ISC/12/SHARKWG-1/02

# Catch Statistics, Length Data and Standardized CPUE for Blue Shark *Prionace glauca* taken by Longline Fisheries based in Hawaii and California

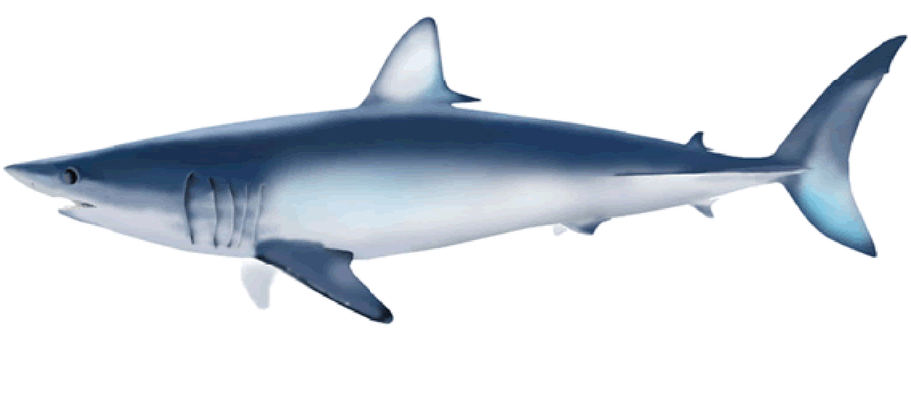
William A. Walsh

University of Hawaii Joint Institute for Marine and Atmospheric Research

Steven L.H. Teo

NOAA Fisheries, Southwest Fisheries Science Center

Email: William.Walsh@noaa.gov



Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June, 2012
National Research Institute of Far Seas Fisheries, Shizuoka, Japan

**Document not to be cited without author's permission.**

## 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.


## 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 it 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[1] 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.

---

[1] Region 1: 0–10ºN, 140–160ºW. Region 2: 0–10ºN, 160–175ºW. Region 3: 10–20ºN, 135–160ºW. Region 4: 10–20ºN, 160–180ºW. Region 5: 20–30ºN, 135–160ºW. Region 6: 20–30ºN, 160–180ºW. Region 7: 30–45ºN, 125–160ºW. Region 8: 30–45ºN, 160–180ºW.

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 are also presented as histograms by sexes and sectors.

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.

Catch distributions from fishery observer data

The distributions of observed blue shark catches and nominal mean CPUE in 5°×5° 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 30–35°N and 155–160°W in 2006. Catches in the nearby squares were lower, but CPUE was relatively uniform from 30°–35°N and 145°–170°W, with a mean of 9.90/1000 hooks. Shallow-set catches and CPUE were lower in 2011 than in 2006, but spanned 45° of longitude and included effort from 35°–40°N and 130°–150°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°N were in the shallow-set sector, whereas all sets in tropical waters (equator to 10°N) were in the deep-set sector. Most sets (87.6%) from 10°–30°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 3) 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 3) 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 4) 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 4) 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.

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

The number of FL measurements taken by the observers exceeded the TL measurements by 10.4%. A total of 7594 sharks 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).

Mean blue shark TL values sorted by sectors, regions, and sexes (Table 3) 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 7). The mean TL values in the shallow-set sector (Figure 8) 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 4). 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).

## 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 × 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 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 improved the accuracy of the blue shark catch 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.


## 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.

## Literature Cited

Clarke, S., Harley, S., Hoyle, S., and Rice, J. 2011. An indicator-based analysis of key shark species based on data held by SPC-OFP. Western and Central Pacific Fisheries Commission. Scientific Committee Seventh Regular Session, 9–17 August 2011. Pohnpei, Federated States of Micronesia. WCPFC-SC7-2011/EB-WP-01.

Compagno, L.J.V. 1984. Sharks of the Order Carcharhiniformes. The Blackburn Press. Caldwell, New Jersey.

Crawley, M. J. 2007. The R Book. John Wiley & Sons, Ltd. The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England.

Draper, N.R. and H. Smith. 1981. Applied Regression Analysis. Second Edition. John Wiley & Sons, Inc. New York.

Grubbs, R.D. 2010. Ontogenetic shifts in movements and habitat use. In: Sharks and their Relatives. II. Biodiversity, Adaptive Physiology, and Conservation. Edited by: Carrier, J.C., Musick, J.A., and Heithaus, M.R. CRC Press. Boca Raton, Florida.

Kleiber, P., S. Clarke, K. Bigelow, H. Nakano, M. McAllister, and Y. Takeuchi. 2009. North Pacific blue shark stock assessment. NOAA Technical Memorandum NMFS-PIFSC-17. 75 pp.

Nakano, H. and M. P. Seki. 2003. Synopsis of biological data on the blue shark *Prionace glauca*. Bulletin of the Far Seas Fisheries Agency 6:18–55.

Nakano, H. and Stevens, J.D. 2008. The biology and ecology of the blue shark, *Prionace glauca*. In: Sharks of the Open Ocean. Edited by: Camhi, M.D., Pikitch, E.K., and Babcock, E.A. Blackwell Science. Oxford, UK.

O'Brien, J.W. and J.S. Sunada. 1994. A review of the southern California experimental drift longline fishery for sharks. CALCOFI Report 35:222-229.

Pacific Islands Regional Office. 2011. Hawaii Longline Observer Program Field Manual. Version: LM.09.11. Honolulu.

Polovina, J.J., M. Abecassis, E.A. Howell, and P. Woodworth. 2009. Increases in the relative abundance of mid-trophic level fishes concurrent with declines in apex predators in the subtropical North Pacific, 1996–2006. Fishery Bulletin 107:523–531.

R Development Core Team (2008). R: A language and environment for statistical computing [online]. Available from http://cran.r-project.org/.

Strasburg, D.W. 1958. Distribution, abundance, and habits of pelagic sharks in the Central Pacific Ocean. US National Marine Fisheries Service Fishery Bulletin 58:335–361.

Walsh, W.A. and P. Kleiber. 2001. Generalized additive model and regression tree analyses of blue shark (*Prionace glauca*) catch rates by the Hawaii-based commercial longline fishery. Fisheries Research 53:115–131.

Walsh, W.A., P. Kleiber, and M. McCracken. 2002. Comparison of logbook reports of incidental blue shark catch rates by Hawaii-based longline vessels to fishery observer data by application of a generalized additive model. Fisheries Research 58:79–94.

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.

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. Catch 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, catch estimates replacing questionable logbook data, and a correction for under-reported sharks. California data from 1988–1990 and 1992–2004 are estimated for the experimental and pelagic longline fisheries, respectively, as described in the methods. * indicates that the data cannot be reported due to data confidentiality rules (fewer than 3 vessels).

| Year | Hawaii | | | | | California (MT) | HI & CA (MT) Total |
|---|---|---|---|---|---|---|---|
| | Observer Catch | Unobserved Logbook | Logbook Correction | Total | Percent Released | | |
| 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 |
| 1993 | NA | 150216 | NA | 150216 | NA | 1.5 | 12349.3 |
| 1994 | NA | 110187 | NA | 110187 | NA | 4.8 | 9062.2 |
| 1995 | 5903 | 89082 | 21380 | 110462 | 64.90% | 25.6 | 9105.6 |
| 1996 | 6914 | 73127 | 17550 | 90677 | 47.40% | 56.4 | 7510 |
| 1997 | 7491 | 72550 | 17412 | 89962 | 31.10% | 60.9 | 7455.8 |
| 1998 | 6509 | 84741 | 20338 | 105079 | 40.40% | 74.9 | 8712.4 |
| 1999 | 3169 | 74853 | 17965 | 92818 | 35.60% | 110.4 | 7740 |
| 2000 | 12144 | 59265 | 7112 | 66377 | 73.80% | 162.7 | 5618.9 |
| 2001 | 14132 | 25297 | 1518 | 26815 | 96.70% | 145.7 | 2349.9 |
| 2002 | 13161 | 26804 | 1608 | 28418 | 98.00% | 95 | 2431 |
| 2003 | 19119 | 42409 | 2545 | 44954 | >99% | 87.2 | 3782.4 |

Table 2, continued.

| Year | Hawaii | | | | | California (MT) | HI & CA (MT) Total |
|---|---|---|---|---|---|---|---|
| | Observer Catch | Unobserved Logbook | Logbook Correction | Total | Percent Released | | |
| 2004 | 23458 | 41440 | 2072 | 43512 | >99% | 36.9 | 3613.6 |
| 2005 | 36621 | 30376 | 1519 | 31895 | >99% | * | * |
| 2006 | 23872 | 34752 | 1738 | 36490 | >99% | * | * |
| 2007 | 32623 | 32929 | 988 | 33917 | >99% | * | * |
| 2008 | 23141 | 29914 | 897 | 30811 | >99% | * | * |
| 2009 | 20405 | 27802 | 834 | 28636 | >99% | * | * |
| 2010 | 31082 | 27503 | 812 | 28315 | >99% | * | * |
| 2011 | 22483 | 33330 | 1012 | 34342 | >99% | * | * |

Table 3. 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 | Δ Residual Deviance | Δ Residual deviance per df | Null deviance reduction | ΔAIC | ΔBIC | Pr>\|χ2\| |
|---|---|---|---|---|---|---|---|
| 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 3, continued.

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

| Parameter | Df | Δ Residual Deviance | Δ Residual deviance per df | Null deviance reduction | ΔAIC | ΔBIC | Pr>\|χ2\| |
|---|---|---|---|---|---|---|---|
| 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 4. 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 | Δ Residual Deviance | Δ Residual deviance per df | Null deviance reduction | ΔAIC | ΔBIC | Pr>\|χ2\| |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | ---- | ---- | ---- | ---- | ---- | ---- |
| Haul year | 14 | 124.24 | 8.87 | 3.39% | 96.24 | **-6.14** | 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 4, continued.

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

| Parameter | Df | Δ Residual Deviance | Δ Residual deviance per df | Null deviance reduction | ΔAIC | ΔBIC | Pr>\|χ2\| | 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 5. 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 6. 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 | Region7 | 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 | 217.2±24.0 | 224.2±29.4 | 228.7±24.7 | 226.8±27.9 | 233.4±28.5 | 251.9±24.7 | 201.7±41.0 |
| *N* = 3 | *N* = 132 | *N* = 370 | *N* = 671 | *N* = 215 | *N* = 512 | *N* = 7 | *N* = 32 |
| Deep-set: ♀ | Deep-set: ♀ | Deep-set: ♀ | Deep-set: ♀ | Deep-set: ♀ | Deep-set: ♀ | Deep-set: ♀ | Deep-set: ♀ |
| 206.0±5.7 | 202.7±24.2 | 208.0±15.9 | 210.0±16.7 | 219.7±25.5 | 221.1±20.8 | 199.6 | 186.4±44.9 |
| *N* = 2 | *N* = 105 | *N* = 416 | *N* = 599 | *N* = 189 | *N* = 240 | *N* = 1 | *N* = 6 |
| Shallow-set: ♂ | Shallow-set: ♂ | Shallow-set: ♂ | Shallow-set: ♂ | Shallow-set: ♂ | Shallow-set: ♂ | Shallow-set: ♂ | Shallow-set: ♂ |
| | | 226.9±14.8 | 212.5±16.4 | 233.8±25.9 | 215.7±32.4 | 194.4±41.7 | 212.7±39.0 |
| *N* = 0 | *N* = 0 | *N* = 34 | *N* = 19 | *N* = 231 | *N* = 1500 | *N* = 672 | *N* = 742 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Shallow-set: ♀ | Shallow-set: ♀ | Shallow-set: ♀ | Shallow-set: ♀ | Shallow-set: ♀ | Shallow-set: ♀ | Shallow-set: ♀ | Shallow-set: ♀ |
| | | 212.5±16.3 | 212.0±19.1 | 217.2±21.7 | 216.6±23.6 | 190.6±42.8 | 188.1±36.3 |
| *N* = 0 | *N* = 0 | *N* = 28 | *N* = 21 | *N* = 364 | *N* = 852 | *N* = 461 | *N* = 194 |

Table 7. Summary of blue shark sex ratios (♂:♀) 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 | Region7 | 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.

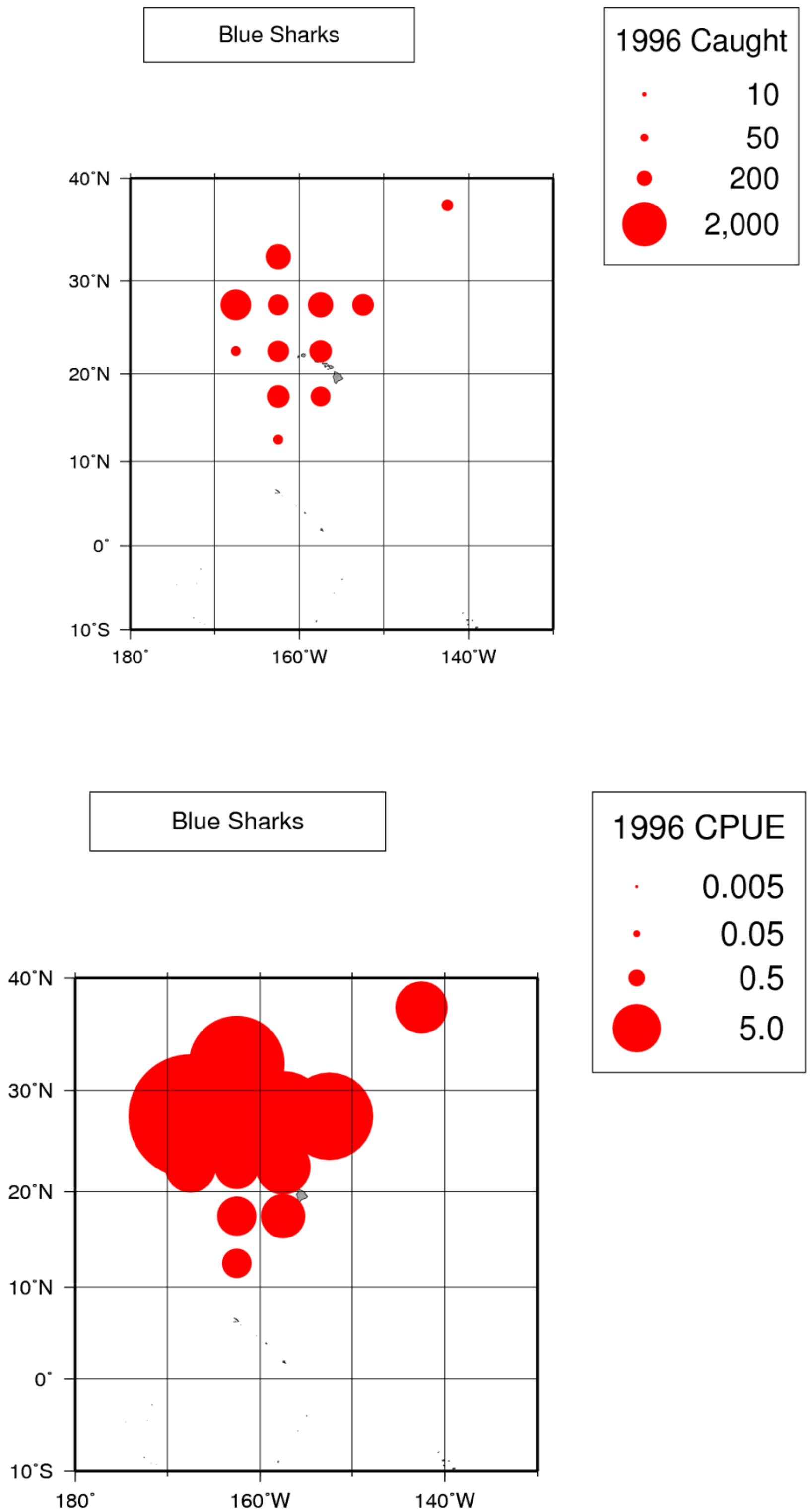
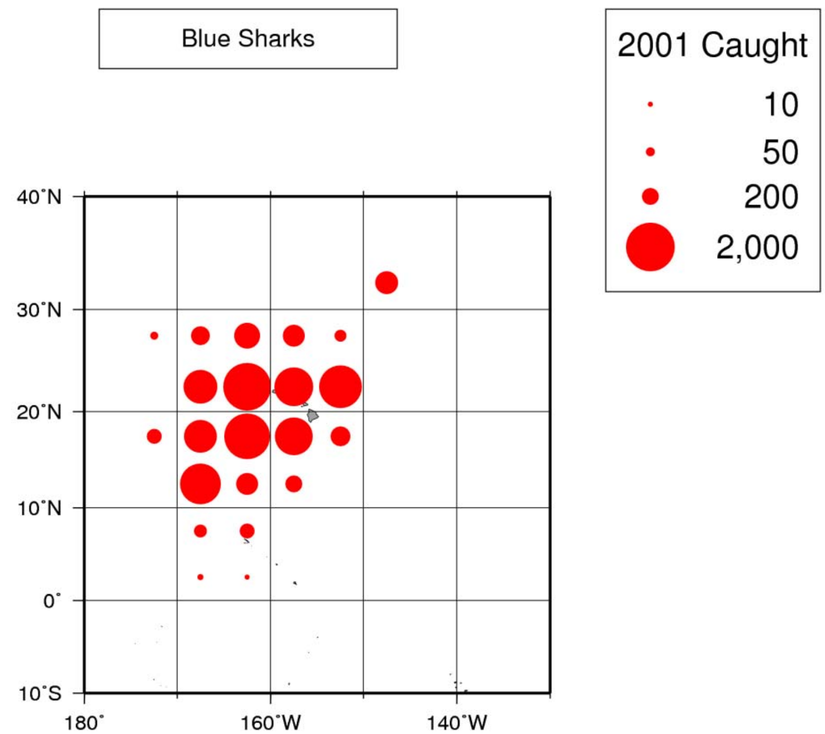


Figure 1, continued.



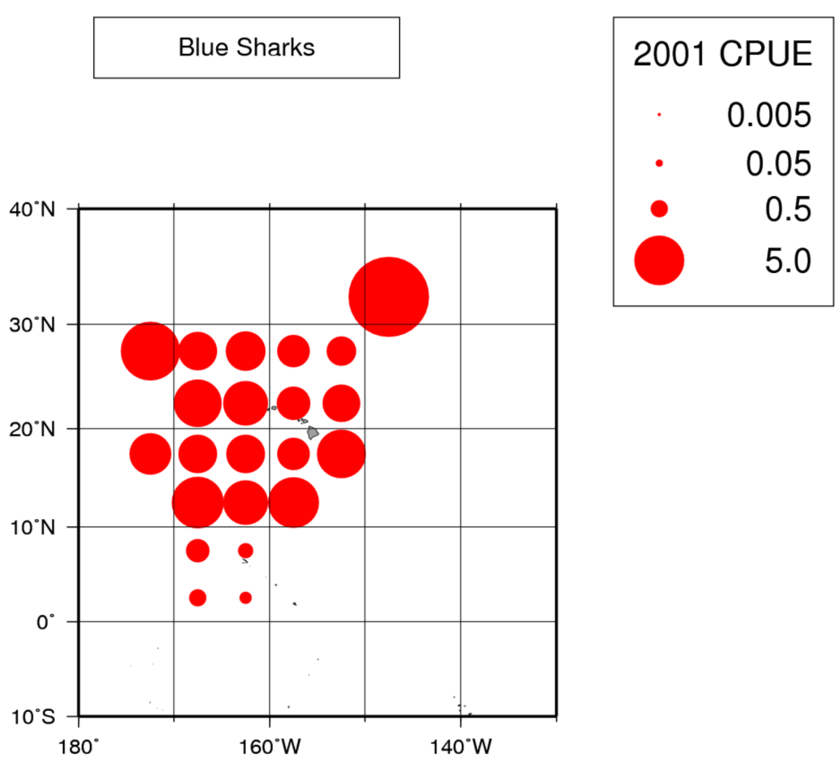
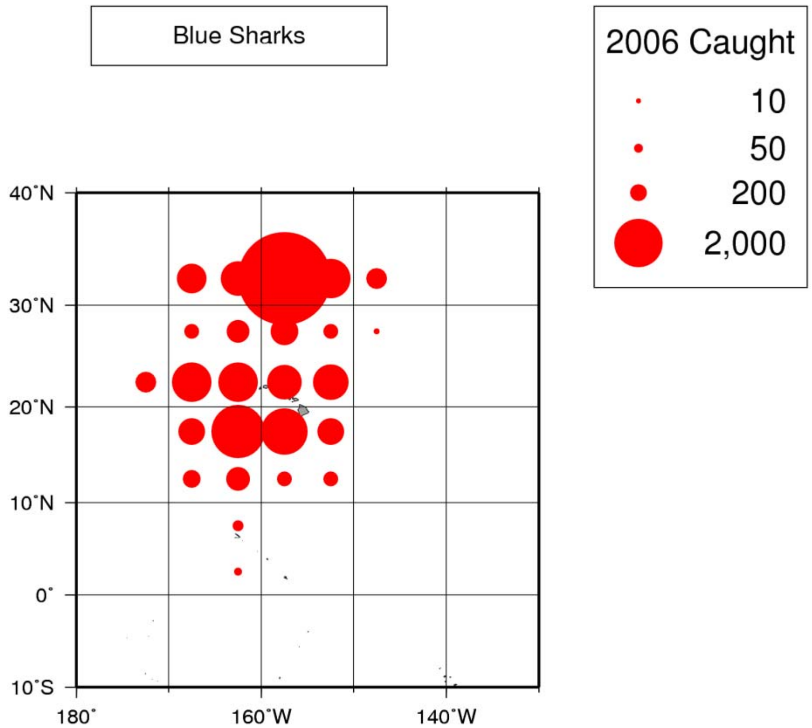



Figure 1, continued.



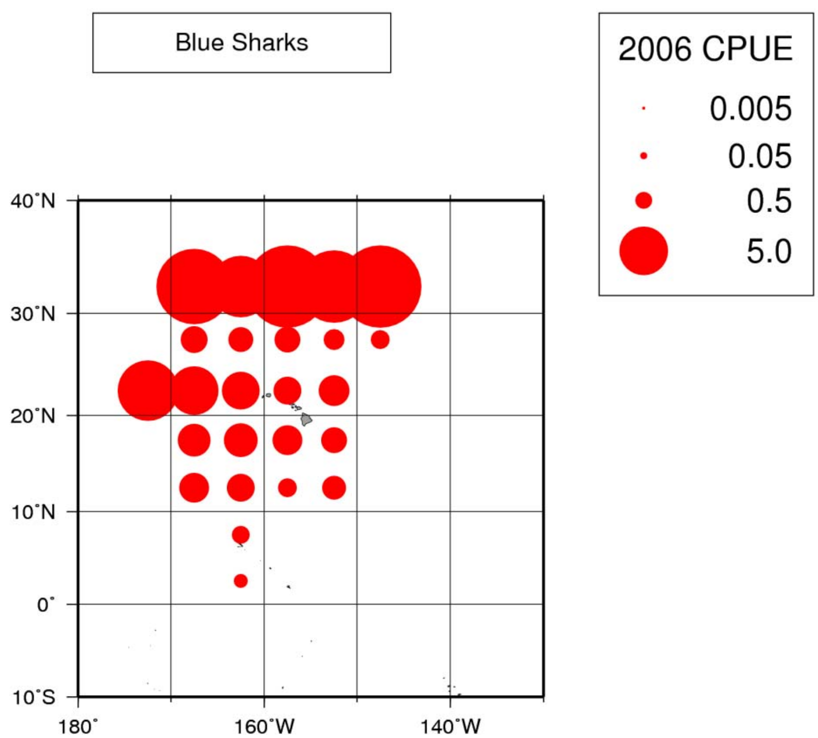
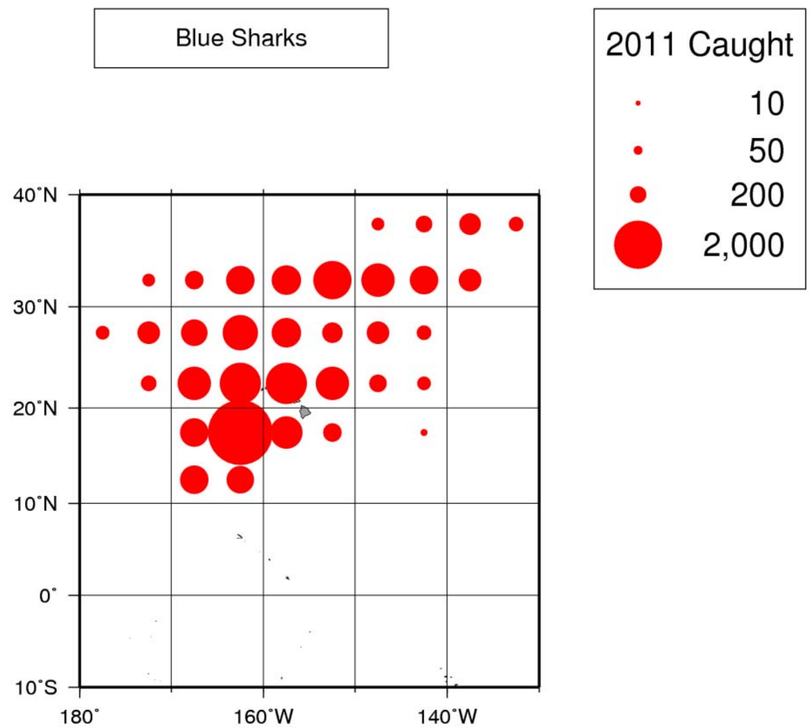



Figure 1, continued.



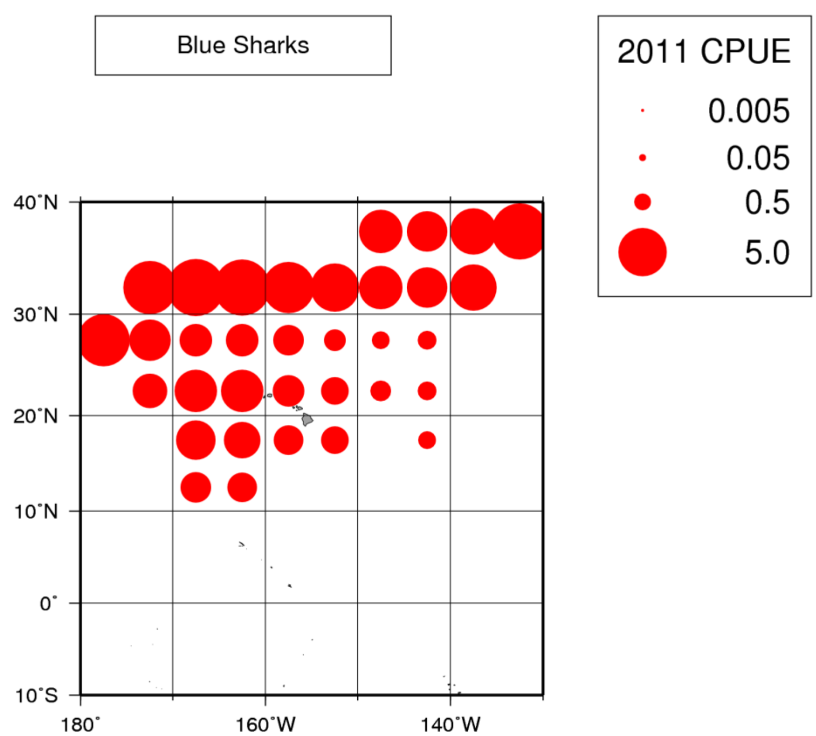
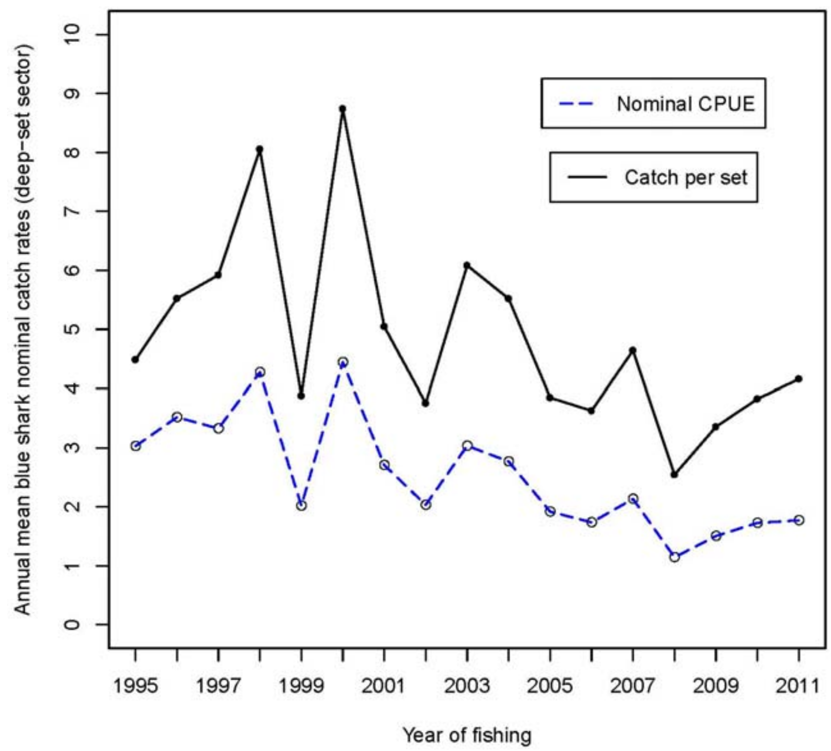



Figure 2. Annual mean blue shark nominal catch rates in the deep-set (upper) and shallow-set sectors (lower) of the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003. CPUE is expressed as blue sharks per 1000 hooks.



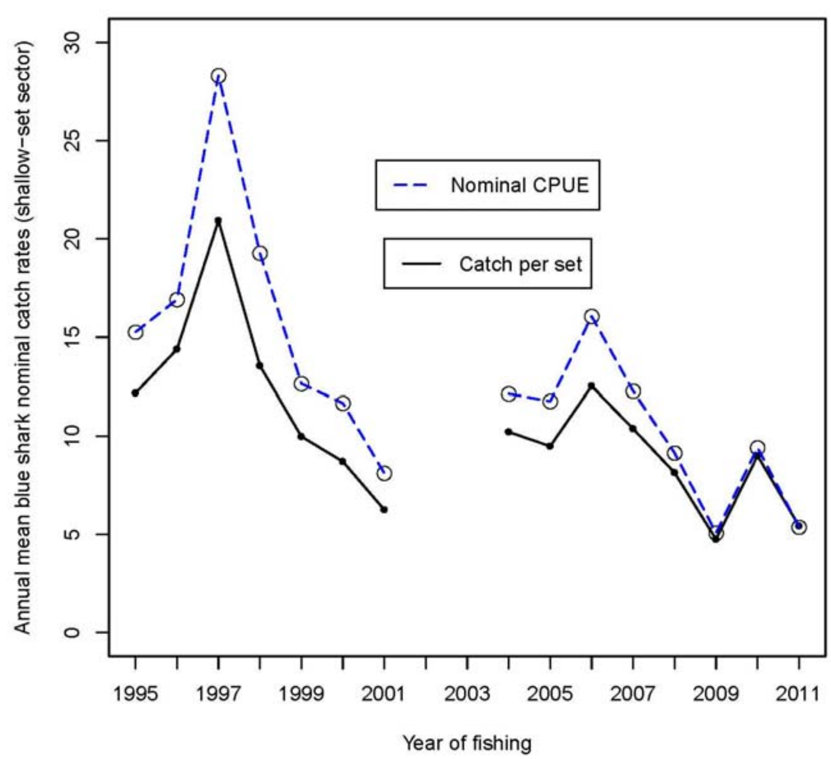



Figure 3. Annual percentages of zero catches (upper) and CPUE on sets with positive blue shark catches (lower) by sector in the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.

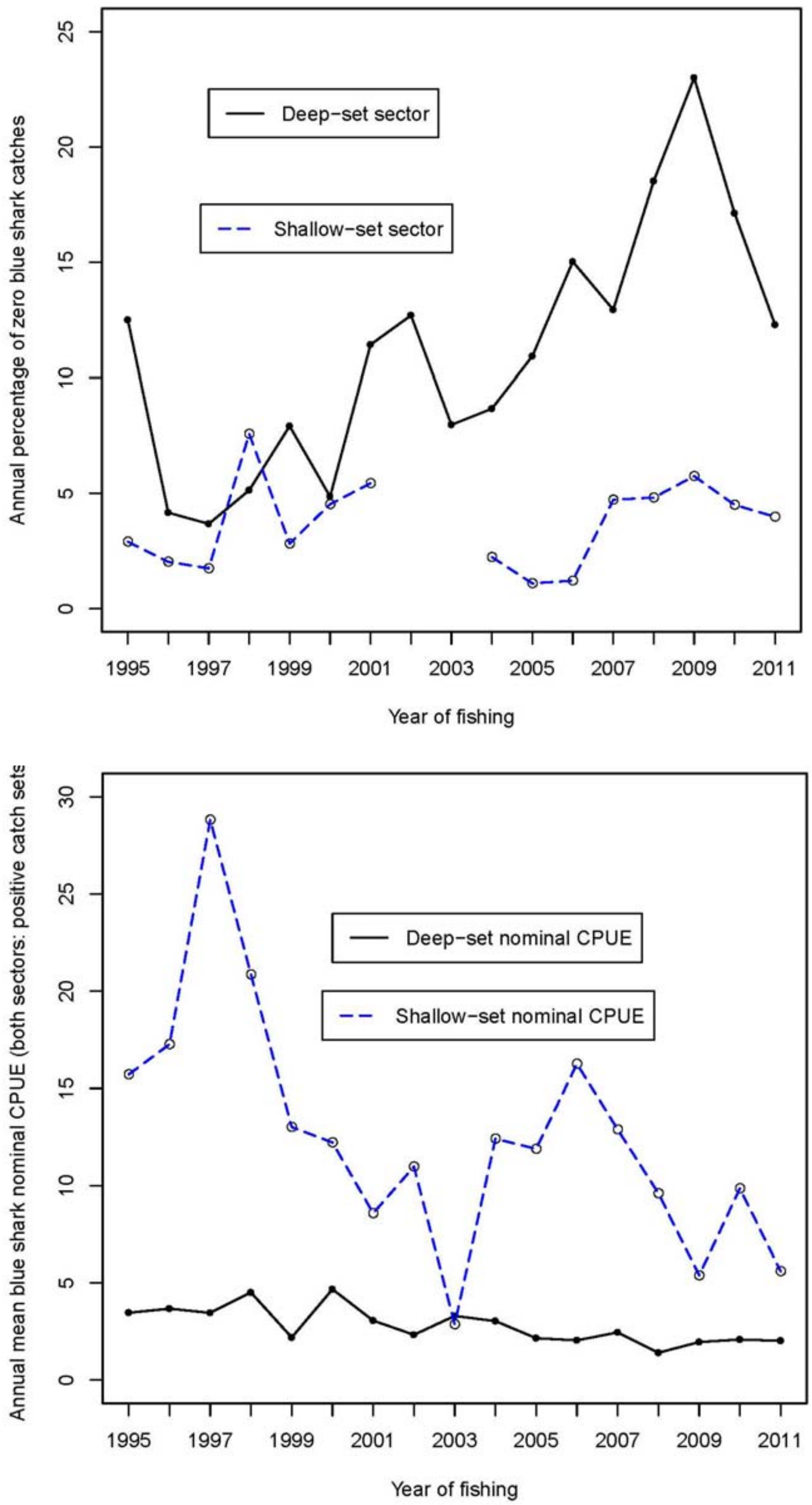
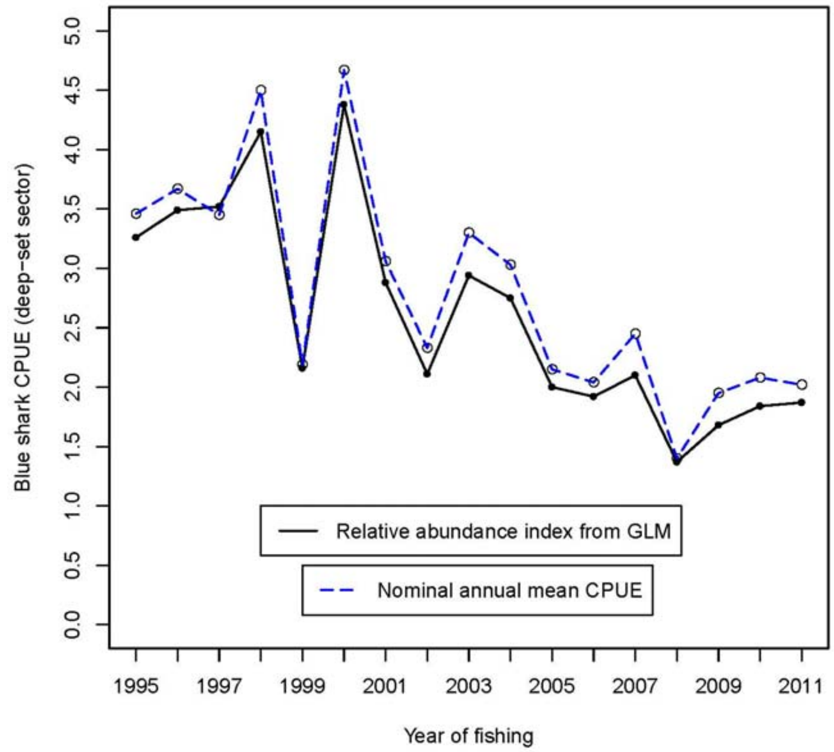


Figure 4. Relative abundance indices obtained from the GLM annual coefficients for blue shark by sector in the Hawaii-based longline fishery. The shallow-set sector was closed throughout 2002 and 2003.



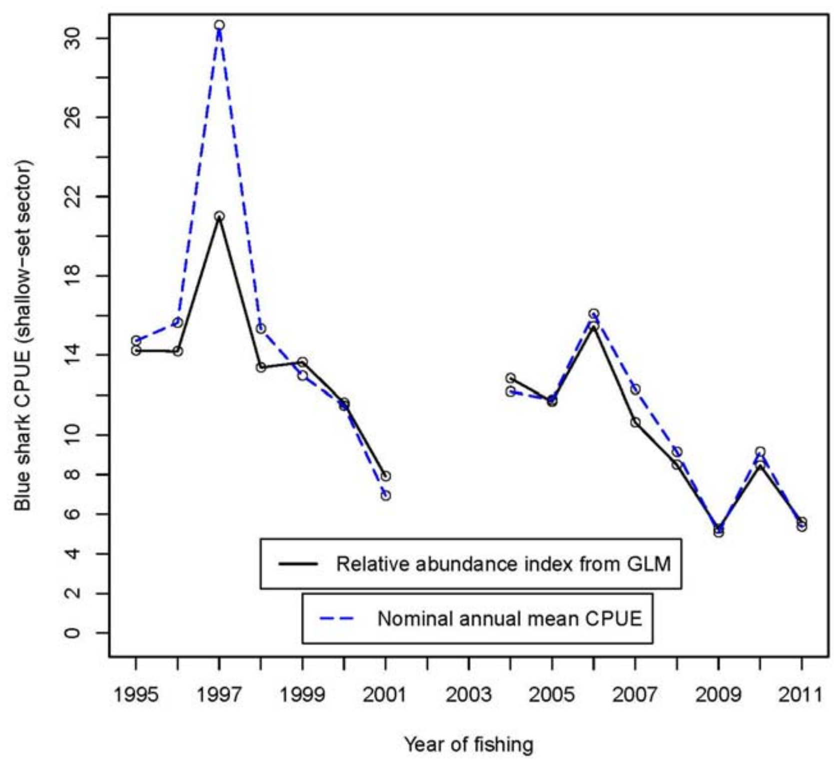
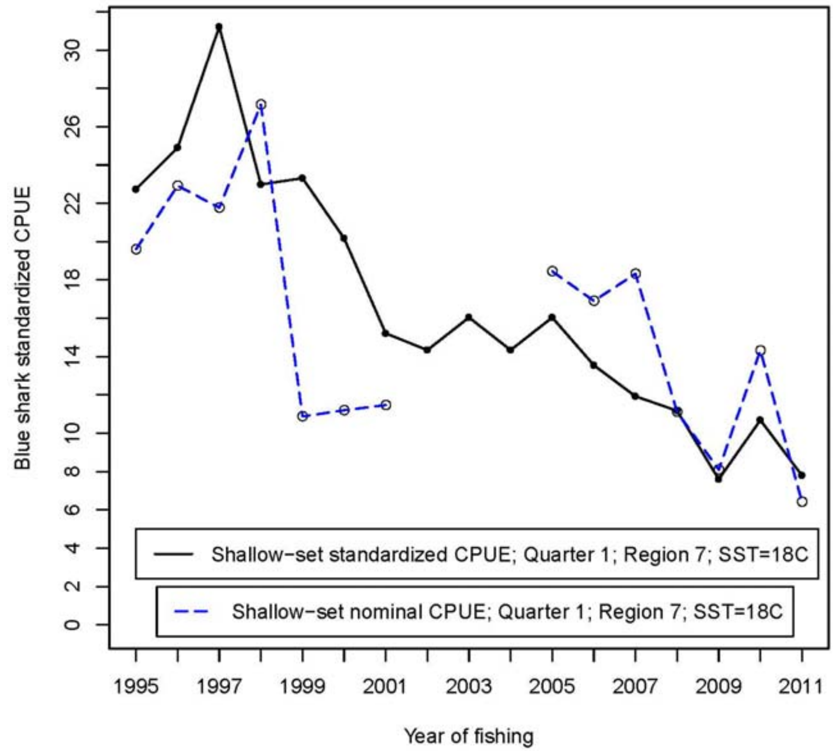



Figure 5. Standardized and nominal CPUE for blue shark by sectors, during quarters and in regions of typically high abundance. CPUE is expressed as blue sharks per 1000 hooks.



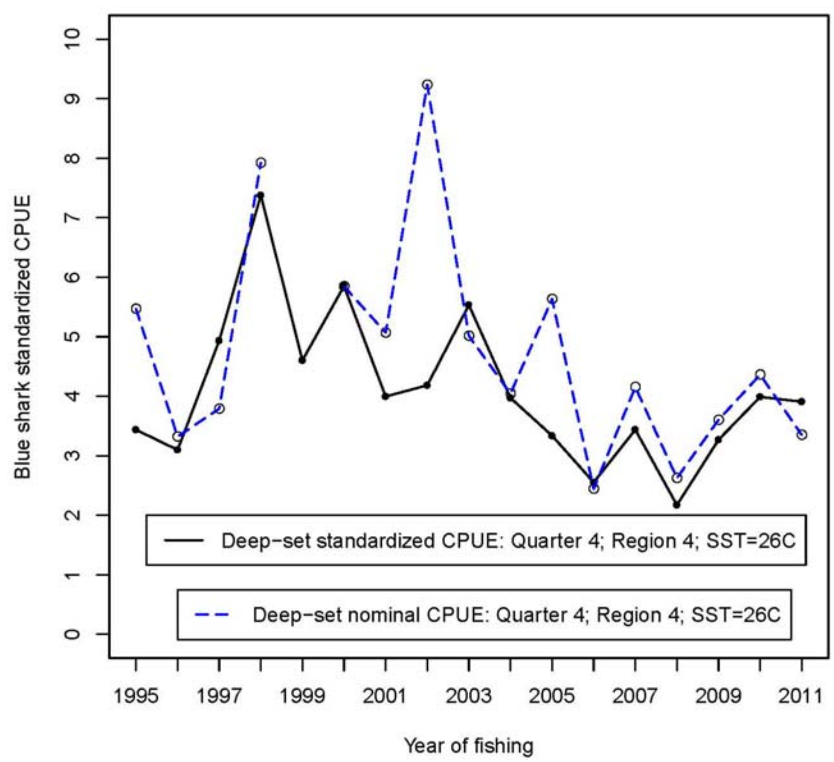



Figure 6.  Size frequency distributions for blue sharks by fishery sectors and sexes from 1995 through 2011.  Bin widths are 20 cm.

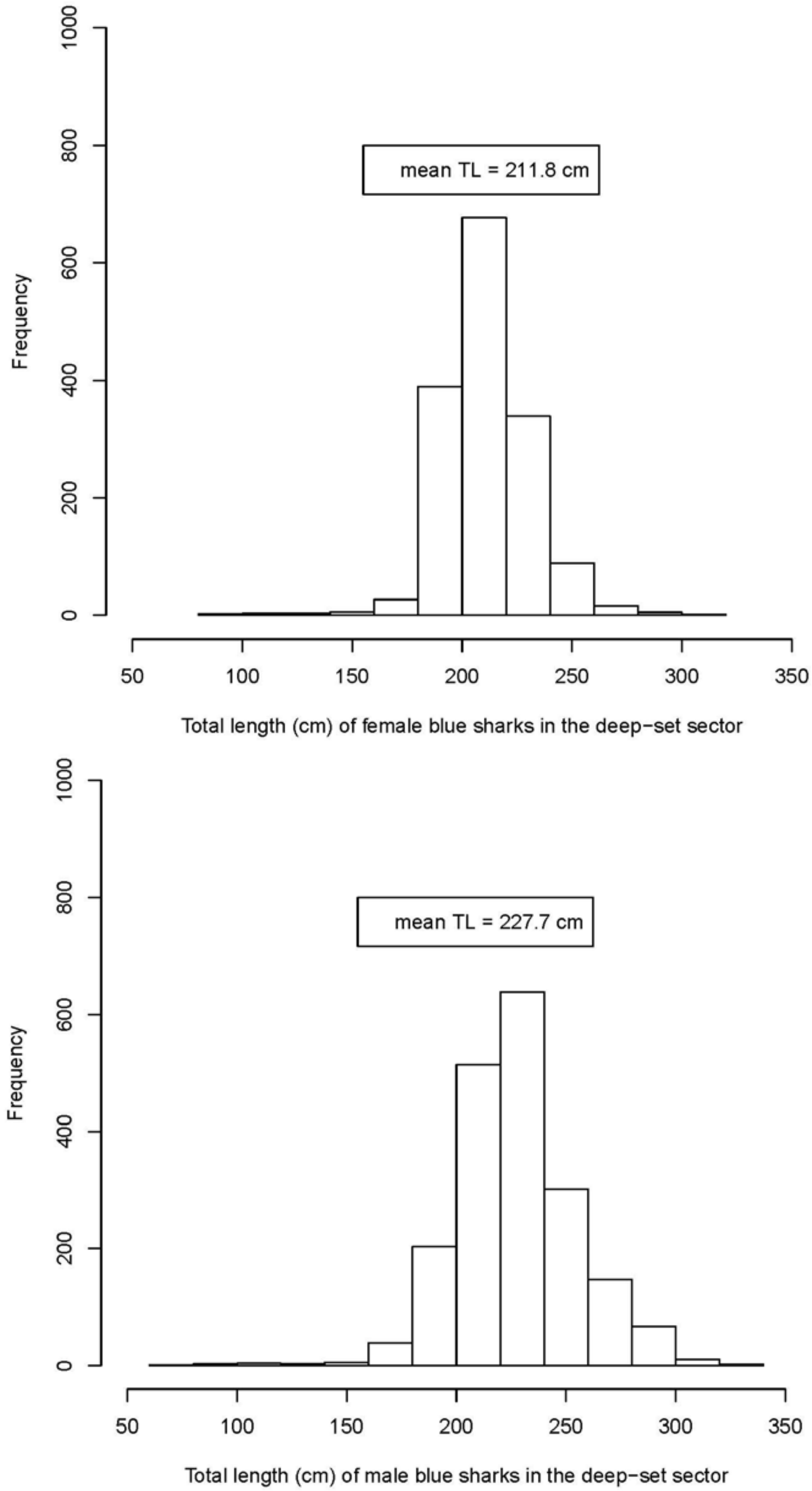
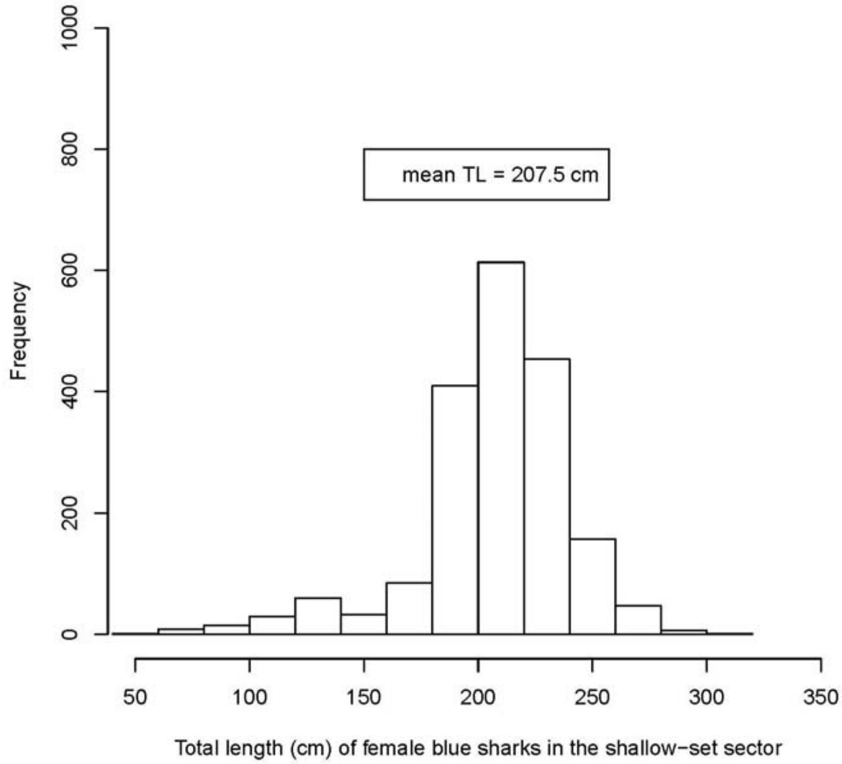


Figure 6, continued.



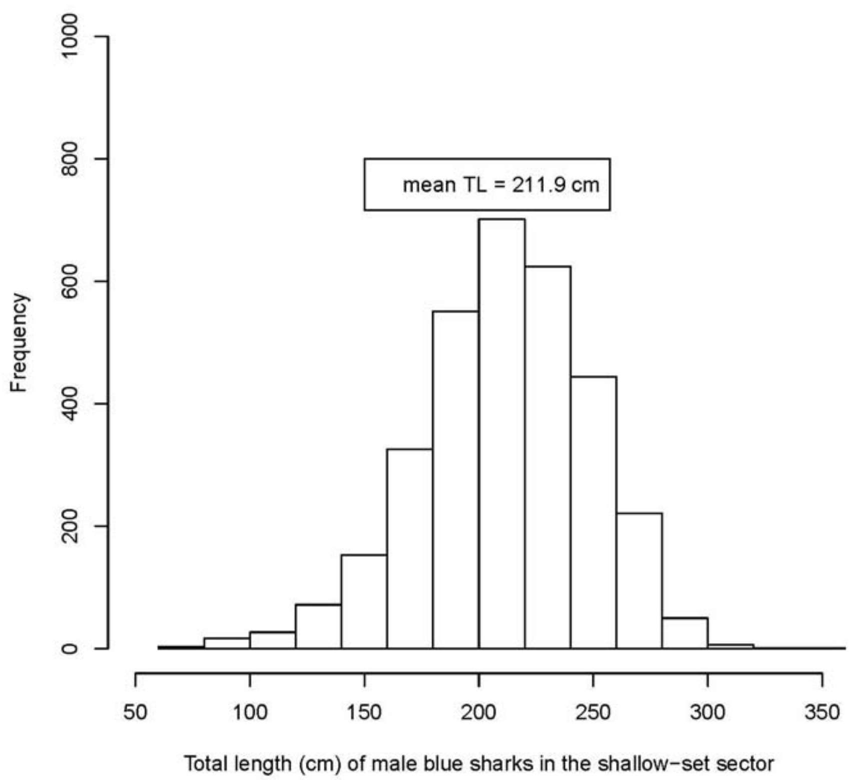
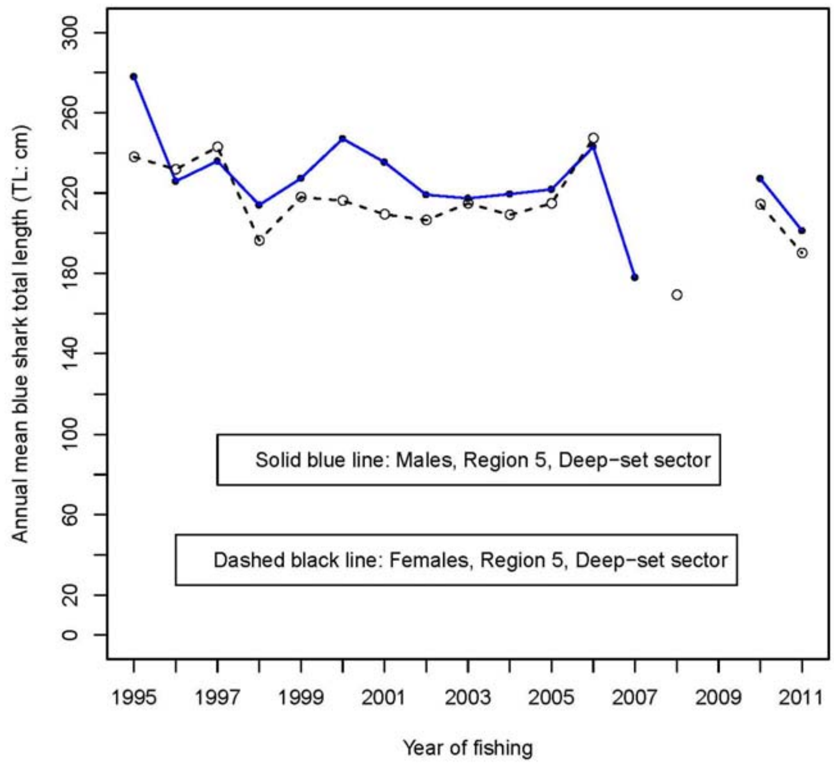



Figure 7. Annual mean blue shark total lengths by sexes in the deep-set sector in Regions 5 and 6 from 1995 through 2011.




.

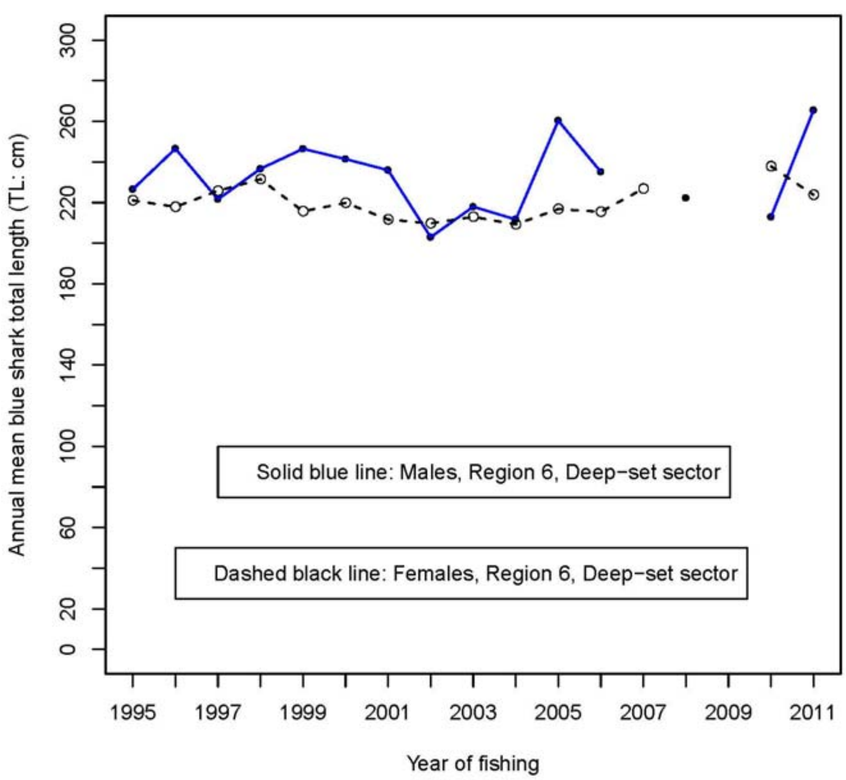
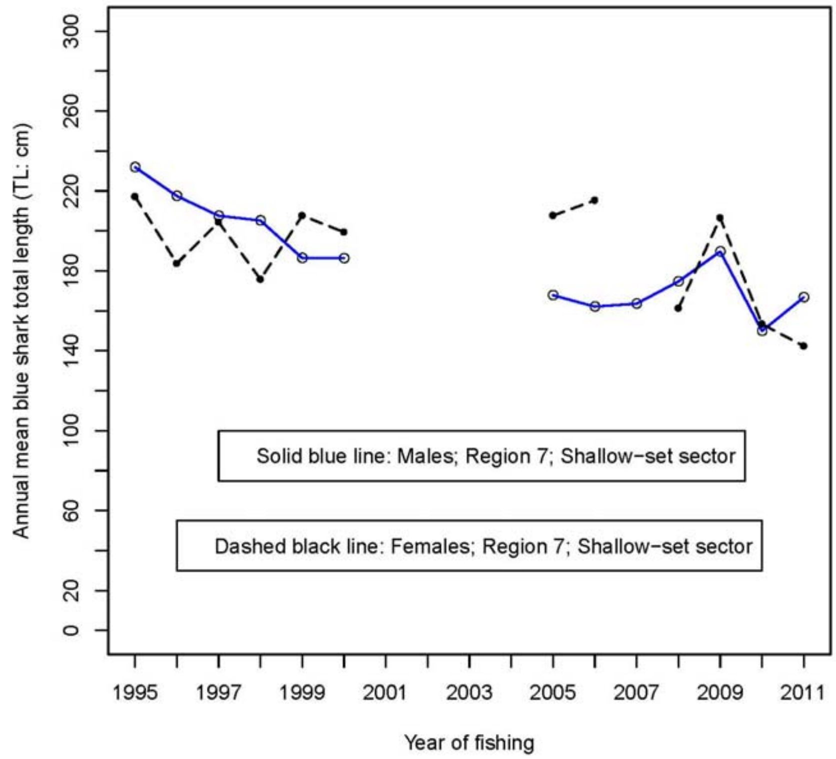


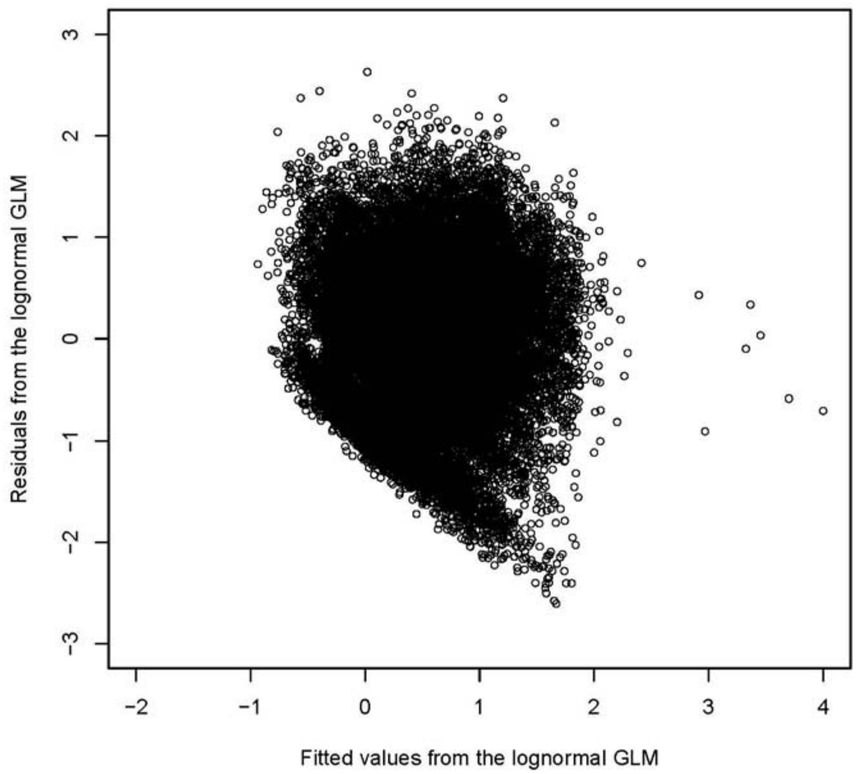
Figure 8. Annual mean blue shark total lengths by sexes in the shallow-set sector in Region 7 from 1995 through 2011.



## 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.



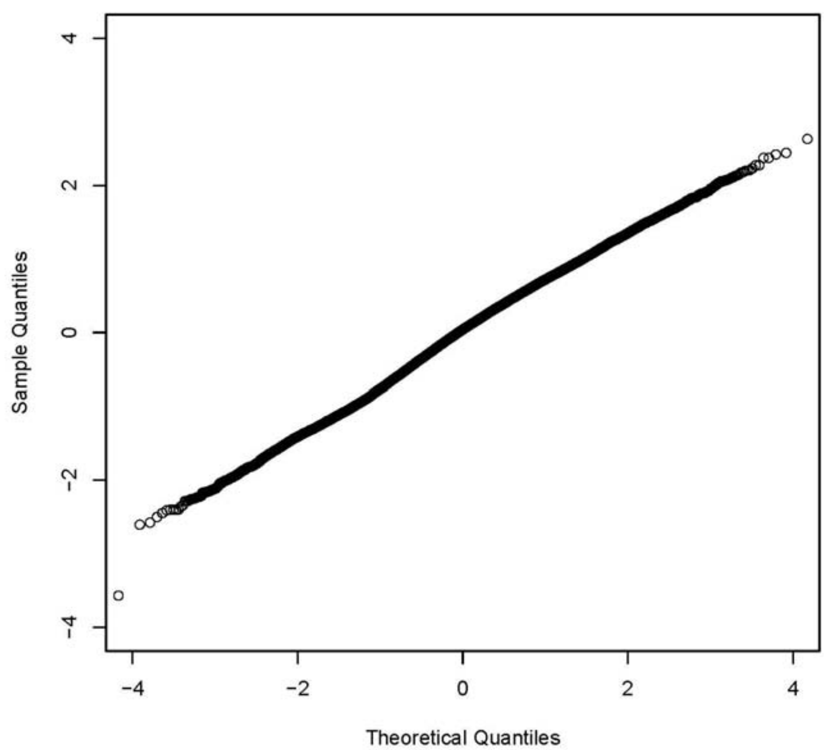
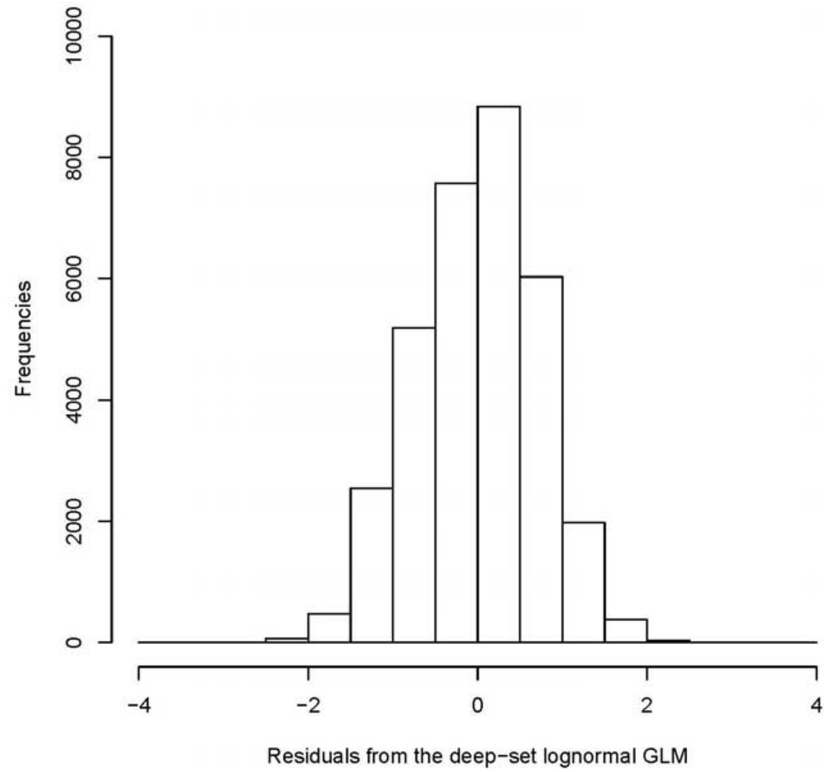



Figure A1, continued.



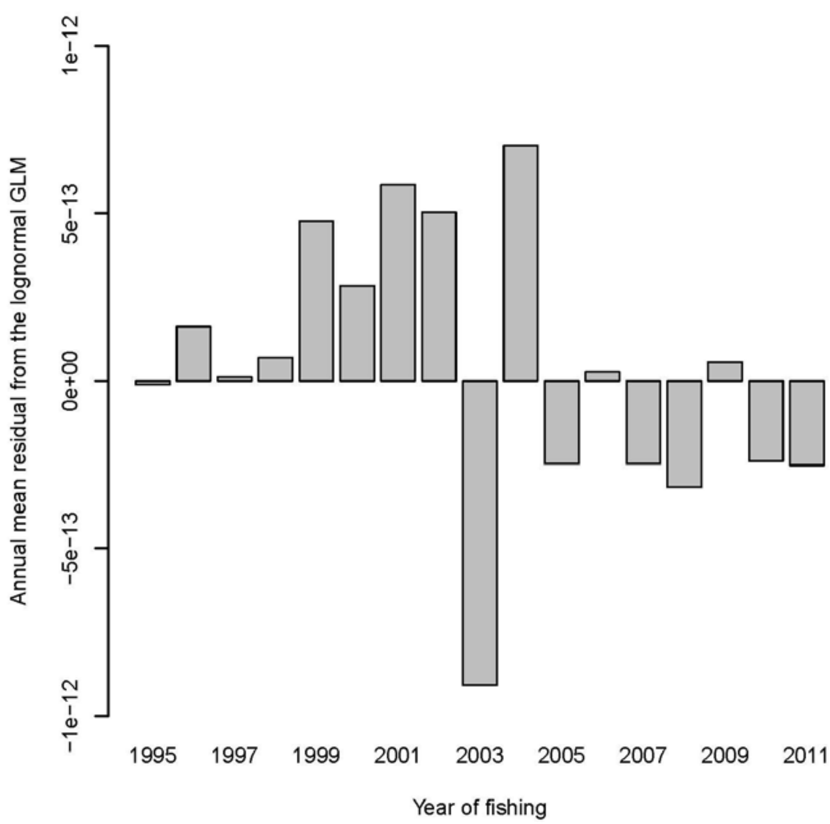
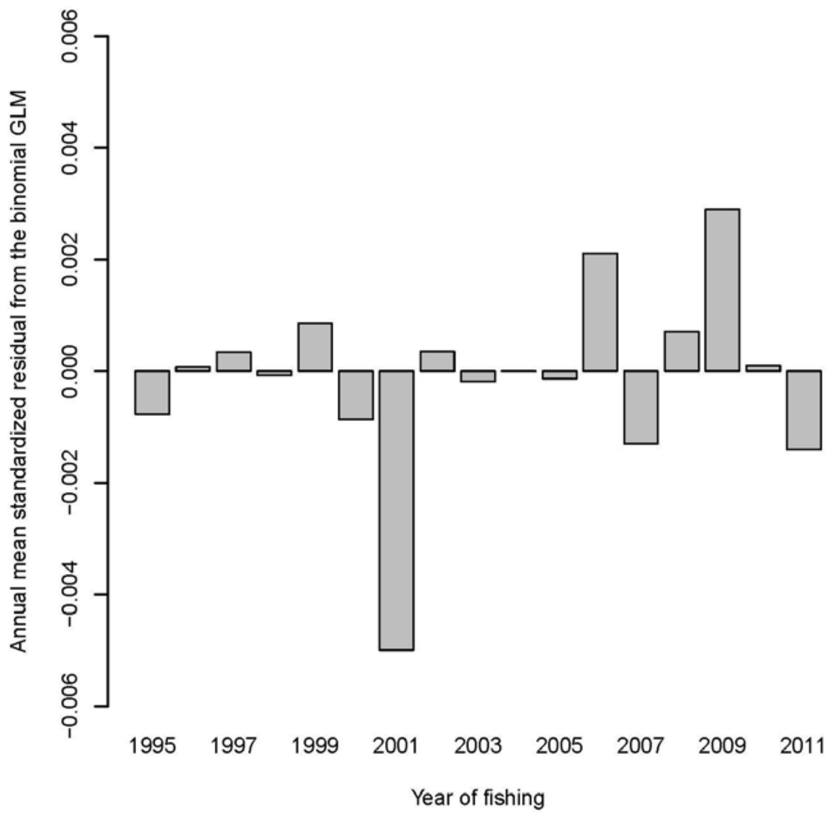



Figure A2. Plots of mean standardized residuals on the values of the factor variables in the binomial GLM of the delta lognormal analysis for the deep-set sector from 1995 through 2011.



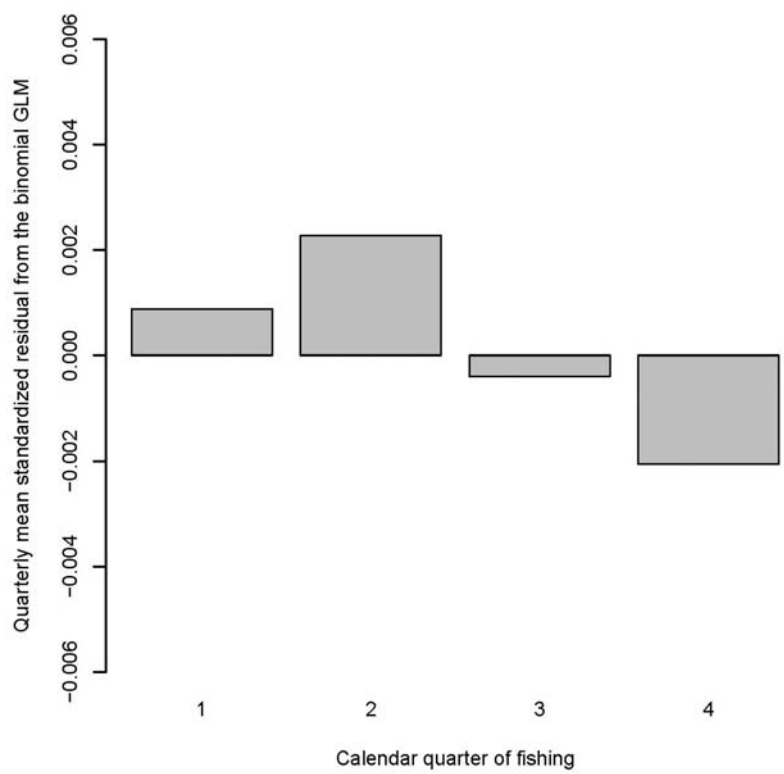
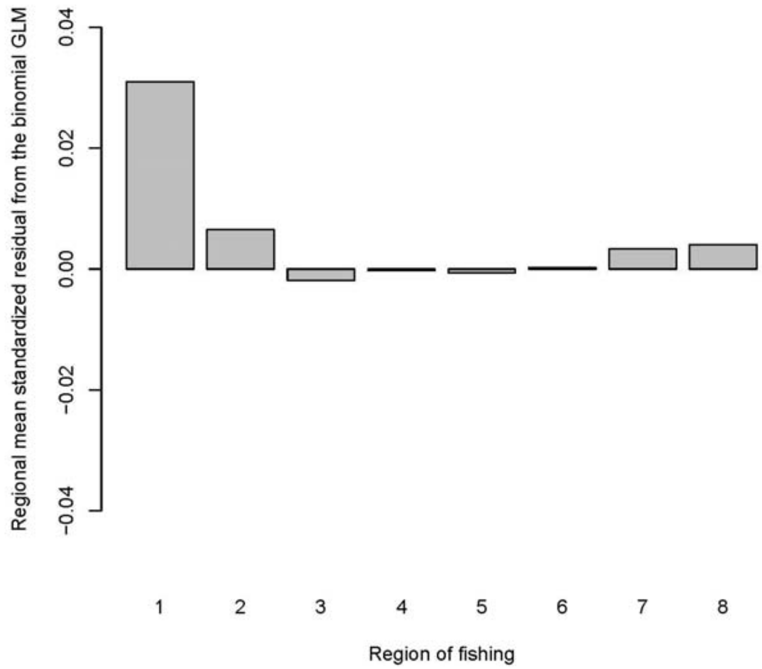



Figure A2, continued.



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 (≤ -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.

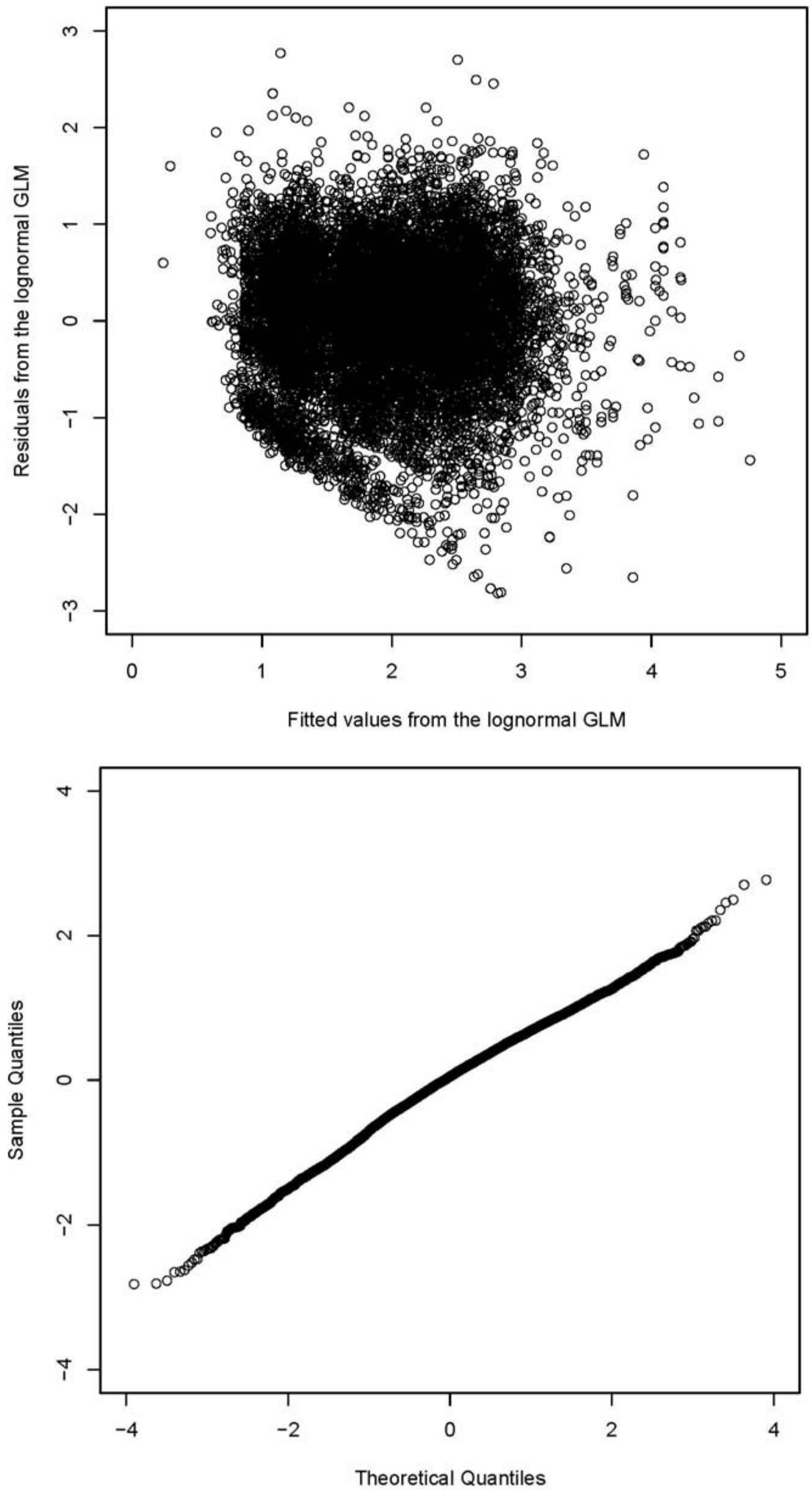
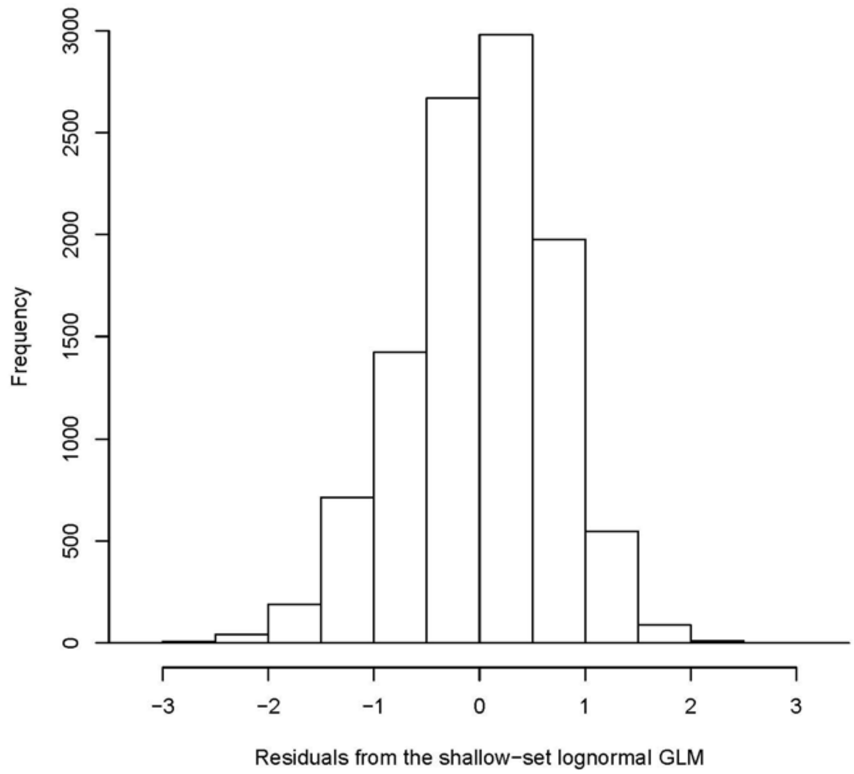


Figure A3, continued.



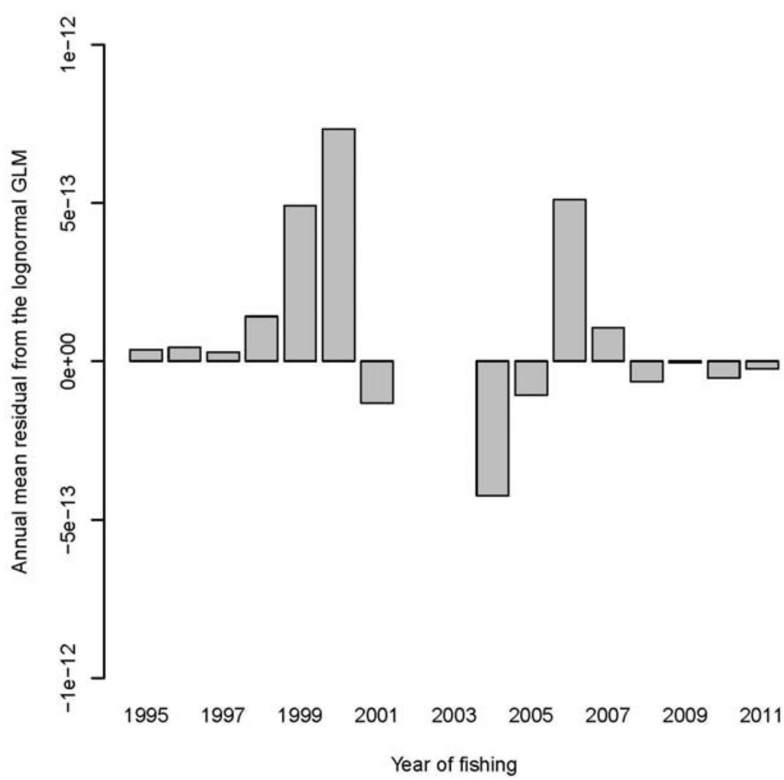
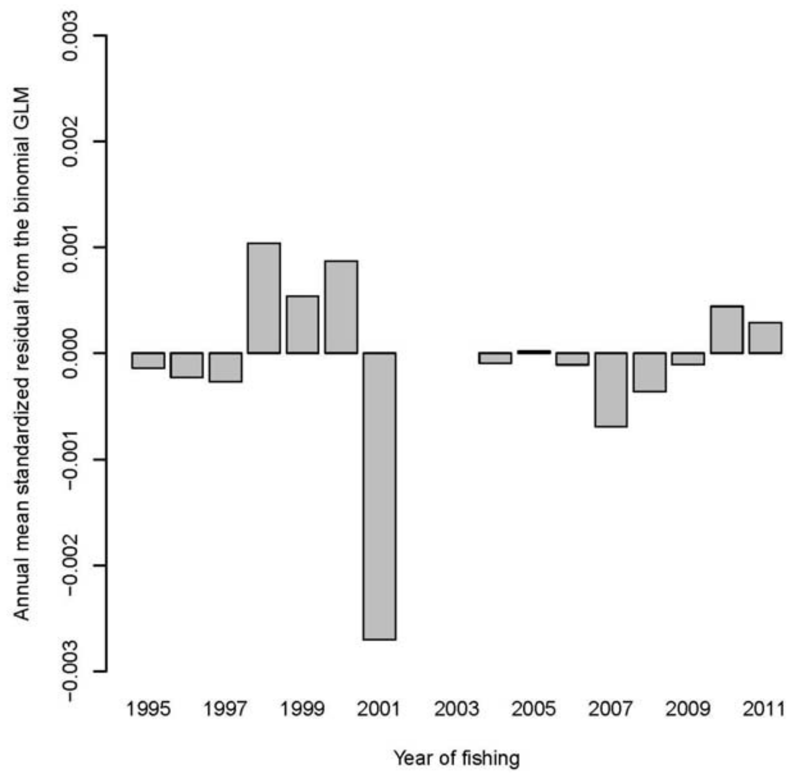



Figure A4. Plots of mean standardized residuals on the values of the factor variables in the binomial GLM of the delta lognormal analysis for the shallow-set sector from 1995 through 2011.



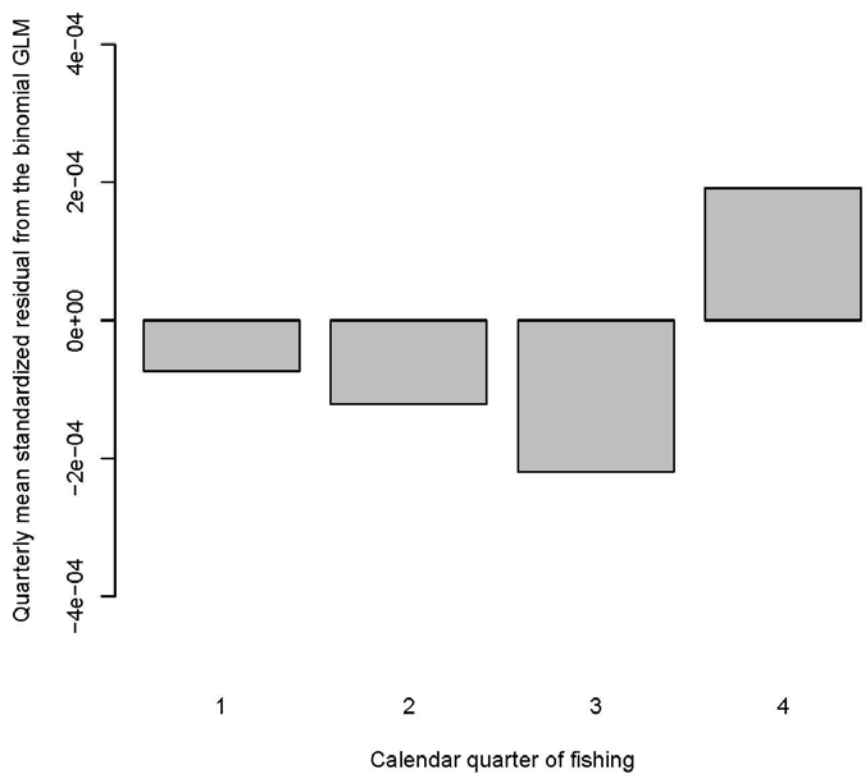
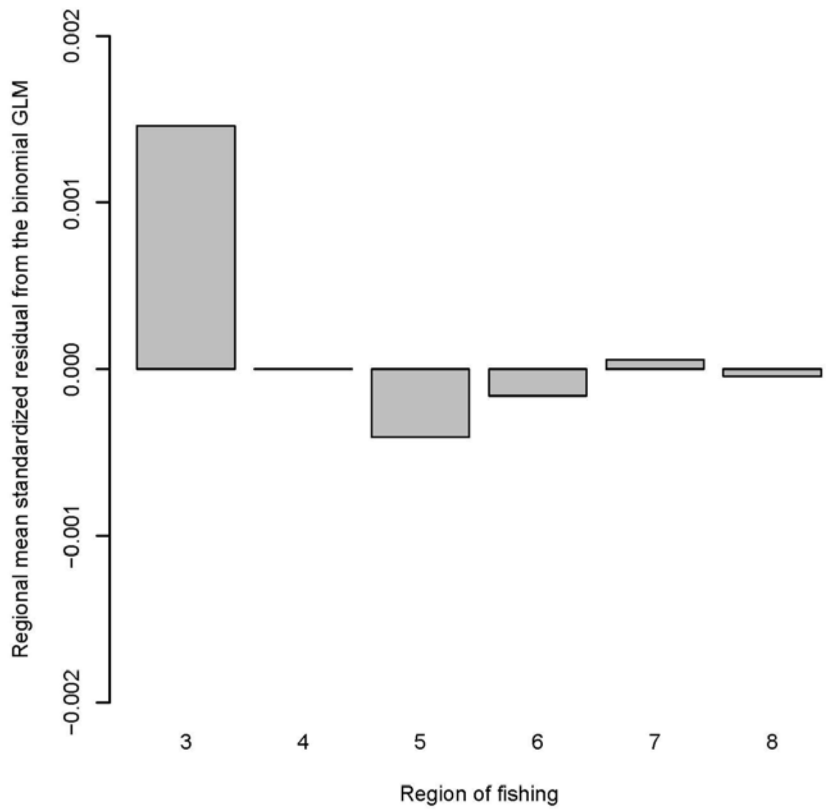



Figure A4, continued.



### 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., ≤ -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.