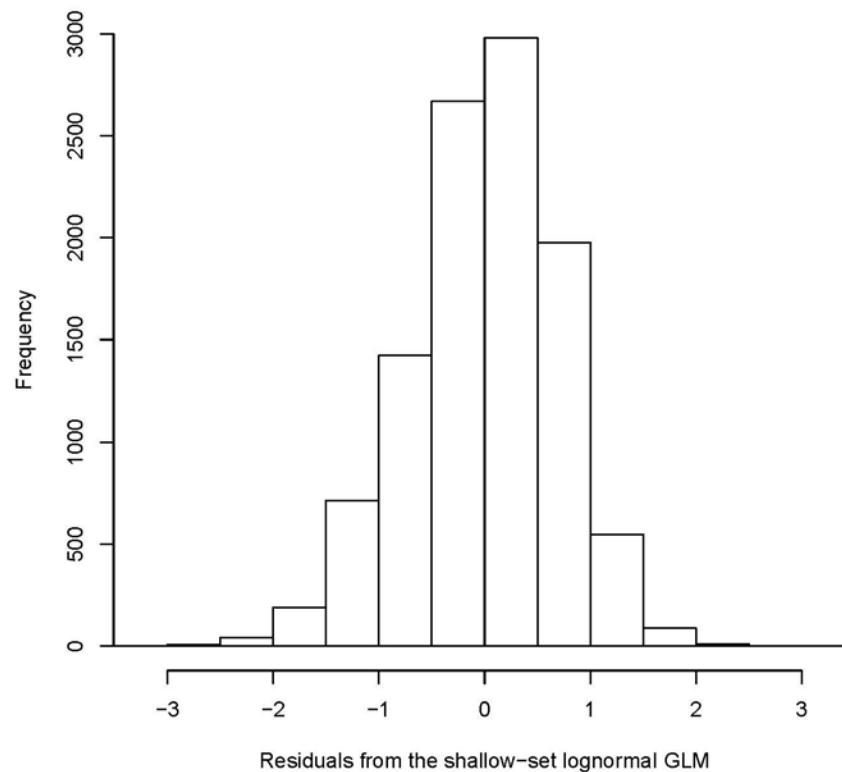


Figure A3, continued.



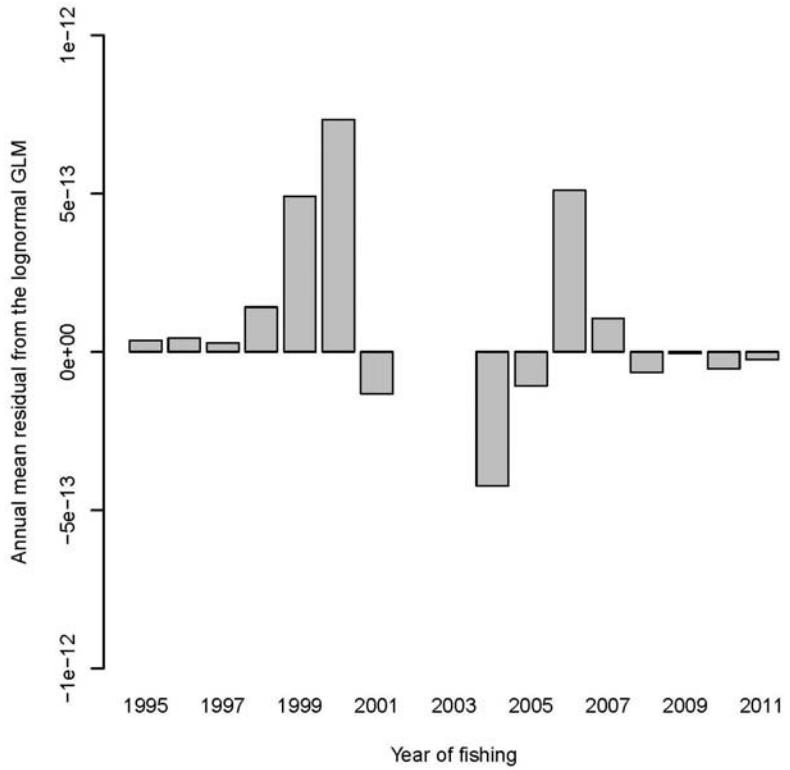
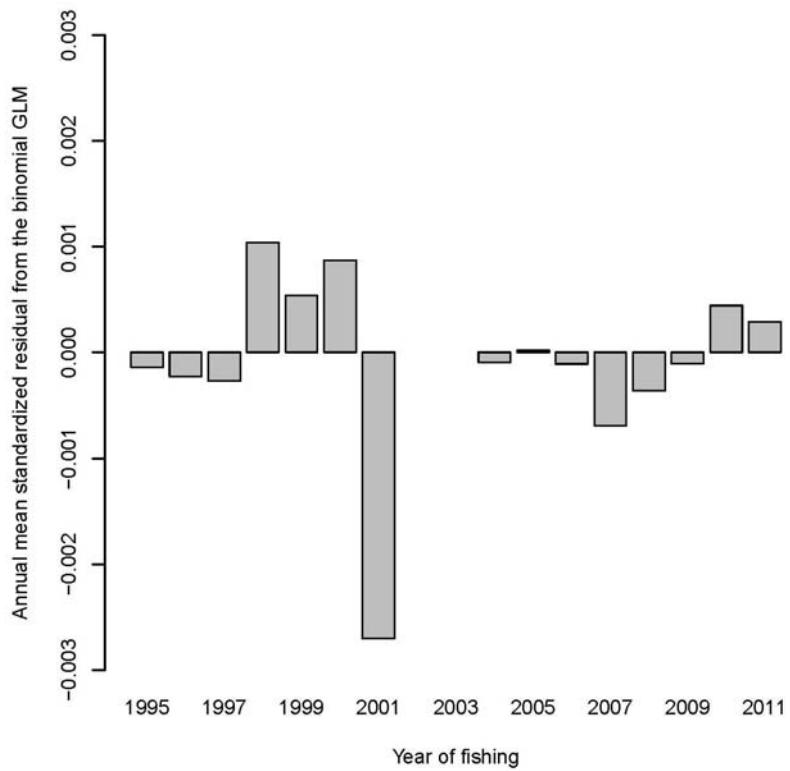


Figure A4. Plots of mean standardized residuals on the values of the factor variables in the binomial GLM of the delta lognormal analysis for the shallow-set sector from 1995 through 2011.



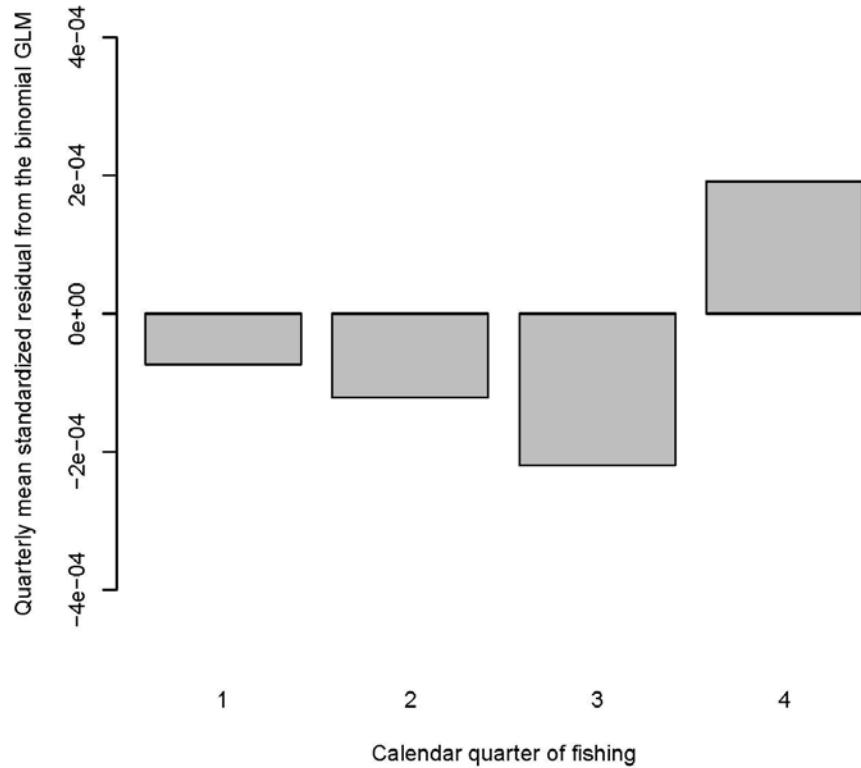
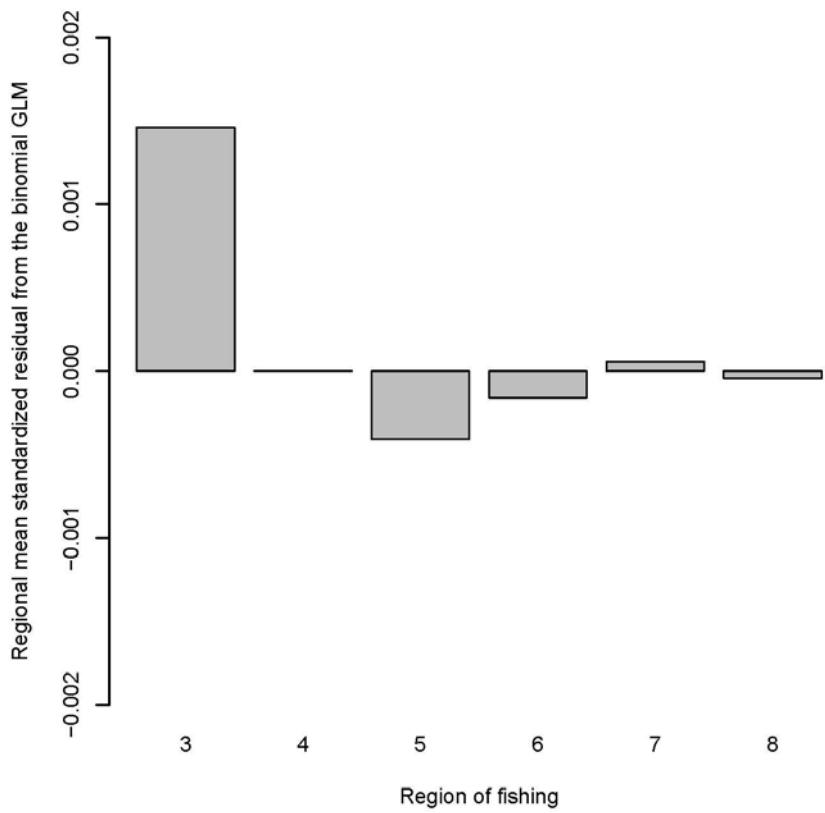


Figure A4, continued.



### 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.