Ongoing and Planned Analyses of Catch and Catch Rate Data for Blue Shark *Prionace glauca* and Shortfin Mako *Isurus oxyrinchus* in the Hawaii-based Pelagic Longline Fishery: 1995–2010[1]

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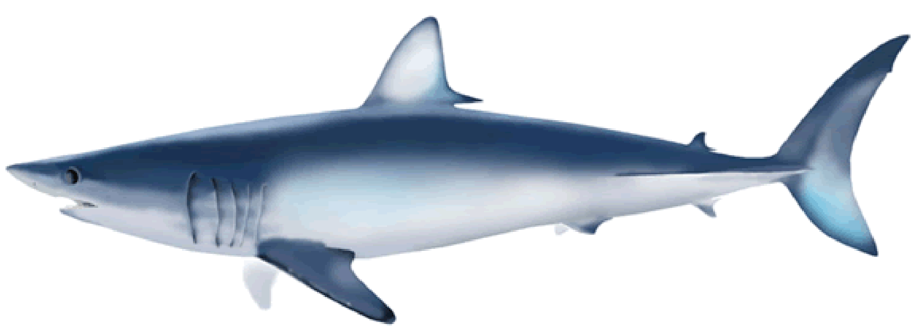

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Abstract

This working paper (WP) presents catch and catch per unit effort (CPUE) data and preliminary CPUE standardizations for blue shark *Prionace glauca* and shortfin mako *Isurus oxyrinchus* from the Hawaii-based pelagic longline fishery in 1995–2010. The data come from the records of the Pacific Islands Regional Observer Program (PIROP) and commercial logbooks submitted to the Pacific Islands Fisheries Science Center (PIFSC). This WP informs the Sharks Working Group of the International Scientific Committee (ISC-SWG) about the data available at the PIFSC, summarizes progress to date with these species, and outlines analytical procedures to be employed during this project. The project objective is to fit statistical models to data from pelagic longline fishery observers and then use the models to estimate fishery-wide catches and compute standardized CPUE time series for use in stock assessments. Results include a description of shark reporting patterns with an explanation of reporting bias, nominal catch statistics, summary analyses of deviance of generalized linear models (GLMs) fitted to observer data and standardized CPUE plots. Nominal CPUE for blue shark decreased between 1995 and 2010, while the percentage of zero blue shark catches increased in the deep-set sector. In contrast, shortfin mako nominal CPUE in 2004–2010 was more than double that in 1995–2001, which correspond to the periods separated by the shallow-set sector closure. A standardized CPUE plot with blue shark indicated that the standardized trend was less variable than the nominal. Regional effects associated with increased geographic expanse, and translocations of effort within both sectors of the fishery are expected to be important in the remaining analyses. Analytical concerns are outlined, and recent activities and their applicability to this project are described. Detailed standardized CPUE time series results and additional size and life history information should be available for April 2012.

Introduction

This working paper presents catch and catch per unit effort (CPUE) data and preliminary CPUE standardizations for blue shark *Prionace glauca* and shortfin mako *Isurus oxyrinchus* from the Hawaii-based pelagic longline fishery. The data were obtained from the records of the Pacific Islands Regional Observer Program (PIROP) and from commercial logbooks submitted to the Pacific Islands Fisheries Science Center (PIFSC).

Species of interest

Blue shark has long been the subject of quantitative research at the PIFSC**.** Publications include that of Walsh et al. (2002), who used PIROP fishery observer data to fit a generalized additive model (GAM) of blue shark catch rates in order to identify under-reporting in the logbooks and improve the accuracy of total catch estimates. Kleiber et al. (2009) presented a stock assessment for blue shark in the North Pacific for 1971–2002, and concluded that the population was near MSY. Walsh et al. (2009) described the longline shark catch using PIROP observer data, reporting that blue shark comprised 84.5% of the total shark catch.

Shortfin mako is currently of interest in this fishery as the only common shark species with higher catch rates in 2004–2006 than in 1995–2000 (Walsh et al. (2009)), having increased by 389.3% in nominal CPUE in the shallow-set sector. At present, nothing is known about whether this reflected a change in abundance or the influence of one or more operational factors. In addition to interest in its possibly increased abundance, shortfin mako is ecologically important as an apex predator and commercially valuable in Hawaii where it is sold as fresh steaks.

Background

An underlying complexity for this project, as summarized in Walsh et al. (2009), is that several regulatory actions during the last decade may have affected shark catches and catch rates. These included a prohibition on shark finning under most circumstances, a closure of the shallow-set sector of this fishery in response to excessive interaction rates with protected sea turtles, and re-location of fishing effort after the shallow-set closure and again after its re-opening.

Objectives

This working paper informs the Shark Working Group of the International Scientific Committee (ISC-SWG) about the data available at the PIFSC, progress to date with these species, and analytical procedures to be employed during the remainder of this project for the ISC-SWG. As such, methodological comments describe both completed and planned work.

The objectives of this project are to fit statistical models to data from Hawaii-based pelagic longline fishery observers. These models will be used to estimate fishery-wide catches and removals and to compute standardized CPUE time series for use in stock assessments conducted under the auspices of the ISC-SWG.

Methods

Present study

Data were obtained from the PIFSC ORACLE archive. All observer data and logbooks came from Hawaii-based longline trips conducted for commercial purposes.

Blue shark and shortfin mako catch, CPUE (in number of sharks per 1000 hooks) and releases data as reported by fishery observers and in logbooks from 1998–2010 were tabulated to document reporting patterns. A definitive comparison will be developed for 1995–2010, but a data problem at the PIFSC currently limits this summary to 13 years in duration.

The nominal annual mean catches per set, CPUE, CPUE on sets with positive catch, and annual percentages of zero catches were plotted for both species. These results are organized by fishery sector (see below).

PIROP observer catch data were used to fit generalized linear models (GLMs) of blue shark and shortfin mako CPUE by the delta-lognormal method. The factor variables were time, as haul year and half-year (October–March; April–October) for blue shark and haul year and haul quarter for shortfin mako, fishing regions[1] and set type (i.e., deep or shallow). Eight regions were defined by 10° latitudinal increments and a longitudinal separation at 160°W. Half-year was used as an explanatory variable for blue shark rather than haul quarter on the basis of exploratory results (see Completed Blue Shark Analyses, below). The set types correspond to the two sectors of this fishery, with deep sets using ≥15 hooks per float whereas shallow sets use <15 hooks per float. In addition, gear is typically deployed near dawn on deep sets but near dusk on shallow sets, and the number of hooks used on deep sets is approximately double that on shallow sets. SST effects were expressed as a continuous third-order polynomial. GLM results are presented in summary analysis of deviance tables. Effects of standardization for blue shark were illustrated by using the models to predict CPUE over time under specific conditions (i.e. at the mean SST, within sectors and regions) as in Maunder and Punt (2004).

Future work

Analyses will commence by fitting GLMs for use in detecting bias in self-reported logbook data from unobserved trips. This differs from a previous study of blue shark (Walsh et al. 2002) in which overdispersed Poisson GAMs were used for this purpose. Corrected data will then be used to predict catches and fishery-wide removals by applying the GLM coefficients. The GLMs will also be used to compute the standardized CPUE time series.

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[1] 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.

Shark sizes (fork lengths: FL) and assorted life history information (e.g., sex ratios, maturation, pupping) will be summarized from opportunistically collected data and notes from observers. These data will be examined for evidence of sexual or ontogenetic segregation.

Results

Reporting patterns

Table 1 summarizes blue shark and shortfin mako catch reporting by fishery observers and in commercial logbooks from 1998–2010. Reporting patterns were similar for both species. The catch rates and mean nominal CPUE reported by observers were greater than those from the logbooks of observed trips, and the values from the observed logbooks were greater in turn than the corresponding values from the unobserved logbooks (Figure 1). The principal reason is that released sharks are reported less frequently and less accurately in logbooks than by fishery observers, even in the presence of observers.

The difference between the numbers of blue sharks reported as released by observers and in logbooks from observed trips (24035) differed by 2.0% from the entire discrepancy between the two data sources (23547). The difference between the numbers of released shortfin makos as reported by the observers and in the logbooks from observed trips (706) was also 2.0% greater than the entire discrepancy between the two data sources (692). Both species were reported less frequently on unobserved trips than by either observers or in the logbooks from observed trips.

Patterns of observed fishing

A shift in effort occurred in both fishery sectors between 1995 and 2010. In 1995–2001, 17% of the shallow sets were deployed in Region 7 (above 30°N, east of 160°W) in the first quarter, and 35% were deployed in the third and fourth quarters. After the re-opening of the shallow-set sector, however, 90% of these sets were deployed at relatively high latitudes early in the year. Shallow sets in Region 7 in the first quarters of 2004–2010 comprised 41% of the total, with another 19% in Region 8 (above 30°N, east of 160°W). During the second quarters of 2004–2010, 17% of the shallow sets were deployed in Region 6 (20°N–30°N, west of 160°W) and 13% in Region 5 (20°N–30°N, east of 160°W). Only 13% of the shallow sets from 2004–2010 were deployed in the third and fourth quarters. The reason was that the season had been effectively shortened by limiting the total number of shallow sets per year.

Fishing in the deep-set sector began in 2000 in both Regions 1 and 7. The largest fraction of deep sets were deployed in Region 5 in 2005 and all years thereafter, whereas the largest number of sets were deployed in Region 4 in four prior years.

Nominal catch statistics

Blue shark nominal CPUE and catches per set as reported by PIROP observers are presented in Figure 2. Nominal CPUE in the shallow-set sector was greater than the catches per set because less than 1000 hooks are usually deployed on shallow sets. The CPUE on shallow sets with positive catch only exceeded the nominal CPUE by 3.3% (0.44 sharks/1000 hooks) because the there were 3.7% zero catches in the sector. Nominal CPUE was less than the catches per set in the deep-set sector because approximately 2000 hooks are usually deployed on deep sets.

Blue shark catches per set decreased on average by 3.25% per year, and nominal CPUE decreased by 0.83/1000 hooks (3.9% annually) between 1995 and 2010 in the shallow-set sector. There are no 2002 or 2003 shallow-set sector data because it was closed. The nominal CPUE trend in the deep-set sector corresponded to an average decrease of 4.8% per year.

Shortfin mako nominal CPUE and catch rates are presented in Figure 3. The annual mean nominal CPUE values in the shallow-set sector from 2004–2010 (0.64/1000 hooks–1.72/1000 hooks) were more than twice those from 1995–2001 (0.09/1000 hooks–0.28/1000 hooks). Nominal CPUE in the deep-set sector was lower and more stable than in the shallow-set sector.

The zero catches of both species (Figure 4) exhibited two features of interest. The first was the apparent trend of increasing zero catches (0.9% per year) for blue sharks in the deep-set sector. The second was the lower percentages of zero shortfin mako catches in 2004–2010 (40.0%–61.5%) than in 1995–2001 (82.3%–95.3%) in the shallow-set sector.

Catch rate standardizations

The blue shark delta-lognormal analysis (Table 2) revealed significant effects of four factor variables and SST, as indicated by reductions in the residual deviance and Akaike Information Criterion (AIC). The pseudo-coefficients of determination indicated that the lognormal model (pseudo-R^2=52.8%) fitted CPUE better than the binomial model explained the probability of positive catch (pseudo-R^2=17.7%). The deviance reductions per degree of freedom indicated that the set type, fishing regions and a non-linear effect of SST were the most important explanatory variables in both models. The temporal variables were least important.

The plot of standardized blue shark CPUE (Figure 5) revealed less variability than with nominal CPUE. The shallow-set standardized trend corresponded to an average decrease in blue shark of 4.2% per year.

The delta-lognormal analysis for shortfin mako (Table 3) demonstrated that the lognormal model explained a greater percentage of the null deviance of CPUE (pseudo-R^2 = 65.0%) than the binomial model did with the probability of catch (pseudo-R^2 = 19.4%), as was true of blue shark. The deviance reductions per degree of freedom indicated that the fishing regions, set type and haul quarter were the most important explanatory variables in both models. Thus, quarterly effects were more important than those of the haul years as a temporal explanatory variable. The principal differences between the two models were the non-significance of SST in the lognormal model and the greater importance of set type as an explanatory variable in the lognormal than in the binomial model.

Discussion

These GLM results represent an appropriate beginning to this project, but analytical questions remain. At present, the intention is to include interactions in the GLMs and to seek other significant explanatory variables.

The increase in shortfin mako catches per set in 2005, the continued high CPUE through 2010, and previously published observations indicate that catches in the shallow-set sector since the re-opening in 2004 must also be examined carefully. Walsh et al. (2009) reported that the sex ratio in the shallow-set fishery in 2004–2006 was significantly different from 1:1 with males more numerous. The mean size of females in the shallow-set sector during these years was also small (133 cm). Data and results from Region 7 in particular must be examined carefully.

Current Activities

Detailed analyses of PIROP catch and CPUE data for oceanic whitetip shark *Carcharhinus longimanus* and silky shark *C. falciformis* were begun in April 2011 at the Secretariat of the Pacific Community – Oceanic Fisheries Programme (SPC–OFP) in New Caledonia in collaboration with Dr. Shelley C. Clarke. The results include CPUE standardizations computed with six models (delta-lognormal, Poisson, quasi-Poisson, zero-inflated Poisson, negative binomial, zero-inflated negative binomial), and are intended for use in stock assessments to be conducted in 2012 under the auspices of the Western and Central Pacific Fisheries Commission (WCPFC).

A manuscript intended for peer-reviewed publication is in preparation. Dr. Jon K.T. Brodziak has expressed interest in applying model averaging techniques to the fitted GLMs and presenting the derivation and results in the paper.

Model averaging techniques may prove directly applicable to this project. Blue shark is by far the most numerous and wide-ranging of all sharks in this fishery (Walsh et al. 2009), with a complex life history that includes migrations and ontogenetic and sexual segregation (Nakano and Stevens 2008). Averaging results from several models should increase confidence in the stock assessment inputs and may aid in the interpretation of the effects of significant explanatory variables. Shortfin mako would be of particular interest as the only species with increasing catches and catch rates.

Completed Blue Shark Analyses

Blue shark catches and catch rates as reported by PIROP observers from 1995–2009 have been analyzed in detail. The intention is to complete the oceanic whitetip and silky sharks paper, and then return to complete blue shark analyses for 1995–2010.

The exploratory phase entailed fitting GAMs of blue shark catches using observer data. GAM results were then used to parameterize GLMs. Delta-lognormal CPUE standardizations and quasi-Poisson catch per set standardizations were computed. Zero catches were analyzed for their spatial distributions.

Analytical Concerns

The major analytical concern will be under-reporting of both species. Checks on blue shark catches in particular can be tedious and time-consuming. The apparent under-reporting of shortfin mako on unobserved trips (Figure 1) must also be investigated to ascertain whether these sharks were not reported, were misidentified or were otherwise recorded incorrectly. These aspects must be dealt with in order to estimate fishery-wide removals.

Results to date have given no indications of unexpected, inordinate difficulties. Thus, it seems reasonable to expect analyses to proceed according to plans.

Conclusions

Blue shark and shortfin mako analyses have used and will continue to use fishery observer data and will be conducted according to published methodology.

Reporting of both species in logbooks, particularly those from unobserved trips, is negatively biased in this fishery. Under-reporting of released sharks is probably the major source of logbook inaccuracy and must be assessed carefully. Estimates of minimum mortality caused by capture and handling stress have been published (Walsh et al. 2009), so mortality estimates for released sharks could be available for the stock assessments if released sharks from unobserved trips could be estimated.

The principal features of the nominal catch statistics were the apparent decrease of blue shark CPUE, accompanied by an increase in zero catches in the deep-set sector, and the increase in shortfin mako CPUE after the re-opening of the shallow-set sector. In both cases, the changes occurred while the geographic expanse of the waters exploited by the fishery increased. Regional effects must be examined in detail to improve the GLMs, and it may be necessary to include interaction terms (e.g., Haul Year × Region; Haul Quarter × Region; Region × Set type).

The delta-lognormal analyses revealed significant effects of several explanatory variables, but the binomial models in particular did not explain high percentages of the probability of positive catch for these species. Attempts to find other significant covariates are necessary.

Standardized CPUE plots in both sectors under specified conditions were more stable than the nominal CPUE for both species. This indicated that standardization removed some variability attributable to the explanatory variables.

The upward trend in zero catches for blue shark in the deep-set sector and the large change in the percentage of zero shortfin mako catches in the shallow-set sector suggest that use of zero-inflated models may be appropriate. Procedures developed with oceanic whitetip and silky sharks are directly applicable in this context. Statistical research to be conducted by Dr. Brodziak in the near future may enhance these capabilities considerably.

Detailed CPUE standardization results, preliminary estimates of fishery-wide catches and removals, preliminary analyses of size measurements and compilations of life history observations for both species by sectors in 1995–2010 should be available for April 2012.

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Acknowledgments

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Table 1. Summary of reported effort, catch and discarding for blue shark *Prionace glauca* and shortfin mako *Isurus oxyrinchus* taken by the Hawaii-based pelagic longline fishery in 1998−2010.

Species	Source	Effort (Sets)	Sets with catch	Catch	Mean catch/set	Mean nominal CPUE	Sets with discards	Discards
Blue shark	Observer	45507	40228 (88.4%)	241676	5.31	3.94	39471 (86.7%)	232110 (5.88/set)
	Logbook (Observed)	45507	35560 (78.1%)	218129	4.79	3.63	34372 (75.5%)	208075 (6.05/set)
	Logbook (Unobserved)	158732	113363 (71.4%)	568744	3.58	2.47	94154 (59.3%)	440014 (4.67/set)
Shortfin mako	Observer	45507	8583 (18.9%)	11931	0.26	0.22	6150 (13.5%)	8739 (0.19/set)
	Logbook (Observed)	45507	7754 (17.0%)	11239	0.25	0.20	5190 (11.4%)	8033 (0.18/set)
	Logbook (Unobserved)	158732	15504 (9.8%)	20086	0.13	0.07	5934 (3.7%)	8403 (0.05/set)

Table 2. Summary of a delta-lognormal GLM analysis of blue shark catch rates fitted by forward entry. Data were reported by fishery observers from 1995–2010. The upper section presents the binomial model (probability of positive catch); the lower section presents the lognormal model (CPUE on sets with positive catch). The null deviance, pseudocoefficient of determination and sample size follow each model summary.

Parameter	Df	Residual Deviance	Deviance Reduction	Deviance reduction per df	Percent reduction of null deviance	AIC & ΔAIC	Median residual
Intercept	1	33620.07	----	----	----	33622.07	0.4379
Haul year	15	32881.98	738.09	49.21	2.20%	32913.98; -708.09	0.4413
Haul half-year	1	32802.37	79.61	79.61	0.24%	32836.37; -77.61	0.4422
Fishing region	7	30296.24	2506.13	358.02	7.45%	30344.24; -2492.13	0.4087
Set type	1	28591.18	1705.06	1705.06	5.07%	28641.18; -1703.06	0.3914
SST (cubic)	3	27656.43	934.75	311.58	2.78%	27712.43; -928.75	0.3780

Binomial GLM null deviance= 33620.07. Explanation of null deviance: 17.7%. *N*=44,969.

Parameter	Df	Residual Deviance	Deviance Reduction	Deviance reduction per df	Percent reduction of null deviance	AIC & ΔAIC	Median residual
Intercept	1	47853.86	----	----	----	120364.9	-0.0716
Haul year	15	45094.85	2759.01	183.93	5.77%	118029.1; -2335.8	-0.0547
Haul half-year	1	44026.35	1068.50	1068.5	2.23%	117075.8; -953.3	-0.0359
Fishing region	7	33898.05	10128.30	1446.9	21.17%	106674.6; -10401.2	0.0366
Set type	1	26231.61	7666.44	7666.44	16.02%	96462.22; -10212.4	0.0202
SST (cubic)	3	22590.19	3641.42	1213.81	7.61%	90514.3; -5947.92	0.0402

Lognormal GLM null deviance= 47853.86. Explanation of null deviance: 52.8%. *N*=39839.

Table 3. Summary of a delta-lognormal GLM analysis of shortfin mako catch rates fitted by forward entry. Data were reported by fishery observers from 1995–2010. The upper section presents the binomial model (probability of positive catch); the lower section presents the lognormal model (CPUE on sets with positive catch). The null deviance, pseudocoefficient of determination and sample size follow each model summary.

Parameter	Df	Residual Deviance	Deviance Reduction	Deviance reduction per df	Percent reduction of null deviance	AIC & ΔAIC	Median residual
Intercept	1	47605.45	----	----	----	47607.45	-0.6618
Haul year	15	46294.72	1310.73	87.38	2.75%	46326.72; -1280.73	-0.5327
Haul quarter	3	44400.81	1893.91	631.30	3.98%	44438.81; -1887.91	-0.5584
Fishing region	7	39828.69	4572.12	653.16	9.60%	39880.69; -4558.12	-0.4790
Set type	1	38740.59	1088.10	1088.1	2.29%	38794.59; -1086.1	-0.4872
SST (cubic)	3	38381.95	358.64	119.55	0.75%	38441.95; -352.64	-0.4743

Binomial GLM null deviance= 47607.45. Explanation of null deviance: 19.4%. *N*=44,969.

Parameter	Df	Residual Deviance	Deviance Reduction	Deviance reduction per df	Percent reduction of null deviance	AIC & ΔAIC	Median residual
Intercept	1	4142.98	----	----	----	18064.33	-0.00525
Haul year	15	3851.33	291.65	19.44	7.04%	17470.79; -593.54	-0.02526
Haul quarter	3	3423.48	427.85	142.62	10.33%	16470.86; -999.93	-0.06835
Fishing region	7	2313.44	1110.43	158.63	26.80%	13135.61; -3335.25	-0.07123
Set type	1	1449.20	863.85	863.85	20.85%	9143.77; -3991.84	-0.10330

Lognormal GLM null deviance=4142.98. Explanation of null deviance: 65.0%. *N*=8542.

Figure 1. Annual mean blue shark (upper) and shortfin mako (lower) catches per set as reported by fishery observers and in logbooks from both observed and unobserved fishing trips. Note the 25:1 ratio of the response scales.

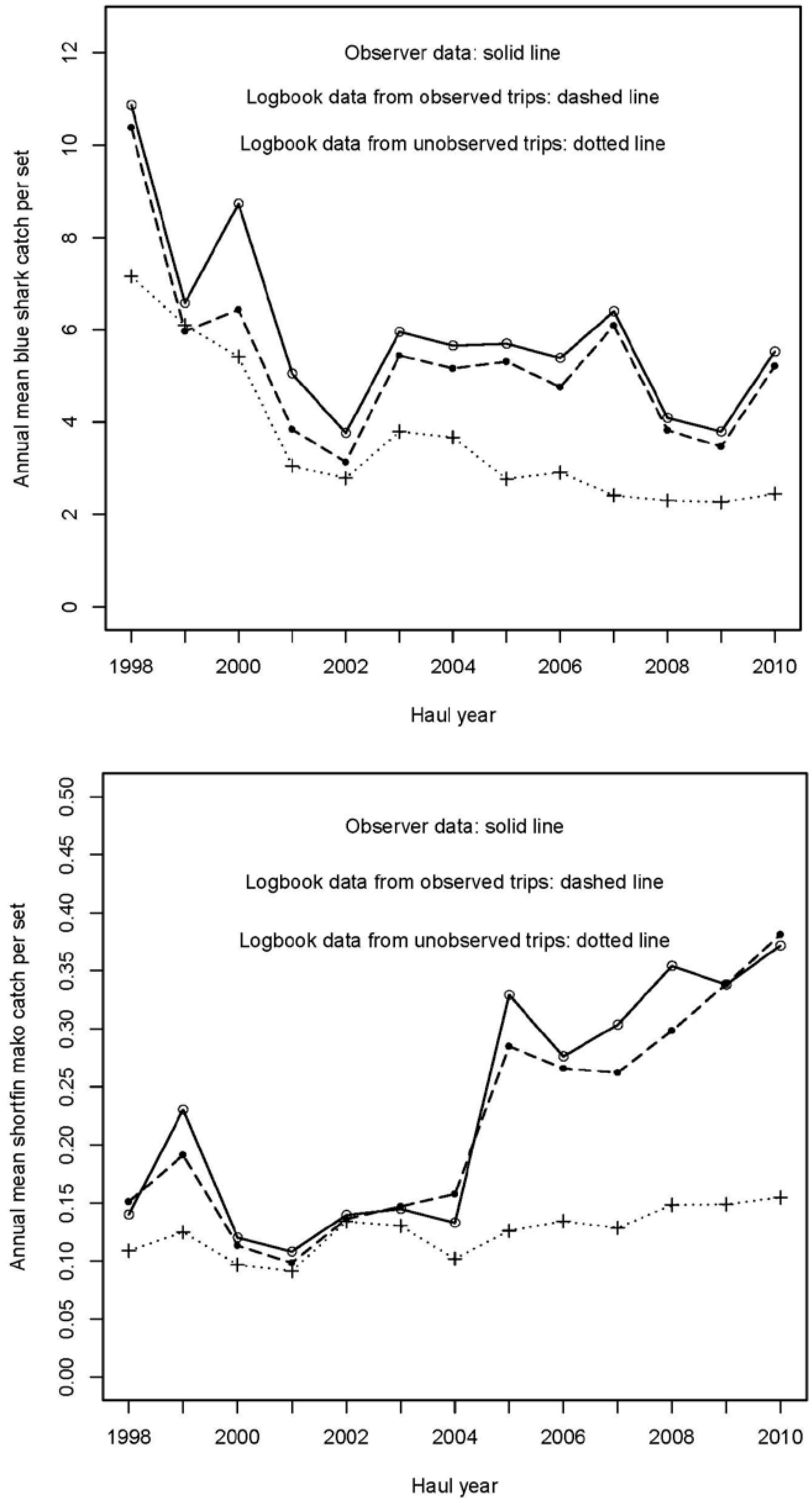
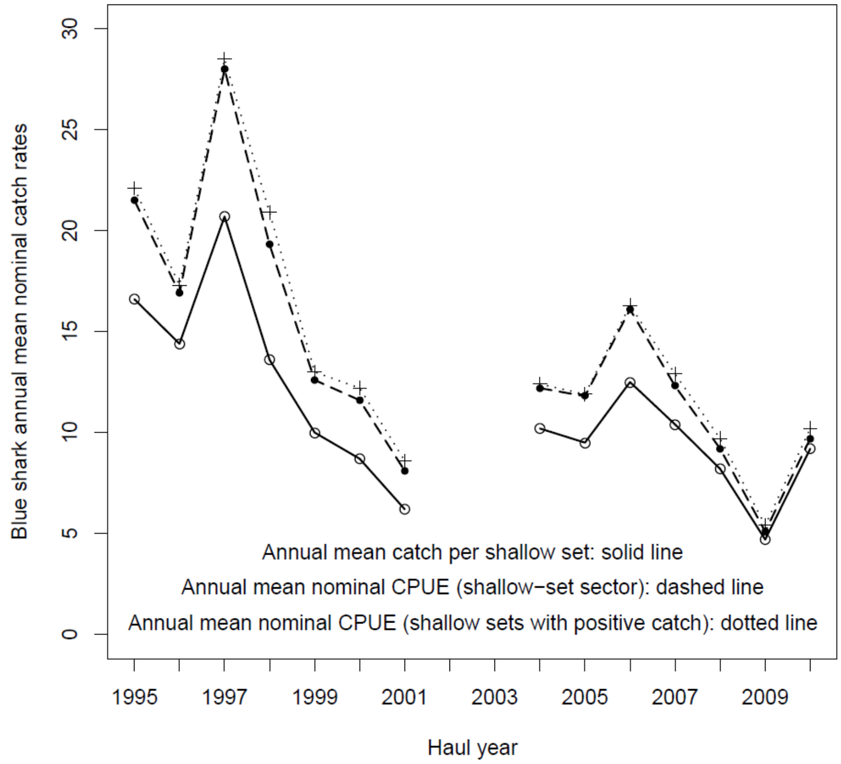


Figure 2. Annual mean blue shark catches per set, nominal CPUE and nominal CPUE on sets with positive catch from the shallow-set (upper) and deep-set (lower) sectors of the Hawaii-based pelagic longline fishery in 1995–2010. Note the 3:1 ratio of the response scales.



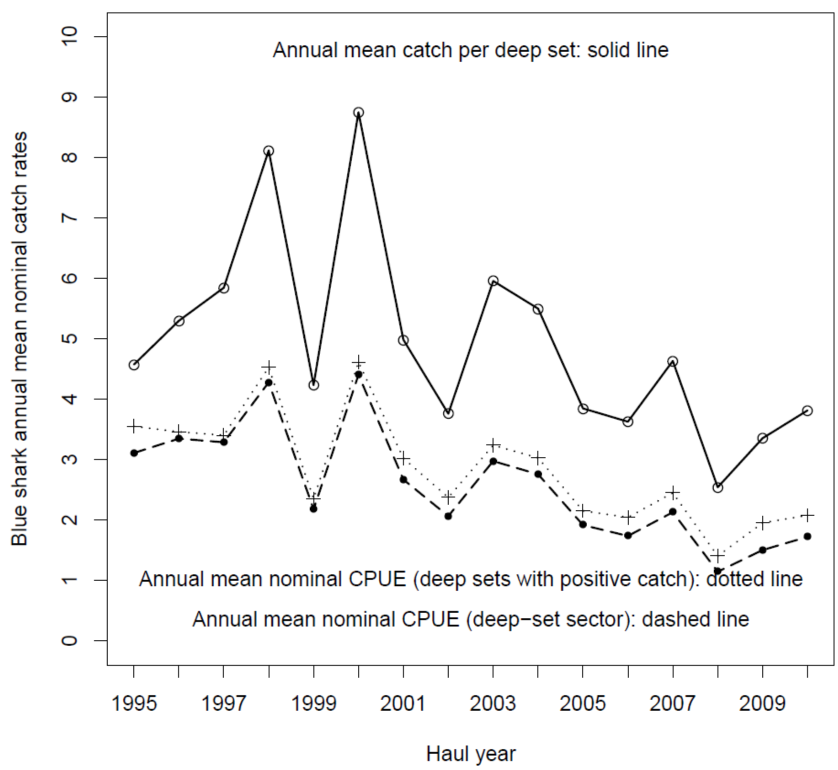


Figure 3. Annual mean shortfin mako catches per set, nominal CPUE and nominal CPUE on sets with positive catch from the shallow-set (upper) and deep-set (lower) sectors of the Hawaii-based pelagic longline fishery in 1995–2010. Note the 3:1 ratio of the response scales.

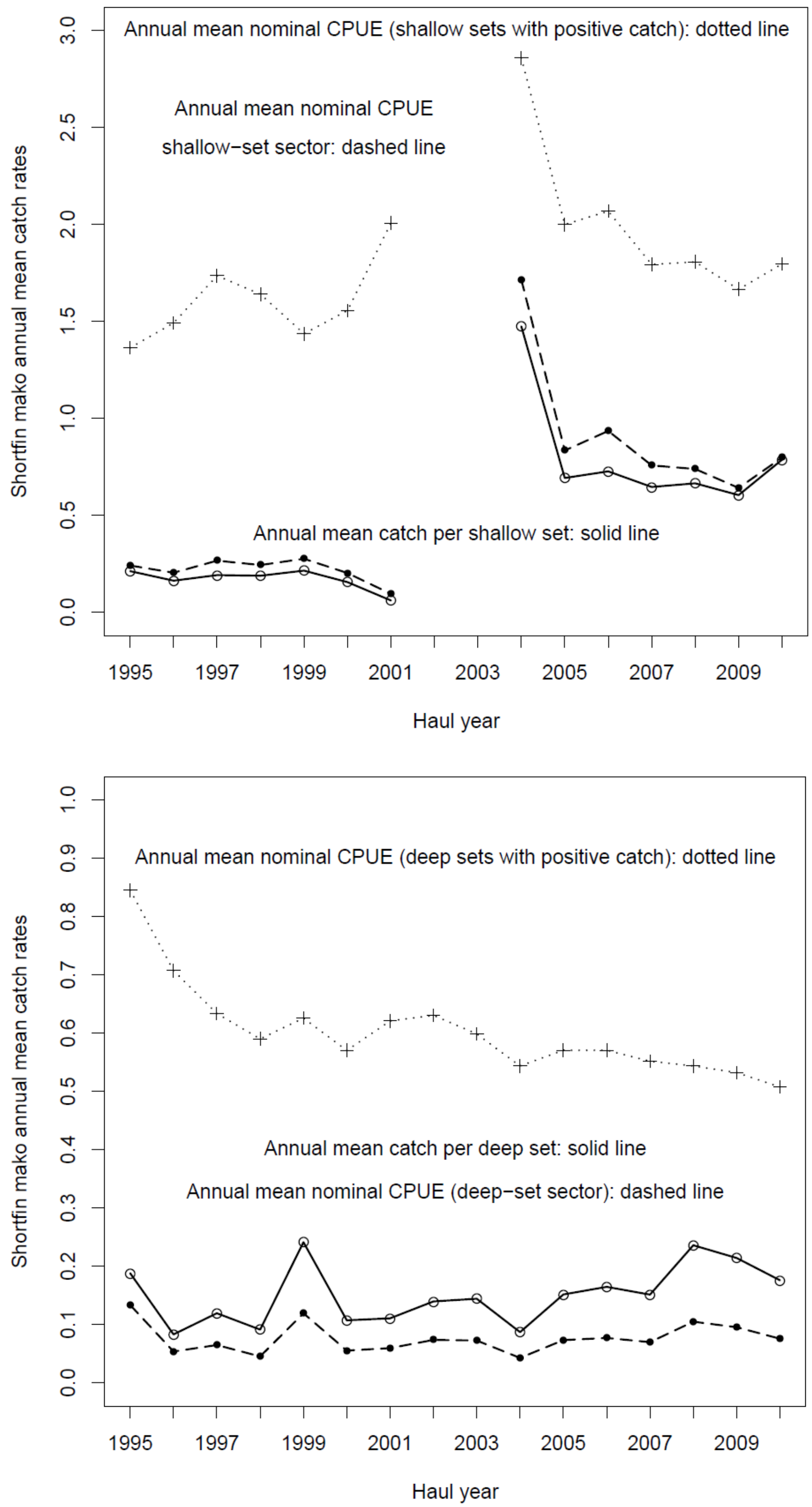


Figure 4. Annual percentages of zero catches of blue sharks and shortfin makos in the deep- and shallow-set sectors of the Hawaii-based pelagic longline fishery in 1995–2010.

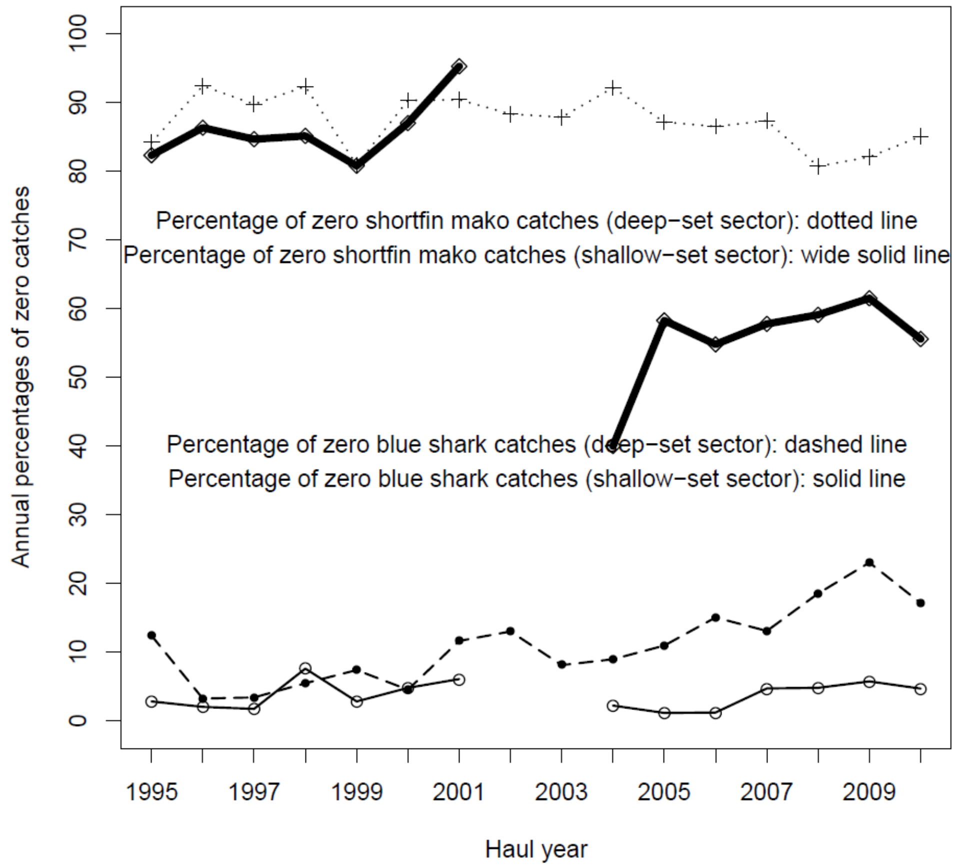


Figure 5. Standardized (solid line) and nominal (dashed line) CPUE for blue shark in the shallow-set sector of the Hawaii-based pelagic longline fishery in 1995–2010.