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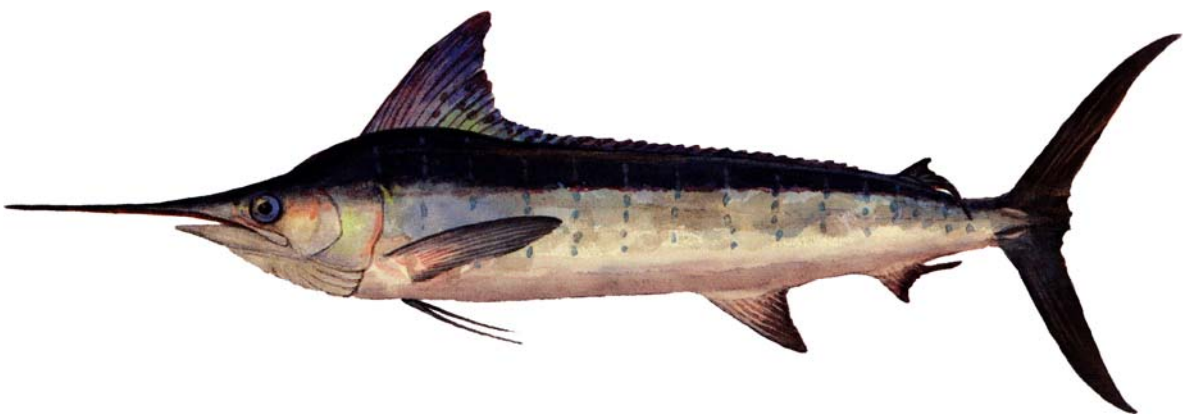

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National Marine Fisheries Service
National Oceanic and Atmospheric Administration
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Corrected Catch Histories and Logbook Accuracy for Billfishes (Istiophoridae) in the Hawaii-based Longline Fishery

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ABSTRACT

This paper presents corrected catch histories, standardized catch rates, and evaluations of the accuracy of federally mandated commercial logbooks for billfishes (Istiophoridae: blue marlin, *Makaira nigricans;* striped marlin, *Tetrapturus audax;* shortbill spearfish, *T. angustirostris*; black marlin, *M. indica*; and sailfish, *Istiophorus platypterus*) taken as incidental catch by the Hawaii-based longline fishery. The study (March 1994–February 2004) was conducted because billfish misidentifications in logbooks caused by similarities in body size, shape, and coloration have long represented a major challenge in monitoring this fishery. The objective was to improve understanding of the composition and magnitude of incidental billfish catches. This paper represents a substantive expansion on an earlier, published analysis of blue marlin catch data by using a longer time series, including all of the istiophorid billfishes taken by this fishery, and providing estimates of standardized catch rates. Results generated by (1) fitting generalized additive models to fishery observer data, (2) applying the model coefficients to the corresponding predictor variables in logbook reports, and (3) comparing the logbook results to sales records documented that the nominal catch data for all species were significantly biased, with inflated estimates for blue marlin, black marlin, and sailfish and negatively biased totals for striped marlin and shortbill spearfish. Misidentifications were the principal cause of these biases, the most common being striped marlin logged as blue. Sailfish, and to a greater extent, black marlin, were rare in the incidental catch of this fishery. After correction of the data, striped marlin was shown to be the dominant species, in both numbers and biomass. Bycatch consisted primarily of small striped marlin and shortbill spearfish discarded at times of peak catches. Standardized catch rates for blue marlin, striped marlin, and shortbill spearfish appeared relatively stable during this short 10-year time series. We conclude that nominal catch data for billfishes can be highly biased as a result of mistakes by a small number of fishermen, even in a carefully monitored fishery, and that the techniques employed herein proved useful in identifying, characterizing, and correcting such bias. The corrected data will serve as the foundation for a research database intended for use in stock assessments and ecosystem-based research.

Key Words: Hawaii-based longline fishery; Istiophoridae; incidental catches; logbook accuracy; corrected catch histories; generalized additive models; standardized catch rates

CONTENTS

INTRODUCTION

A recent paper (Walsh et al., 2005) presented a corrected catch history for blue marlin, *Makaira nigricans*, from March 1994 through June 2002 in the Hawaii-based longline fishery, along with an analysis of the accuracy of federally mandated commercial logbooks. The results were obtained by fitting a statistical model to fishery observers' reports of incidental blue marlin catches, applying the model coefficients to predict catches on unobserved longline trips, and then using linear regression techniques and fish auction sales records to evaluate the accuracy of the logbooks and correct them as necessary. This paper extends the previous analyses to include the other billfishes (Istiophoridae: striped marlin, *Tetrapturus audax;* shortbill spearfish, *T. angustirostris*; black marlin, *M. indica*; and sailfish, *Istiophorus platypterus*) taken as incidental catch by this fishery from March 1994 through February 2004, along with updated results for blue marlin. By so doing, this paper contributes to an improved understanding of the species composition and magnitude of incidental billfish catches by the Hawaii-based longline fishery during the 10-year study period.

This and the preceding study were conducted because billfish misidentifications in commercial logbooks caused by superficial similarities in body size, shape, and coloration have long represented a major challenge in monitoring this longline fishery. The most common error found in the 1994–2002 study was striped marlin reported as blue, although other misidentifications were also documented (e.g., blue marlin reported as striped or black marlin; shortbill spearfish reported as blue, black or striped marlin) (Walsh et al., 2005). Moreover, reporting errors were not necessarily limited to a single type of misidentification; numerous trips were characterized by several types (e.g., shortbill spearfish reported as striped marlin, striped marlin reported as blue marlin, and blue marlin reported as black marlin) (Walsh et al., 2005). Results presented herein address these complexities.

This paper also expands on the previous blue marlin analyses (Walsh et al., 2005) by presenting standardized catch rates for blue marlin, striped marlin, and shortbill spearfish. These estimates should aid stock assessment scientists at the National Oceanic and Atmospheric Administration (NOAA) Fisheries, Pacific Islands Fisheries Science Center (PIFSC)[1] in evaluating apparent intra- and interannual variation in relative abundance of this ecologically, economically, and recreationally important group of highly migratory fishes.

MATERIALS AND METHODS

Data Sources

This study uses data gathered during the first 10 years of the Pacific Islands Regional Observer Program (March 1994–February 2004). These data included species-specific catch tallies and operational (e.g., position, number of hooks deployed, set and haul times) descriptors

[1] This facility was the National Marine Fisheries Service Honolulu Laboratory until April 2003.

from each longline set (Pacific Islands Regional Office, 2003). Sea surface temperature (SST) data used in the analyses were weekly mean values measured by an advanced, very high resolution radiometer borne by a NOAA satellite. Because the observers receive specialized training at the outset of employment and undergo debriefings after trips, their records were expected to be generally accurate. Nonetheless, the observer data were screened to ensure accuracy by both the observer program and ourselves prior to use in model fitting. The full sample used to compute descriptive catch and effort statistics included 14,415 longline sets. This data set was truncated for the detailed analyses (see GAM Fitting Procedures, below).

Federally mandated commercial logbooks (National Marine Fisheries Service Western Pacific Daily Longline Fishing Logs) have been collected and archived in their original and electronic forms at the PIFSC since November 1990. A report (i.e., one logbook page) is required for each longline set, which normally corresponds to one fishing day. The reports provide species-specific tallies of the catch as well as several operational parameters that are also recorded by the observers, which provide a basis for comparison. The analyses presented herein used logbook reports from March 1994 to February 2004. The full sample used to compute descriptive statistics prior to truncating the data to permit the detailed analyses (see GAM Applications to Logbook Reports, below) was 110,612 longline sets.

Sales records (i.e., numbers sold by species and the weights of sold fish) from the public fish auction conducted by the United Fishing Agency, Ltd. (UFA), Honolulu, have been provided electronically to the Hawaii Division of Aquatic Resources (HDAR) since January 2000. The HDAR, in turn, provides these electronic data to the PIFSC through a data-sharing agreement. Prior to 2000, NMFS or HDAR biologists gathered these data at the auction twice weekly (out of 6 business days). Sales records were used to verify species identifications when errors were suspected in the logbook data, in which case the numbers of fish logged as kept on any particular trip were compared to those sold. It was not possible to check every trip from the auction sampling days (i.e., prior to 2000) because the work involved would have been prohibitive. When sales data were available, they were considered definitive for four reasons: the auction personnel are very experienced; price differences among species demand careful identifications; the presence of buyers represents a second check; and identification of fish is easier while on display than while working at sea. When auction sales records were unavailable (i.e., from business days prior to 2000, when PIFSC or HDAR biologists did not attend the auction), possible misidentifications were checked by comparing logbook records to Commercial Marine Dealer Reports submitted to the HDAR, which permitted evaluation and correction of some additional trips with questionable catch data.

General Statistical Tests

Billfish catches on observed longline sets were assessed with paired *t*-tests, using the one-sided alternative that the numbers of fish reported by observers would be greater than those in the corresponding logbook reports. Comparisons of observer data and similar data from unobserved trips were performed with two-sample *t*-tests. Interannual variation in fish weights was tested by one-way analyses of variance, computed within quarters to remove seasonal effects. The significance criterion for all tests was $P < 0.05$.

Generalized Additive Models

This study and its predecessor were based upon the use of generalized additive models (GAMs). A GAM can be expressed as:

$$\log(\mu) = \sum_{j=1}^{p} S_j\,(x_j\,, d_j), \tag{1}$$

where μ represents the conditional mean catch for the set of predictors ($x_1, x_2, \ldots, x_p$), S_j represents an unspecified smooth function, and d_j represents the degrees of freedom of the smoother. Detailed discussions of generalized additive models (GAM) theory and methodology were presented by Hastie (1992), Venables and Ripley (1994), and Schimek and Turlach (2000).

GAM Fitting Procedures

GAMs were fitted to catch data from fishery observers according to general procedures previously used with blue shark, *Prionace glauca* (Walsh and Kleiber 2001; Walsh et al., 2002) and blue marlin (Walsh et al., 2005; Walsh et al., 2006). Each GAM was fitted as a robust Poisson model, with catch (i.e., number caught per longline set) as the response variable. The fitting algorithm employed spline smoothers. Operational and environmental variables (the date of fishing (mo/yr), sea surface temperature (SST), latitude, longitude, hooks deployed, begin-set time and vessel length) were the predictors. Reductions in the Akaike Information Criterion (AIC) and residual deviance were used to determine the order of entry for the predictors, while F-tests were used as the significance criterion ($P < 0.05$), and smoother plots with a standardized y-axis were used to depict predictor effects. These and all other statistical procedures were conducted in S-Plus Version 6.1.2 (Insightful Corp., 2002). The allocation of degrees of freedom to predictors in each GAM was intended to facilitate interspecific comparisons and to avoid bias caused by overparameterization (Walsh et al., 2006). Because the date, SST°, and latitudinal effects were our principal interests, graphical output in the text emphasizes these variables; detailed results from the GAMs are provided in Appendix A.

GAMs for blue marlin, striped marlin, and shortbill spearfish were fitted to data from 13,737 longline sets, which represented 95.5% of the observed effort during the study period. The remainder consisted of longline sets with missing predictor values (3.2%), high influences (0.4%), or previously documented misidentifications by observers (0.9%). GAMs were not fitted for sailfish and black marlin because the annual catches were very low (see Evaluation of Logbook Reports of Black Marlin and Sailfish Catches, below).

GAM Applications to Logbook Reports

The coefficients from the GAMs for blue marlin, striped marlin, and shortbill spearfish were applied to 103,745 unobserved longline sets with the ‘predict.gam’ function in S-Plus. This sample size represented 93.6% of unobserved fleet-wide effort during the study period. Longline sets with predictor values outside the observer data ranges or with missing predictor variables (7066) were not included in this application.

The correspondence between reported and predicted catches for these three species was assessed by transforming both variables to $\log_e X{+}1$ and then computing the regression of the former variable on the latter (Walsh et al., 2002; Walsh et al., 2005). The studentized residuals (SR) (Cook and Weisberg 1982; Draper and Smith 1981; Hoaglin et al. 1983) were used to identify possible outliers; "large" values were considered to be SR ≥ |2|. Fishing trips with two or more sets with SR ≥ |2| or any with SR ≥ |3| were checked against auction records or monthly sales receipts (if available) to identify possible misidentifications. When sales data confirmed misidentifications, the catch composition was corrected accordingly (see Correction Procedures, below). The log-log regression of reported catches on predicted catches was then re-computed with the corrected data, to represent an estimate of "optimal" reporting accuracy.

Evaluation of Logbook Reports of Black Marlin and Sailfish Catches

Black marlin and sailfish were known to comprise very small fractions of the catch of this fishery (personal communication, K.E. Kawamoto, NOAA Fisheries, PIFSC). Therefore, these species were checked directly against auction records or monthly sales receipts. All fishing trips with reports of multiple catches of these species were checked. Vessels with five or more trips with confirmed multiple misidentifications were rechecked for all reported catches of these species, including individual fish. There were no attempts to check reports of individual catches of these fishes in the absence of such patterns of error.

Correction Procedures

Logbook catch data were corrected after checking both the electronic data and the original logbook forms to approximate the sales data as closely as possible. In those instances when one (or more) species from a trip was (were) completely misidentified (e.g., all striped marlin reported as blue, or all blue marlin reported as black), all fish in question were reclassified. When the catch included both correctly identified and misidentified fishes, the minimum numbers necessary to equal the number sold for each species were corrected. For example, if the logbook listed 20 striped marlin caught and kept on a trip, but the UFA data listed sales of 5 striped marlin and 5 shortbill spearfish, the logbook would have been corrected to 15 striped marlin and 5 shortbill spearfish caught and kept, despite the indication that the catch contained approximately equal numbers of the 2 species.

The corrected catches and quarterly mean weights are presented in Appendix B. This interval corresponds to that used in stock assessments at the PIFSC.

Standardized Catch Rates

Standardized catch rates were computed from fishing activity that targeted bigeye tuna, *Thunnus obesus*, (N = 11,438 observed longline sets) because this represented the longest, relatively homogeneous time series. This subset of the observer data was identified on the basis of inquiries directed by the observers to captains regarding their target species. After setting all predictors except the date to their mean values for this type of fishing, standardized rates were obtained by applying the GAM coefficients with the 'predict.gam' function in S-Plus. The mean standardized rates for the three major species were then regressed on years by quarter to assess temporal trends. The regressions were computed by quarter to remove seasonal variation.

RESULTS

Observer Coverage and Fishing Effort

The levels of observer coverage and the pattern of observer allocation changed considerably between March 1994 and February 2004 (Table 1). The former increased from 4.7% of fleet-wide effort in 1995, the first full year of the study in which 40.9% of the active vessels carried an observer at least once, to 21.7% in 2003, when 95.5% of the vessels carried an observer at least once and 82.7% twice or more. The mean observer coverage rate throughout the study was 11.5%. The initial allocation pattern in 1994 emphasized coverage of swordfish trips because high interaction rates with sea turtles were expected. As of 1995, however, observer allocation was altered to approximate fleet-wide activity more closely. By 2002 and thereafter, all observed trips targeted bigeye tuna.

The average annual effort of the Hawaii-based longline fleet was 12,503 longline sets deployed during 1,123 trips by 110 vessels (Table 1). A substantial fraction (16.3%) was located north of 30°N in 1994. By 2003, however, only 4.5% of the longline sets were deployed at these latitudes (Fig. 1[2]). This geographic shift reflected a series of management decisions. Specifically, swordfish-targeted effort by this fishery was prohibited in April 2001 so as to minimize interactions between longline gear and threatened or endangered sea turtles. This caused a southward shift in effort away from areas where surface waters had previously been fished for swordfish, *Xiphias gladius*, to subsurface depths as the fleet began to target bigeye tuna almost exclusively. In addition to this change in locale, observed trips that targeted bigeye tuna were also characterized by a 60.4% increase in hook numbers per set between March 1994 and February 2004.

The fleet deployed nearly 30 million hooks within the region bounded by 0°–35°N latitude and 128°–175°W longitude in 2003, with effort concentrated to the west and southwest of the main Hawaiian Islands in the first half of the year, and to the east and northeast in the second. In general, this fleet moves seasonally to remain near the 26°C SST isotherm to target bigeye tuna (personal communication, W.A.E. Machado, NOAA Fisheries, PIFSC).

Nominal Catch Statistics

Black Marlin and Sailfish

Logbook reports of black marlin catches (Table 2) were highly inflated (*N* = 5,778). Direct checks with sales data revealed that 83.8% of these fish were misidentified. An additional

[2] The map presents nonconfidential data; i.e., at least three vessels fished in the square during 2003.

4.4% were deemed misidentifications on the basis of circumstantial evidence (i.e., the logbook reports were submitted by vessels with previously documented patterns of misidentifications, but sales data were not available for the trips in question). Despite these corrections, the remaining total for the study period (N = 686 black marlin) probably remained highly inflated. A lack of sales data from 1994 and 1995 precluded checks on 46.9% of the remaining black marlin reported.

Logbook reports of sailfish catches (N = 4,638) were also inflated, and the corrected sailfish catch total (N = 2,749) also appeared to be upwardly biased. The corrected logbook catch total from 1994 to 1999 was 36.0% less than the nominal. In 2000–2004, with complete sales data available, the corrected total was 53.1% less than the nominal. Observer data revealed that sailfish were usually taken by morning sets (mean begin-set time: 0710 h) in relatively warm waters (mean SST = 26.9°C). In addition, 21.3% of these sailfish were taken on sets that targeted yellowfin tuna, *T. albacares*, although only 3.9% of observed effort targeted this species.

Misidentifications of these species were heterogeneously distributed within the fleet. Logbook reports from 10 vessels listed 26.8% of the black marlin misidentifications; seven vessels submitted logbook reports with 21.1% of the sailfish misidentifications. Logbook reports from two vessels contained numerous misidentifications for both species.

Blue Marlin, Striped Marlin, and Shortbill Spearfish

Nominal blue marlin catches were upwardly biased by misidentifications, as indicated by a significant difference between the mean catch rates in the observer reports and the logbooks from the same observed sets (paired *t*-test; $P < 0.001$). Logbook reports from 18 observed trips listed at least 25 more blue marlin than the corresponding observer reports. The tendency toward misidentifications was even more pronounced in the unobserved catch data.

Catches of striped marlin and shortbill spearfish on observed trips conformed to the expected pattern (i.e., observed catch ≥ (observed) logbook catch) (Walsh, 2000). Higher catch rates on unobserved than observed trips reflected the relatively high observer allocation to swordfish-targeted and ‘mixed-species’ effort in 1994–1995 (Walsh et al., 2005).

Nominal catch-per-unit-effort (CPUE) data unexpectedly exhibited exact agreement between the observers and unobserved logbooks for striped marlin and close agreement for shortbill spearfish. This apparently reflected inaccurate reporting of hook numbers on unobserved tuna-targeted trips. The mean hook numbers in the paired observer and logbook reports agreed exactly (1757 hooks per set), but the logbooks from unobserved trips reported 6.6% fewer hooks than the observed mean, which was a highly significant difference (two-sample *t*-test; $P < 0.001$).

The nominal catches of the three major species (Fig. 2) exhibited both intra- and interannual variation. Blue marlin catch rates (Figure 2a) usually peaked in the late summer–early autumn. The mid-1997 peak included many small fish (Appendix B); the monthly mean weights in July–September (57.2 – 59.5 kg) were less than those from all other third quarters

(61.7–101.6 kg). Striped marlin (Fig. 2b) catch rates were generally highest in early-mid winter, especially in December 1995 (mean: 4.0 per set) and December 2003 (mean: 3.6 per set). These fish did not differ significantly in weight from those caught in the other fourth quarters (one-way analysis of variance: $P > 0.50$). These two Decembers had the highest monthly mean SST during the study period (1995: 25.9°C; 2003: 26.3°C; other years: 24.5–25.2°C). Shortbill spearfish catch rates (Fig. 2c) usually peaked in January or February followed by decline, but the high catch rates that began in the fourth quarter of 1998 continued through the third quarter of 1999. These included many small fish; the mean weights from both the first (13.0 kg) and second quarters of 1999 (12.2 kg) were significantly less than those from all other corresponding quarters (both analyses of variance: $P < 0.025$).

Generalized Additive Models (GAMs)

The GAMs for blue marlin, striped marlin, and shortbill spearfish (Table 3; Fig. 3) were fitted using seven predictors. Some were correlated, particularly SST and latitude ($r = -0.688$; df = 13,735; $P = 0$); others (e.g., hooks per set, begin-set time) were essentially proxy variables for the type of fishing. For example, tuna-directed sets ordinarily deployed about 2,000 hooks in the early morning, whereas sets targeting swordfish generally deployed about 800 hooks in the late afternoon. Vessel length was also related to the type of fishing; the mean lengths of vessels that targeted swordfish and tunas were 23.8 and 20.8 m, respectively.

All predictors yielded significant deviance reductions (all F-tests, $P < 10^{-4}$) and exhibited significant nonlinearity (all F-tests, $P < 10^{-3}$). The GAMs explained similar proportions of the deviances (0.361–0.395). Detailed GAM output (i.e., model fit plots and smoother traces with standard errors) is provided in Appendix A as Figures A1–A4.

The date of fishing (Fig. 3a), which represented seasonal changes in relative abundance, fleet activity, or both, was very significantly related to the catch rates of blue and striped marlin, yielding the largest deviance reductions and the second largest per degree of freedom. These temporal effects were expressed as oscillatory patterns, with blue and striped marlin generally attaining their respective maxima in late summer–early autumn and early winter. The relationship between the date of fishing and shortbill spearfish catch rates was also significant; its major feature was a pronounced dome-like curvature in 1998–1999 rather than a roughly even oscillation.

Sea surface temperature (SST) was also closely related to catch rates of the two marlin species. The SST smoother trace (Fig. 3b) for blue marlin suggested that relatively high catch rates would be expected from ca. 25°–30°C, whereas that for striped marlin was dome-shaped ca. 24°–27°C. The blue marlin trace exhibited a slight flattening ca. 27°C, while the striped marlin trace reached its maximum ca. 25°C. There was no obvious, strong relationship between SST and shortbill spearfish catch rates ca. 22°–28°C.

The latitude trace for blue marlin indicated that the incidental catch of this species north of ca. 20°N would be relatively low (Fig. 3c). Striped marlin catch rates appeared largely independent of latitude from approximately 22° to 28°N, with declines to the north and south. A large fraction (37.8%) of the observed shortbill spearfish catch was taken from 17° to 20°N.

The relationships between catch rates and the remaining predictors were generally consistent with expectations (Appendix A). Catch rates for blue and striped marlin increased from east to west, with a stronger trend in the former species, whereas shortbill spearfish catch rates appeared largely independent of longitude. The relationships between catch rates and hook numbers were generally positive. The effects of certain predictors were curved near their extremes. There were high blue marlin catch rates (1.6 per set) on longline sets deployed between 2200 h and 0500 h. This apparently reflected confounding of the begin-set time and the target species, which was not used as a predictor; 36.7% of the sets deployed between these hours targeted yellowfin tuna, *T. albacares*.

Application of GAM Coefficients to Logbook Data from Unobserved Trips

Catch data for blue marlin, striped marlin, and shortbill spearfish were edited and corrected after preliminary regression analyses (Table 4). In total, 8.1% of the unobserved sets were corrected, decreasing the catch estimates for blue marlin, black marlin, and sailfish and increasing those for striped marlin and shortbill spearfish. Nearly all (97.2%) of the corrections were necessitated by misidentifications. Among the corrected sets, 90.4%, 6.3%, and 1.9%, and 0.01% involved two, three, four, or all five species, respectively. The greatest fraction (40.2%) involved blue and striped marlin, with 88.0% decreasing numbers of the former species while increasing those of the latter. The other major types of corrections consisted of black marlin reclassified as blue (10.9%) or striped marlin (15.5%), and striped marlin reclassified as shortbill spearfish or vice versa (10.0%). Comparison of observer coverage and misidentification rates demonstrated that reporting accuracy improved over time. Misidentification rates (all species combined) were significantly, negatively correlated with annual observer coverage rates ($r = -0.604$; df = 9; $P < 0.05$).

The corrected data, as monthly means, are presented in Figure 4. The most obvious feature was the reduction in size of peaks in the nominal data (e.g., blue marlin in the autumn of 1995). The corrected catch composition (in numbers) (Table 5) conformed to the pattern: striped marlin > shortbill spearfish > blue marlin > sailfish > black marlin.

The percentages of large SR (4.4%–6.2%), used to identify possible outliers, approximated the expected 5%, but the preponderance (86.2%–96.5%) was positive in sign, rather than symmetrical, for each species. Prior experience with blue marlin (Walsh et al., 2005) demonstrated that large positive SR generally detected errors caused by misidentifications. Most of the large SR for striped marlin and shortbill spearfish, however, were associated with sets that yielded large catches and did not require correction; 67.7% and 59.9% exceeded the 90th percentile for striped marlin (4 per set) and shortbill spearfish (3 per set), respectively. Though relatively few, most of the large negative SR with striped marlin (59.8%) and shortbill spearfish (86.6%) revealed misidentifications as blue marlin during peak periods (striped marlin:

November–December 1995, November–December 2003; shortbill spearfish: December 1998–May 1999).

The regression analyses (Table 6) of the log-transformed catches and GAM predictions further demonstrated the effects of data correction. The test statistic, regression coefficient, and coefficient of determination were greater with the corrected than the uncorrected data for all three species. The variance about the regression decreased considerably with the corrected data for blue marlin and slightly for shortbill spearfish but increased with striped marlin. The reason for the latter was that many of the corrections entailed substituting positive values for zeroes (i.e., reassigning misidentified blue marlin as striped marlin).

Biomass of the three major species (tonnes) was estimated by multiplying the monthly catch totals by the monthly mean weights. In blue marlin, nominal data yielded an estimate of nearly 3,279 tonnes taken on unobserved sets from January 1995 through February 2004. The corrected data yielded an estimate of 2,659 tonnes. The nominal and corrected estimates for striped marlin were 3,234 and 3,616 tonnes, respectively. The shortbill spearfish biomass estimates differed by only 1.1% (nominal: 1,219 tonnes; corrected: 1,232 tonnes). The biomass pattern was striped marlin > blue marlin > shortbill spearfish > sailfish > black marlin.

Estimated Catches (Observed and Unobserved)

Table 7 presents combined (i.e., observed + unobserved) estimates of catches (numbers of fish) and apparent reporting bias for the three major species throughout the study period. The apparent bias in the nominal total (i.e., the percent difference between the nominal data and the observer total plus the GAM estimate) for blue marlin was 39.6%, caused by overreporting of blue marlin on both observed and unobserved sets. In both striped marlin and shortbill spearfish, the apparent bias was smaller and negative (striped marlin: - 5.1%; shortbill spearfish: - 13.5.

Bycatch

Bycatch, defined herein as billfishes caught but discarded at sea, rather than being landed for sale or personal use (U.S. Department of Commerce, 1996), was assessed with the observed sets. Observer reports indicated that 7.0% of the striped marlin catch were not kept; the logbooks from these trips indicated that bycatch comprised 3.8%. When striped marlin bycatch was listed in both, the mean value for the logbooks was slightly greater (observers: 1.4 released striped marlin per set; logbooks: 1.7 released striped marlin per set). Thus, differences in bycatch estimates were primarily caused by the reporting frequencies. Observers reported striped marlin bycatch on 6.9% of the sets, whereas the logbooks did so on 3.8%. In shortbill spearfish, observers reported bycatch on 6.0% of the sets, whereas the logbooks listed bycatch on 2.2%. The logbook reports indicated that bycatch comprised 9.4 and 4.8% of the catch, respectively. No attempt was made to evaluate blue marlin bycatch on these observed sets because any such released fish could have been misidentified.

Striped marlin and shortbill spearfish bycatch was heterogeneously distributed both temporally and within the fleet. The mean number of discarded spearfish in 1999 as reported by observers (0.25 per set) was more than double those from all other years (0.04–0.12 per set), but the logbook mean from the observed sets (0.01 per set) was the second lowest (0.008–0.08 per set). This reflected a large difference in reporting frequency; 14.5% of the observed sets in 1999 listed spearfish bycatch, but only 0.9% of the logbook reports did so. A substantial fraction of the observed striped marlin bycatch (27.1%) was reported in the fourth quarters of 1995 and 2003. The distribution within the fleet was such that 33.0% of the shortbill spearfish and 39.0% of the striped marlin bycatch reported by observers were traced to 9 and 14 vessels, respectively.

Standardized Catch Rates

The standardized catch rates computed from observed bigeye-tuna targeted sets (Fig. 5) exhibited no clear trends in striped marlin and shortbill spearfish. Although both species exhibited intra- and interannual variation, all within-quarter linear regressions of the mean standardized catch rates on time were nonsignificant (eight F-tests, all $P > 0.05$). The principal feature was the sustained period of high shortbill spearfish catch rates in 1998–1999. In contrast, the linear regressions for blue marlin in the first and third quarters were significant (two F-tests, both $P < 0.05$). The coefficients were negative and equivalent to mean decreases of 3.4% and 2.1% per year in the first and third quarters, respectively.

The standardizations reduced certain apparent peaks in the nominal and corrected data (e.g., striped marlin in the fourth quarters of 1998 and 2001; shortbill spearfish in the first quarter of 2003), which reflected removal of covariate effects. The striped marlin from these two quarters were caught in slightly cooler and more northerly waters (mean SST: 25.5°C; mean latitude: 21°10” N) than in the other fourth quarters (mean SST: 25.8°C; mean latitude: 20°80” N). Though small, both differences were highly significant (two two-sample t-tests, both $P < 0.001$). In the case of shortbill spearfish, the mean number of hooks during the first quarter of 2003 (1,998) was 14.5% greater and significantly different (two-sample t-test, $P < 0.001$) from the mean in the other first quarters (1,745).

DISCUSSION

The results in this paper, generated for a closely related group of ecologically, economically, and recreationally important fishes, are expected to prove useful from both applied and theoretical perspectives. In practical terms, the evaluations of logbook accuracy have elucidated sources and magnitude of bias in the nominal catch data while contributing to studies of stock status. The corrected striped marlin data have already been used in a completed stock assessment, and the corrected blue marlin data will be used in a forthcoming assessment (personal communication, G.T. DiNardo, NOAA Fisheries, PIFSC). In addition, as described in Walsh et al. (2005), the Hawaii-based longline fishery is characterized by virtually ideal monitoring circumstances, with a centrally located and readily observed fleet, excellent compliance with logbook submittal requirements, and sale of ca. 95% of the landings through a single public fish auction whose records can be used to verify analytical results. Hence, this and the preceding study should permit fisheries scientists and managers to assess typical (i.e., uncorrected) and optimal (i.e., corrected) logbook accuracy for mixed billfish catches with minimal extraneous impediments. Assessments of bycatch and standardized catch rates are directly relevant to fishery management. In a more conceptual vein, the GAM output describes the effects of extrinsic factors on catch rates. As such, this work may permit informed conjecture regarding changes in catch rates if either the fishery or the environment changes in the future.

Logbook Accuracy

The Hawaii-based longline fishery is well-monitored (Walsh et al., 2005), but the results of this study documented that the nominal logbook data for four of the five istiophorid species taken as incidental catch during the 10-year study period were characterized by substantial bias. The pattern consisted of an inverse relationship between misidentification rates and catch sizes with these species. Moreover, the results demonstrated that a relatively small number of individuals (or vessels) can exert highly disproportionate effects on catch statistics. Thus, "typical" logbook accuracy for mixed catches of billfishes may require careful evaluation. It was noteworthy however, that the misidentification rates varied inversely with observer coverage rates. Additional analyses should identify the minimum coverage level required to maintain this favorable trend. It would also be useful to continue Quality Assurance/Quality Control work when corrected catch data have been provided, as in this paper, to ensure that the longest and most accurate time series possible are available for use in stock assessments.

The data correction process used in this project was conservative, based on direct (i.e., sales records) or strong circumstantial evidence, and in the three major species, only after application of rigorous evaluation criteria predicated on examination of residuals from regression analyses (Walsh et al., 2005). The consequence is that unknown fractions of the misidentifications or other biases undoubtedly remain within the corrected catch data sets. Nonetheless, the error was reduced to the extent practicable.

It should also be noted that residuals from preliminary analyses have now proven useful as diagnostics with four species, but the basis for utility has varied among them. In blue shark, which can be very numerous in the catch of this fishery, the large SR primarily revealed under- and nonreporting (Walsh et al., 2002). Blue marlin, in contrast, comprise a small fraction of the catch, and the large SR were primarily indicators of overreporting caused by misidentifications. Striped marlin and shortbill spearfish are taken at moderate levels in the catch, and their large SR were often associated with real but unusually high catches. Thus, the SR proved useful in identifying inappropriate reporting or misconduct with a very numerous bycatch species, incorrect reporting with a species taken in low numbers as incidental catch, and accurate reporting of large and potentially interesting incidental catches with two species taken at intermediate levels.

The variety of misidentifications was greater than expected. Sailfish, in particular, is highly distinctive in appearance, yet the nominal total was 68.7% greater than the corrected, and even this estimate of the upward bias was almost certainly conservative. Similarly, black marlin, which is characterized by a long, stout bill, rigid pectorals, and a steeply elevated head profile and can attain great size, were sometimes logged as shortbill spearfish, which is much smaller, with a bill ≤ 15% of body length and slightly elevated head profile (Nakamura, 1985). The underlying causes of such egregious errors were not investigated, but it would not be surprising if extraneous factors (e.g., literacy problems) were involved. Approximately two-thirds of the participants in this fishery were not born in the U.S., do not speak English well, and may also be limited in their English reading proficiency (personal communication, S.D. Allen, NOAA Fisheries, PIFSC).

Consequences of Misidentifications

The misidentifications described herein have impeded understanding of this fishery in at least three ways. In a recent study of blue and striped marlin catches, Dalzell and Boggs (2003) evaluated the nominal Hawaii longline data and inferred that the annual CPUE for blue marlin in 1995 was the highest in the last decade and that the CPUE in both 1993 and 1994 had closely approached that level. Results presented in this paper and previously (Walsh et al., 2005) have demonstrated that the nominal blue marlin catch in 1995 was considerably inflated. It was not possible to determine whether this also held true for 1993 and 1994 because there were no observer data from 1993 and insufficient sales data from 1994. Nonetheless, the clearly identified errors did contribute to confusion regarding the relative abundance of these species. In a similar context, the roundscale spearfish, *T. georgii*, has recently been recognized as present in the western North Atlantic Ocean, and landings of this species may have been listed as white marlin, *T. albidus*, thereby introducing uncertainty into stock assessments for white marlin, which is considered heavily overfished (Shivji et al., 2006). The second effect was the possible distortion of the physiological and geographical ecology of these species. Walsh et al. (2005) demonstrated that the apparent high catches of blue marlin north of Hawaii in the fourth quarter of 1995 were primarily striped marlin. Left uncorrected, these misidentifications could have engendered flawed understanding of seasonal movement patterns and effects of SST. The third deleterious effect consisted of the possible introduction of bias into ecosystem models (Cox et al., 2002). To the extent that misidentifications have inflated stock biomass estimates for blue marlin, for example, estimates of the ecotrophic efficiencies of prey would be inflated while their own would be negatively biased (T.E. Essington, University of Washington, College of Fisheries, personal communication).

Catches of the Major Species

Blue marlin catch data, including the characteristics and sources of its biases, were described by Walsh et al. (2005). The higher estimate of overreporting presented herein (39.6% vs. 29.4%) was probably attributable to two factors. The first was an improved understanding of and ability to use sales data from HDAR for 1994–1999, which permitted evaluation and correction of trips that had not previously been corrected. The second factor was that the GAM used by Walsh et al. (2005) was overparameterized; subsequent work (Walsh et al., 2006) demonstrated that an overparameterized model yielded an inflated estimate of the total catch, which would have narrowed the difference between the predicted and corrected catch total estimates.

Striped marlin was the most numerous istiophorid in the catch of this fishery, comprising 41.7%–60.8% of the annual totals and 52.7% of the entire billfishes catch throughout the study period. This status reflected particularly high catches in the fourth quarters of 1995 and 2003. Unlike blue marlin and shortbill spearfish, however, there was no evidence that these high catch years were associated with recruitment. The SST data suggested that the fish may have been more available to the fishery as a result of oceanographic conditions. In addition to numbers caught, this species also comprised 48% of the biomass of the three major species. Thus, in both numerical and biomass terms, striped marlin was the dominant istiophorid species in the incidental catch of this fishery.

Shortbill spearfish catch data were the most difficult to correct, which was a procedural artifact. Specifically, it was not uncommon for logbooks to report relatively large catches of this species and striped marlin in early- and mid-winter. In such instances, fish of either or both species may have gone unsold, and if the logbook totals were greater than the sales totals, corrections were not possible, even if the proportions appeared inaccurate. It is possible and indeed likely that bias attributable to misidentifications of these species remains in the corrected catch data, but it could not be estimated. It is not even clear whether any such bias would be positive or negative. In addition, unreported bycatch could not be corrected in any of these species.

Catches of the Minor Species

Sailfish and black marlin represented the extremes of the error pattern, with rarity masked by overreporting that ranged from at least 69% in the former species to 8.4-fold in the latter. Black marlin data were so inaccurate that this species should probably be regarded as a solitary, extremely rare, and enigmatic migrant in this fishery. Sailfish data from the observers, in contrast, did provide clues to factors that influence catch rates with this species. Relatively high catch rates on sets that targeted yellowfin tuna were comprehensible because yellowfin is a shallower-dwelling species than bigeye tuna. Hence, it was not surprising that epipelagic predators such as sailfish and blue marlin would be taken as incidental catch.

Bycatch

Billfish bycatch did not represent a major problem in this fishery. The observer data indicated that striped marlin and shortbill spearfish bycatch probably comprised 5%–10% of the catch on a numerical basis. In the latter species, it probably comprised even less in terms of biomass (because discards occurred during peak catch periods) or economic value (because auction prices decrease during periods of excess supply). Hence, bycatch tended to occur when it was least consequential. Moreover, because bycatch, like systematic misidentifications, was not uniformly distributed within the fleet, it is reasonable to expect that improved accuracy for bycatch in the logbooks could be achieved by judicious observer allocation, should this be deemed necessary. There is an additional, subtle point to be made regarding bycatch reporting. Some vessel operators list substantial numbers of discards in logbook reports that exhibit very close agreement with sales data (i.e., the logbook entry for kept fish ≈ the number sold at UFA). In such cases, the discards listings actually reflect exceptionally accurate reporting.

Standardized Catch Rates

Standardized catch rates for striped marlin and shortbill spearfish did not increase or decrease significantly throughout the 10-year study period. As such, incidental catches of these species were essentially stable. Catch rates of blue marlin, in contrast, decreased significantly in the first and third quarters of these years, but it remains questionable as to whether these apparent declines were meaningful. The standardized catch rate in the first quarter of 1994 was the second highest during the study period, which gave it a large influence, but a paucity of sales data from that time precluded checks on possible misidentifications by observers. The standardized catch rates from the third quarters of 2002 and 2003 were lower than in all other third quarters. This may have reflected a seasonal decrease in relative abundance or availability to the fishery, but could also have resulted from improved accuracy in identifications by observers or the influence of other unidentified factor(s). Finally, it is not clear that apparent declines in alternating quarters could be regarded as a meaningful trend.

CONCLUSIONS

Use of statistical modeling and regression techniques in combination with commercial sales records permitted correction of longline logbooks, which yielded more realistic catch histories for this ecologically, economically, and recreationally important group of highly migratory fishes. Although the corrected data retained bias, its magnitude was reduced considerably in each species and its sources and characteristics were elucidated. The analyses demonstrated that the accuracy of catch data for rare species, in particular, can be very significantly and adversely affected by misidentifications by a small minority of vessel operators.

Striped marlin was the dominant species among the istiophorid billfishes taken as incidental catch by the Hawaii-based longline fishery, both numerically and in terms of biomass. Inferences based upon the nominal data suggesting that biomass of the incidental blue marlin catch exceeded that of striped marlin would be incorrect.

Billfish bycatch did not represent a major problem in this fishery. It consisted primarily of striped marlin or small shortbill spearfish caught and discarded during periods of high relative abundance of these species when their economic value was minimal.

Standardized catch rates for the three major billfish species on bigeye tuna-targeted, observed trips were approximately stable throughout the 10-year study period. Even in blue marlin, there was no consistent declining trend. The principal source of variation in both the nominal and corrected catch rates was years with unusually high catches. In blue marlin and shortbill spearfish, these may have represented periods of enhanced recruitment in the population, whereas high catches of striped marlin probably reflected oceanographic conditions.

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Table 1.--Summary of effort in the Hawaii-based longline fishery (March 1994–February 2004). Entries are active vessels, trips[3], sets, and percentages of set types[4].

Year	Vessels	Trips	Sets	Set types SF	Set types MS	Set types T		Vessels	Trips	Sets	Set types SF	Set types MS	Set types T
Observer (all data)								Logbook (all data)					
1994–2004	158	1,195	14,415	4.1	9.8	86.1		184	10,037	11,0612	8.7	18.2	73.1
Observer (data used in GAM development)								Logbook (data used in GAM applications)					
1994–2004	158	1,171	13,737	4.1	10.0	85.9		183	9,978	103,745	8.8	18.7	72.6
1994	44	46	469	48.2	17.5	34.3		121	802	7,749	40.1	12.4	47.6
1995	43	47	525	13.1	36.0	50.9		110	1,079	11,046	15.0	24.5	60.4
1996	47	52	608	9.7	42.1	48.2		104	1,047	10,928	9.6	31.5	58.9
1997	33	37	457	11.8	46.0	42.2		105	1,082	11,309	8.8	26.3	64.9
1998	41	48	550	11.3	31.8	56.9		115	1,091	11,742	9.2	26.7	64.1
1999	36	39	433	12.5	28.2	59.4		120	1,098	12,267	5.9	26.4	67.7
2000	70	108	1230	2.8	20.0	77.2		123	986	9,669	4.8	27.2	68.1
2001	96	216	2329	0.4	4.0	95.6		101	795	8,537	0.0	3.2	96.8
2002	100	271	3,194	0.0	0.0	100.0		101	867	8,526	0.0	0.2	99.8
2003	104	264	3,195	0.0	0.0	100.0		110	947	10,105	0.0	0.0	100.0
2004	67	74	747	0.0	0.0	100.0		96	206	1,867	0.0	0.0	100.0

[3] The pooled trip totals are less than the sums of the annual totals because some fishing trips deployed longline sets during two calendar years.
[4] ‘SF’, ‘M’, and ‘T’ denote swordfish-, mixed species-, and tuna-targeted sets, respectively. See Ito and Machado (2001) for descriptions of set types.

Table 2.--Summary of nominal catch data[5] (March 1994 – February 2004). Entries for each species are the catch per set and catch per unit effort (CPUE; i.e., catch per 1,000 hooks) pooled and by set types.

	All longline set types				Tuna		Mixed species		Swordfish	
Species	Source	Catch	Catch/set	CPUE	Catch/set	CPUE	Catch/set	CPUE	Catch/set	CPUE
Blue marlin	Observer	5,156	0.36	0.24	0.36	0.21	0.44	0.52	0.11	0.13
	Logbook (O)	6,092	0.42	0.29	0.42	0.25	0.58	0.69	0.16	0.19
	Logbook (U)	53,467	0.48	0.41	0.46	0.31	0.70	0.86	0.27	0.31
Striped marlin	Observer	20,465	1.42	0.84	1.51	0.82	0.97	1.13	0.50	0.63
	Logbook (O)	18,297	1.27	0.74	1.37	0.74	0.76	0.89	0.42	0.54
	Logbook (U)	134,161	1.21	0.84	1.39	0.82	0.86	1.04	0.44	0.56
Shortbill spearfish	Observer	13,105	0.91	0.51	1.02	0.55	0.27	0.29	0.10	0.14
	Logbook (O)	11,992	0.83	0.46	0.94	0.50	0.23	0.25	0.05	0.07
	Logbook (U)	88,024	0.80	0.48	1.02	0.59	0.25	0.26	0.05	0.06
Black marlin	Observer	70	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.02	< 0.01	< 0.01
	Logbook (O)	263	0.02	0.01	0.02	0.01	0.02	0.03	0.01	0.02
	Logbook (U)	5,778	0.05	0.04	0.05	0.03	0.06	0.07	0.03	0.03
Sailfish	Observer	318	0.02	0.01	0.02	0.01	0.04	0.03	< 0.01	< 0.01
	Logbook (O)	454	0.03	0.02	0.03	0.02	0.04	0.04	0.01	0.01
	Logbook (U)	4,638	0.04	0.03	0.04	0.03	0.05	0.06	0.02	0.02

[5] Data sources are the fishery observers ('Observer'; *N* = 14,415 longline sets), logbooks from observed sets ('Logbook (O)'; *N* = 14,415 longline sets), and logbooks from unobserved sets ('Logbook (U)'; *N* = 110,612 longline sets)

Table 3.--Analyses of deviance of observed catches per set. Entries are the reductions in the Akaike Information Criterion and residual deviance, the *F*-test and its significance, the stepwise percent deviance reductions, and the deviance reduction per degree of freedom.

Species	Predictor	Δ AIC	Δ Residual Deviance	d.f.	F_{enter}	*P*	Deviance explained	Deviance/ d.f. parameter
Blue marlin	Date of fishing	4,382.72	4,462.36	39.8	83.022	0	26.2	111.56
	SST	937.43	945.86	4.2	173.477	0	5.6	189.17
	Begin-set time	397.81	407.89	5.0	63.352	0	2.4	81.58
	Longitude	190.81	210.25	9.7	16.983	0	1.2	21.03
	Latitude	142.31	162.05	9.9	12.858	0	1.0	16.21
	Vessel length	67.66	77.62	5.0	12.357	$6.1*10^{-12}$	0.5	15.52
	Hooks	46.1	56.02	5.0	9.005	$1.7*10^{-8}$	0.3	11.20
Null Deviance = 17,021.96; d.f. = 13,736 Residual Deviance = 10,699.91; d.f. = 13,657.39 Pseudo-R^2 = (17,021.96 – 10,699.91) / 17,021.96) = 0.371								
Striped marlin	Date of fishing	10,818.5	10,898.43	40.0	124.609	0	28.3	272.46
	SST	2,506.72	2,513.32	3.3	386.072	0	6.5	502.66
	Latitude	869.41	889.59	10.1	46.766	0	2.3	88.96
	Longitude	306.34	325.58	9.6	18.254	0	0.8	32.56
	Vessel length	293.69	303.29	4.8	34.482	0	0.8	60.66
	Hooks	163.95	173.49	4.8	19.975	0	0.5	34.70
	Begin-set time	76.67	87.14	5.2	9.186	$4.6*10^{-9}$	0.2	17.43
Null Deviance = 38,447.7; df = 13,736 Residual Deviance = 23,256.85; df = 13,658.22 Pseudo-R^2 = (38447.7 – 23,256.85) / 38,447.7 = 0.395								

Species	Predictor	ΔAIC	ΔResidual Deviance	d.f.	F_{enter}	*P*	Deviance explained	Deviance/ d.f. parameter
Shortbill spearfish	Latitude	6,918.06	6,938.08	10.0	345.288	0	23.1	693.8
	Date of fishing	2,933.78	3,010.71	38.5	45.321	0	10.0	75.3
	Begin-set time	671.75	681.60	4.9	85.844	0	2.3	136.3
	Hooks	214.50	224.53	5.0	27.930	0	0.7	44.9
	Longitude	114.55	134.53	10.0	8.444	$7.8*10^{-14}$	0.4	13.5
	Vessel length	71.33	80.84	4.8	10.698	$6.8*10^{-10}$	0.3	16.2
	SST	36.07	46.08	5.0	5.586	$2.1*10^{-5}$	0.2	9.2

Null Deviance = 30,096.37; df = 13,736
Residual Deviance = 18,980; df = 13,657.84
Pseudo-R^2 = (30,096.37 – 18,980) / 30,096.37 = 0.369

Table 4.--Summary of correction[6] of catch data from the Hawaii-based longline fishery (March 1994–February 2004).

Species	Catch (uncorrected)	Sets with catch	Corrected sets	Sets with catch (corrected)	Correction	Misidentifications	Catch (corrected)
Blue marlin	50,715	24,183	5,367	22,379	-10,127	-9670	40,588
Striped marlin	128,924	46,930	6,503	50,082	15,266	15,039	144,190
Shortbill spearfish	84,177	35,293	2,177	35,727	1263	1276	85,440
Sailfish	4,638	2,903	935	2,117	-1889	-1788	2,749
Black marlin	5,778	3,471	2,886	609	-5092	-4940	686

[6] Blue marlin, striped marlin, and shortbill spearfish catch data were corrected by using the studentized residuals generated by applying the GAM coefficients to logbook catch data and computing the log-log regressions of catches on GAM predictions (N = 103,745). Sailfish and black marlin catch data were corrected on the basis of either direct checks against sales records or circumstantial evidence.

Table 5.--Summary of the billfishes catch composition (March 1994–February 2004). Entries are percentages.

Year	Blue marlin	Striped marlin	Shortbill spearfish	Sailfish	Black marlin
1994 – 2004	15.3	52.2	31.3	1.0	0.2
1994	23.5	51.7	21.4	2.2	1.2
1995	14.7	60.8	23.2	1.0	0.3
1996	18.9	58.3	21.5	0.9	0.4
1997	25.6	47.9	25.0	1.3	0.2
1998	13.2	52.7	32.4	1.4	0.2
1999	11.1	43.2	44.5	1.0	0.1
2000	18.4	41.7	39.2	0.6	0.1
2001	14.6	57.8	26.7	0.9	0.0
2002	14.2	43.2	41.7	0.9	0.0
2003	8.9	54.3	36.5	0.3	0.0
2004	6.5	58.0	35.4	0.1	0.0

Table 6.--Summary of applications of GAM coefficients to catch data from unobserved longline sets (March 1994–February 2004). Entries for each species are the type of logbook data, linear regression, *F*-test, coefficient of determination, and variance about the regression. The independent variable is the GAM-predicted value; the dependent variable is the uncorrected or corrected value from the logbook.

Species	Data Type	Regression	*F*	R^2	s^2_{y*x}
Blue marlin	Uncorrected	$\log_e(Y+1) = 0.0609 + 0.6819\log_e(X+1) + \varepsilon$	$15{,}810_{1,103743}$	0.132	0.1962
	Corrected	$\log_e(Y+1) = 0.0238 + 0.7058\log_e(X+1) + \varepsilon$	$22{,}200_{1,103743}$	0.176	0.1498
Striped marlin	Uncorrected	$\log_e(Y+1) = 0.7582\log_e(X+1) - 0.0325 + \varepsilon$	$28{,}200_{1,103743}$	0.214	0.3580
	Corrected	$\log_e(Y+1) = 0.8377\log_e(X+1) - 0.0436 + \varepsilon$	$33{,}390_{1,103743}$	0.244	0.3692
Shortbill spearfish	Uncorrected	$\log_e(Y+1) = 0.0140 + 0.6491\log_e(X+1) + \varepsilon$	$31{,}770_{1,103743}$	0.234	0.2609
	Corrected	$\log_e(Y+1) = 0.0076 + 0.6696\log_e(X+1) + \varepsilon$	$34{,}020_{1,103743}$	0.247	0.2593

Table 7.--Summary of combined catch estimates[7] and reporting bias on observed and unobserved longline sets (March 1994–February 2004).

Fishery Observer Data and GAM Estimate of Catch				
Species	Observed catch	GAM-predicted catch	Estimated catch	
Blue marlin	4,757	35,582	40,339	
Striped marlin	19,352	134,774	154,126	
Shortbill spearfish	12,582	98,011	110,593	
Fishery Observer Data and Corrected Logbook Data				
Species	Observed catch	Corrected logbook catch	Observed + Corrected catch	Δ (%)
Blue marlin	4,757	40,907	45,664	13.2
Striped marlin	19,352	144,190	163,542	6.1
Shortbill spearfish	12,582	85,440	98,022	-11.4
Nominal Logbook Data				
	Nominal Logbook catch (observed sets)	Nominal Logbook catch (unobserved sets)	Nominal Logbook total	Δ (%)
Blue marlin	5,610	50,715	56,325	39.6
Striped marlin	17,362	128,924	146,286	-5.1
Shortbill spearfish	11,529	84,177	84,177	-13.5

[7] N = 117,482 longline sets (103,745 unobserved + 13,737 observed longline sets); 94.0% of total effort.

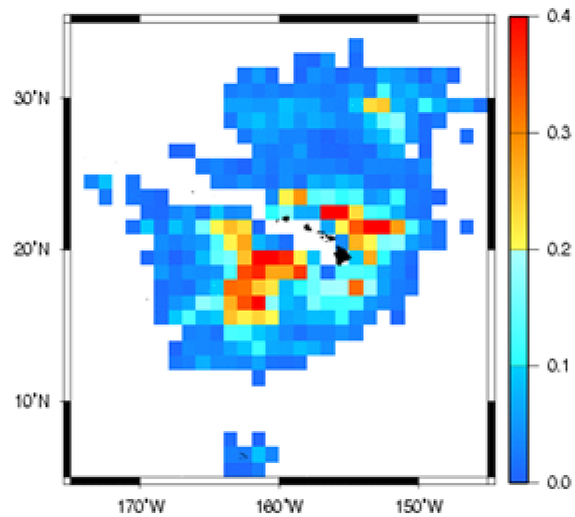

Figure 1.--Distribution of effort (nonconfidential data) by the Hawaii-based longline fishery in 2003 aggregated within 2˚ latitude*2˚ longitude squares. Scale is expressed as hooks*10^6.

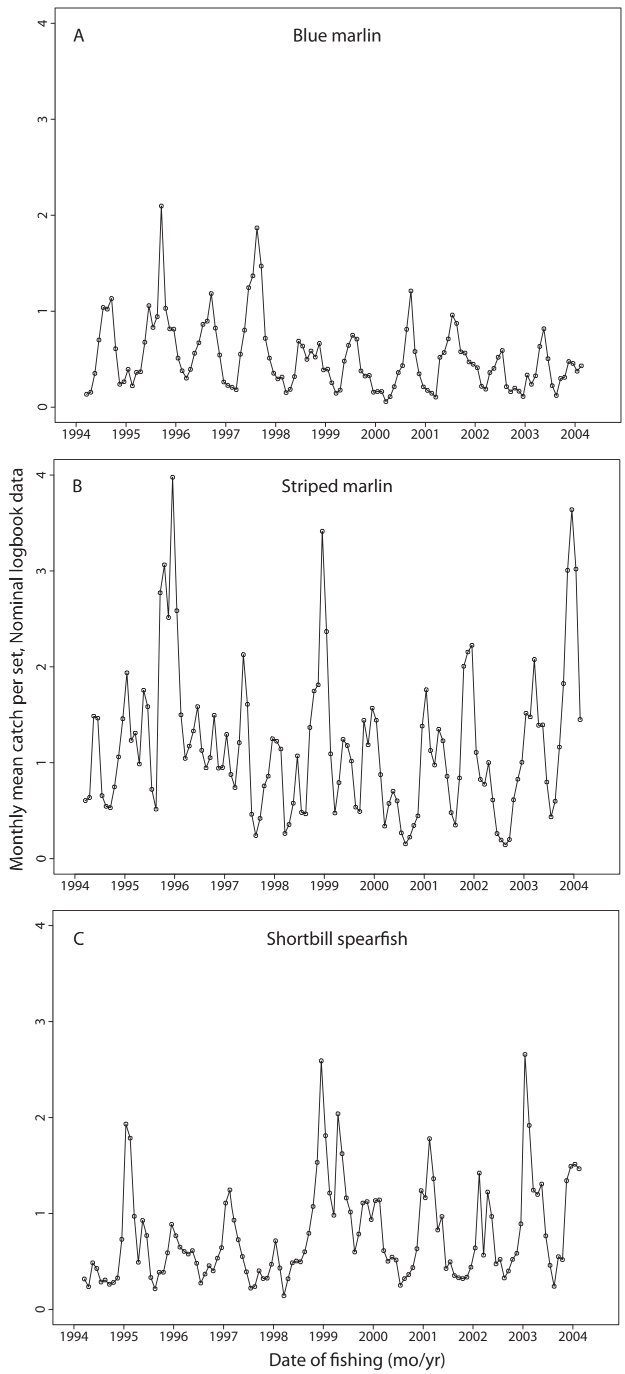

Figure 2.--Monthly mean catches per set for (a) blue marlin, (b) striped marlin, and (c) shortbill spearfish in the Hawaii-based longline fishery (nominal data; March 1994–February 2004).

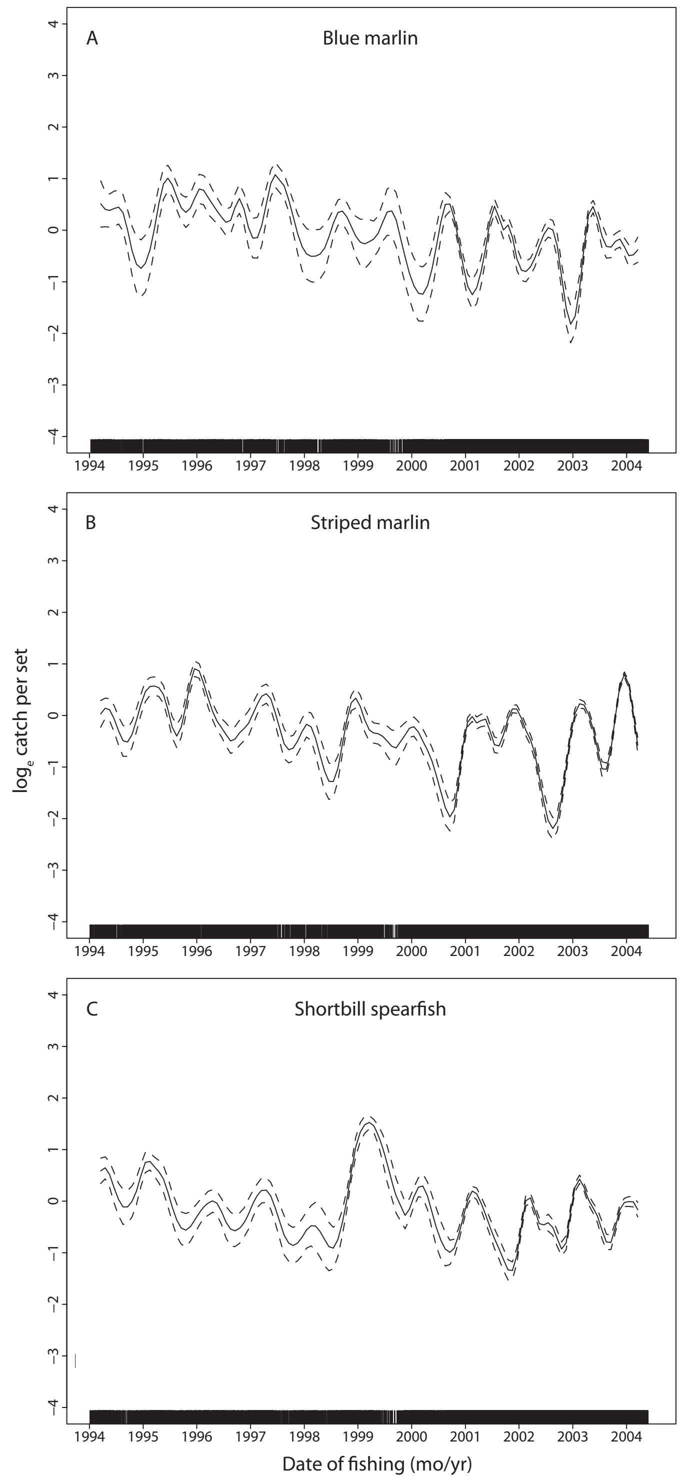

Figure 3.--Smoother traces from GAMs depicting the relationships between catches per set and the date of fishing for (a) blue marlin, (b) striped marlin, and (c) shortbill spearfish.

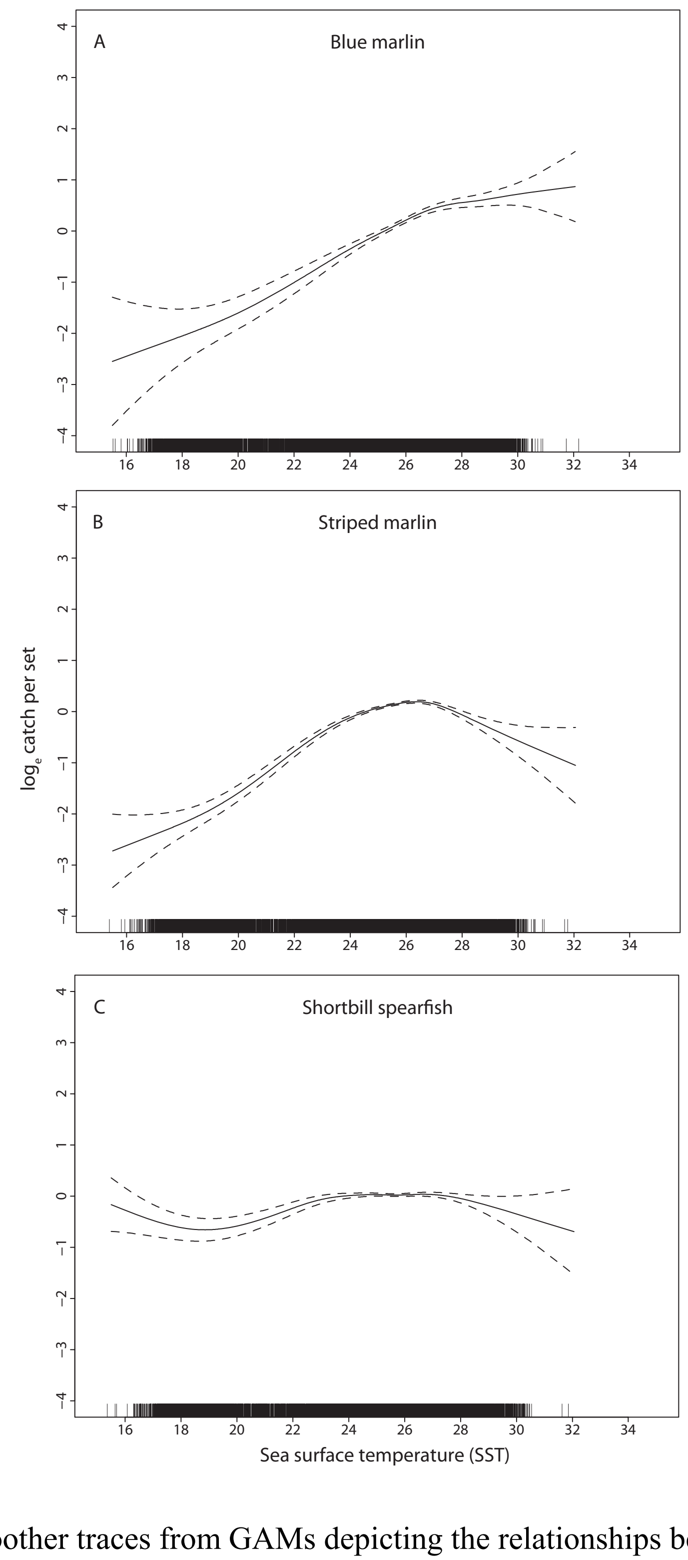

Figure 4.--Smoother traces from GAMs depicting the relationships between catches per set and sea surface temperature for (a) blue marlin, (b) striped marlin, and (c) shortbill spearfish.

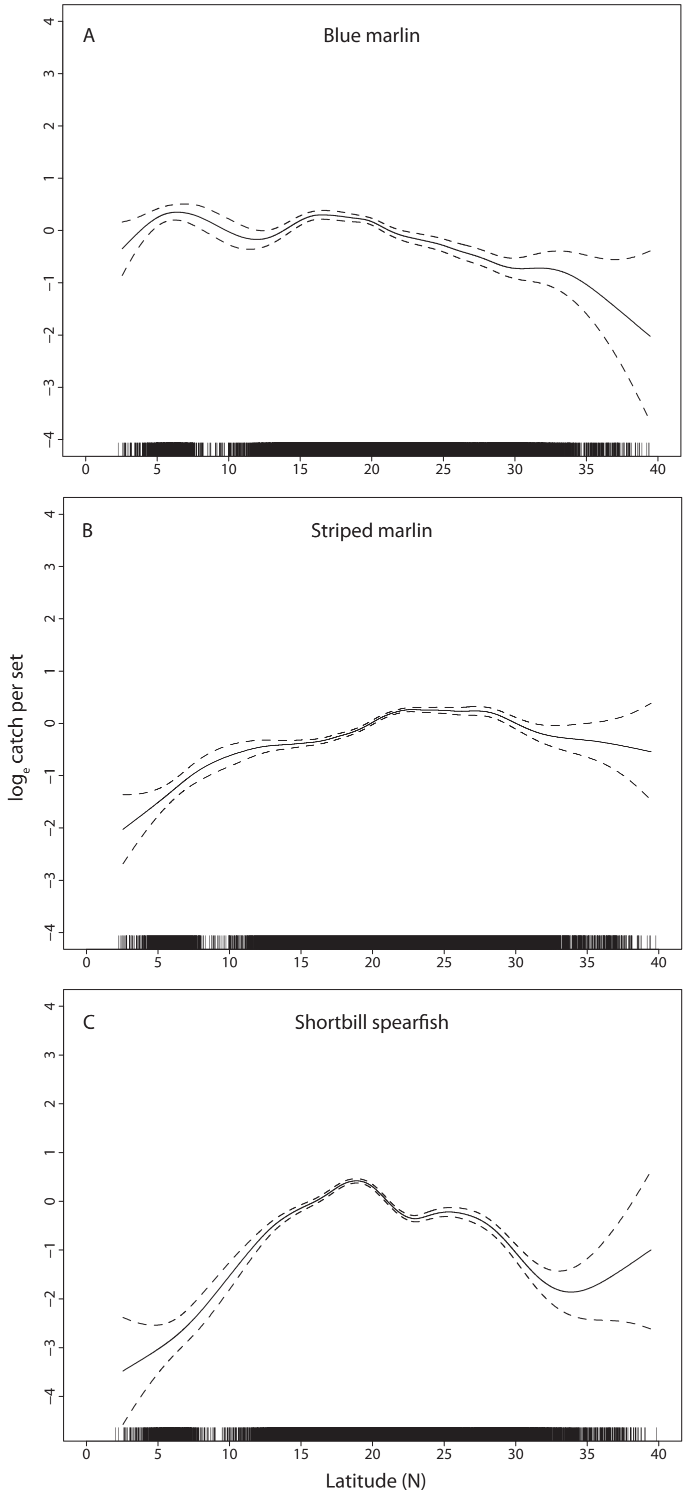

Figure 5.--Smoother traces from GAMs depicting the relationships between catches per set and latitude for (a) blue marlin, (b) striped marlin, and (c) shortbill spearfish.

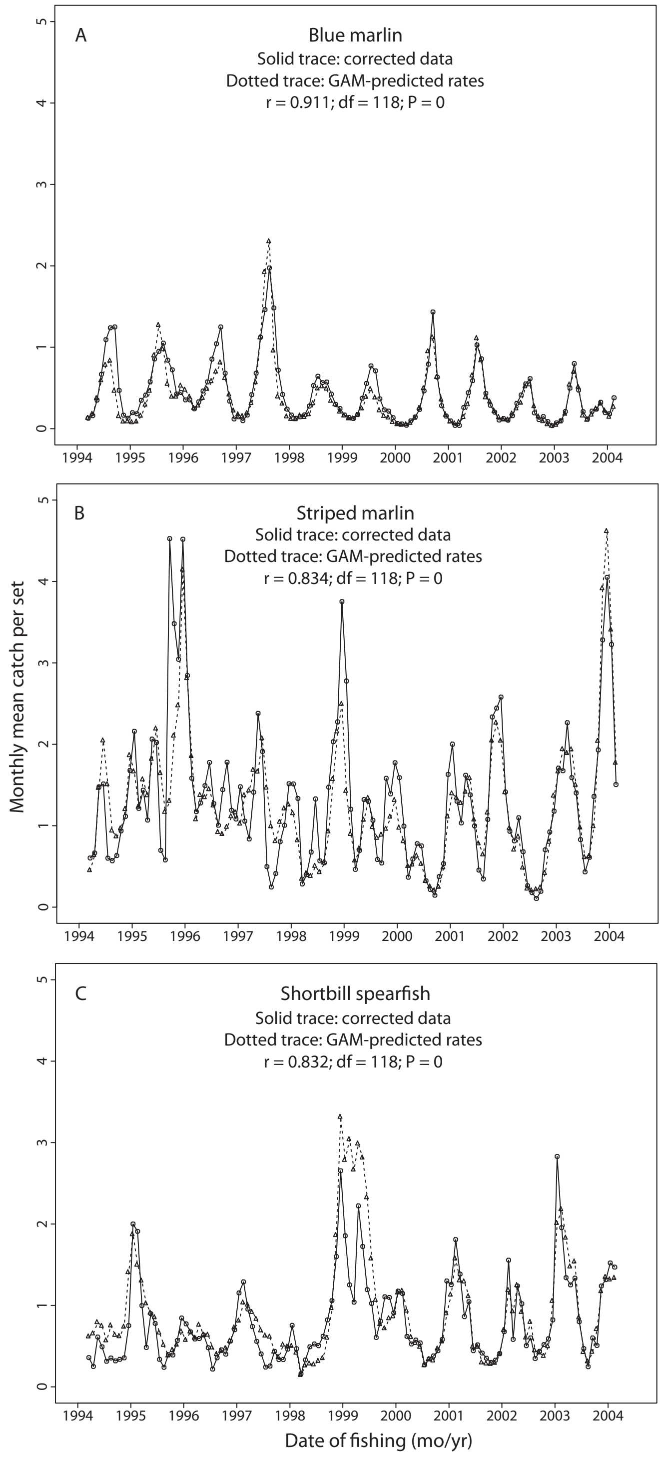

Figure 6.--Monthly mean catches per set for (a) blue marlin, (b) striped marlin, and (c) shortbill spearfish in the Hawaii-based longline fishery (corrected data and GAM-predicted rates; March 1994–February 2004).

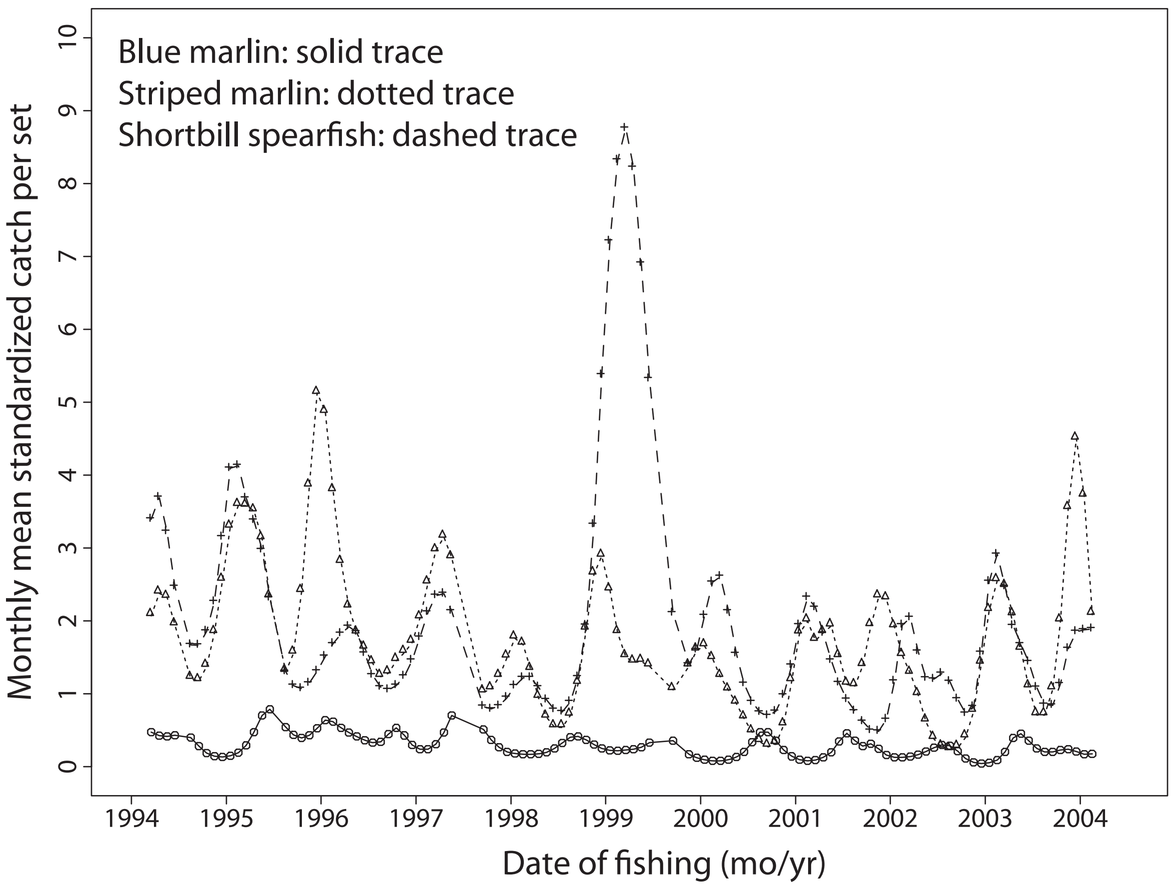

Figure 7.--Standardized catches per set for blue marlin, striped marlin, and shortbill spearfish on observed, bigeye tuna-targeted trips in the Hawaii-based longline fishery (March 1994–February 2004).

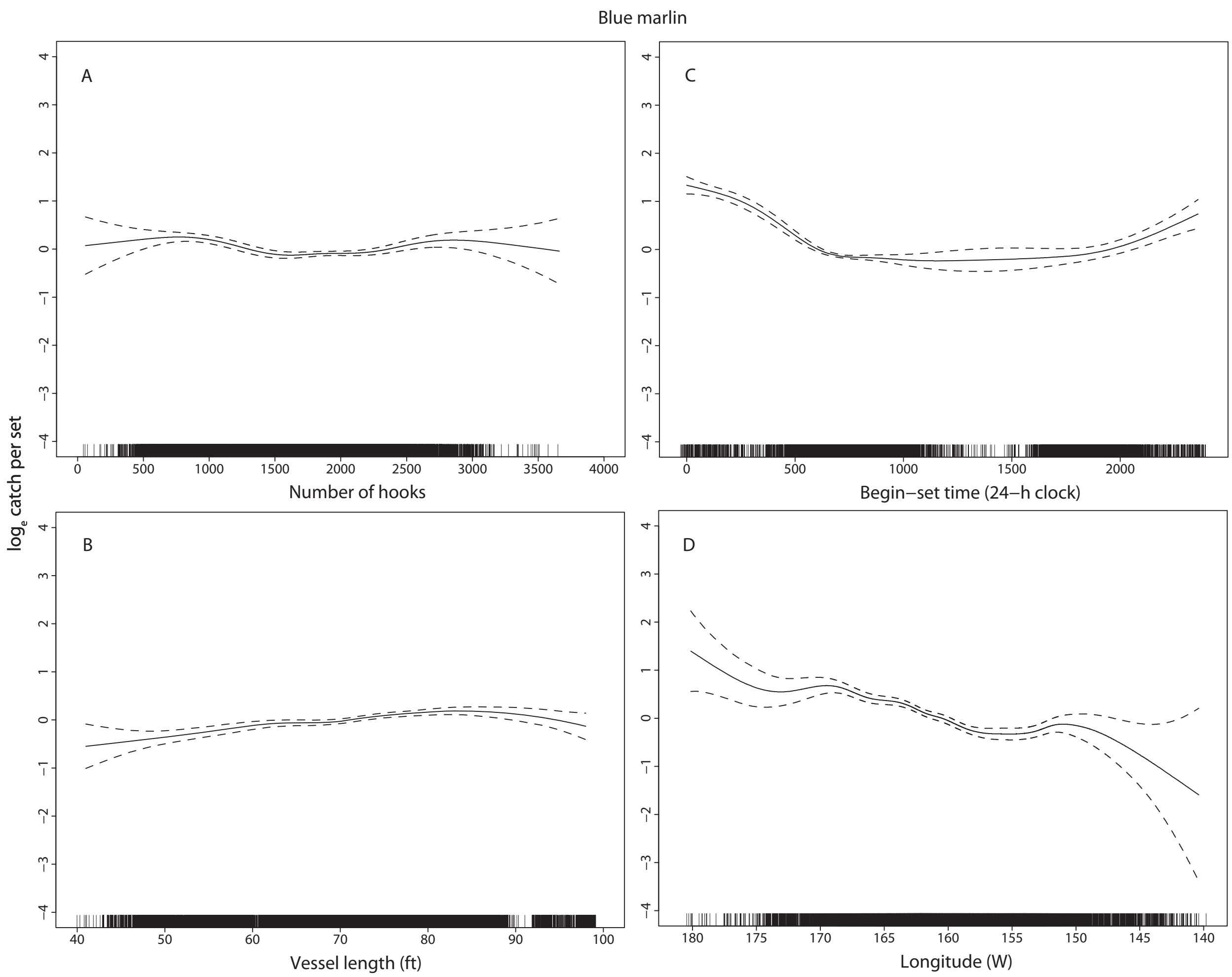

Figure A1.--Smoother traces from a GAM depicting the relationships between blue marlin catches per set and (a) hook numbers per set, (b) begin-set time, (c) vessel length, and (d) longitude.

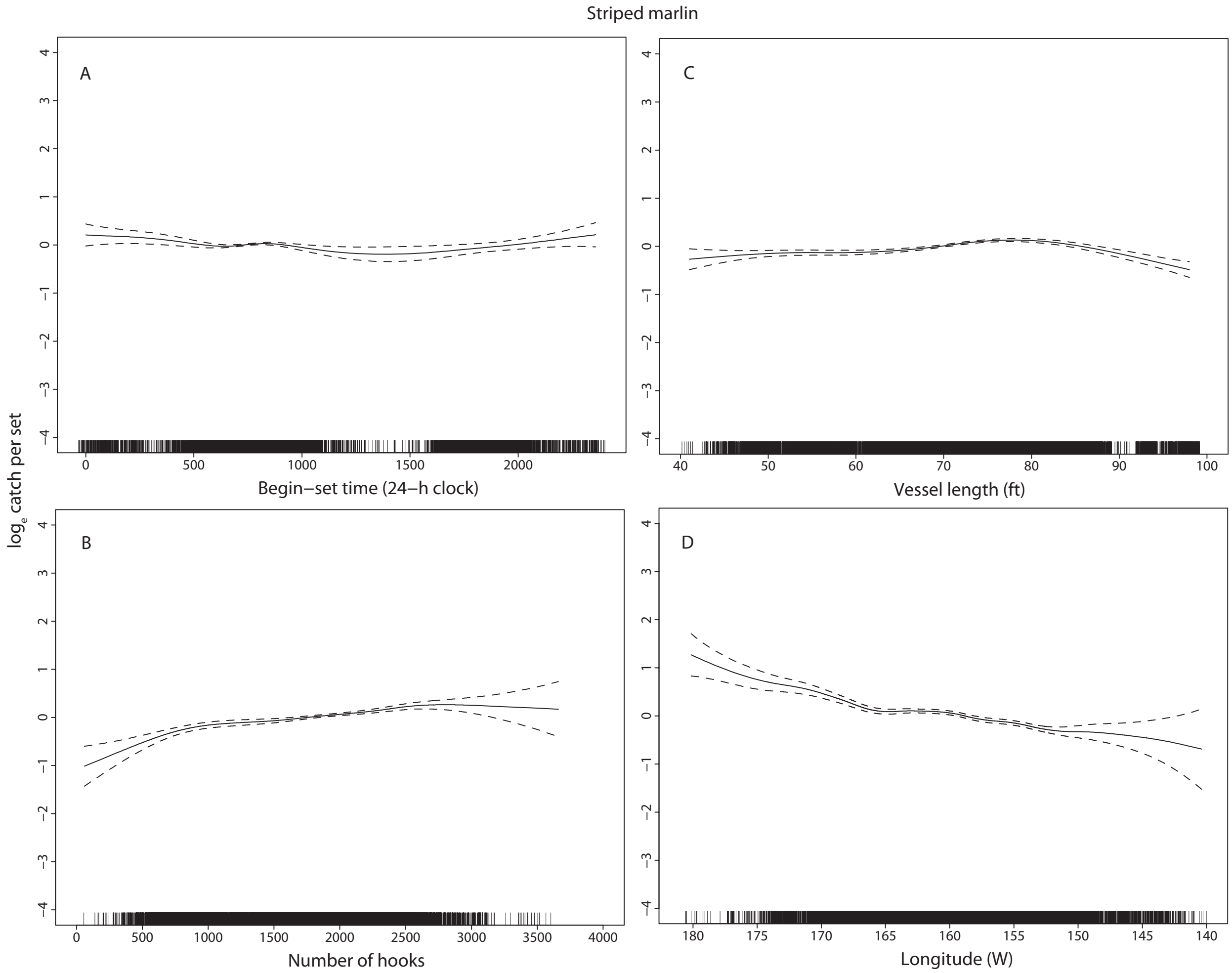

Figure A2.--Smoother traces from a GAM depicting the relationships between striped marlin catches per set and (a) hook numbers per set, (b) begin-set time, (c) vessel length, and (d) longitude.

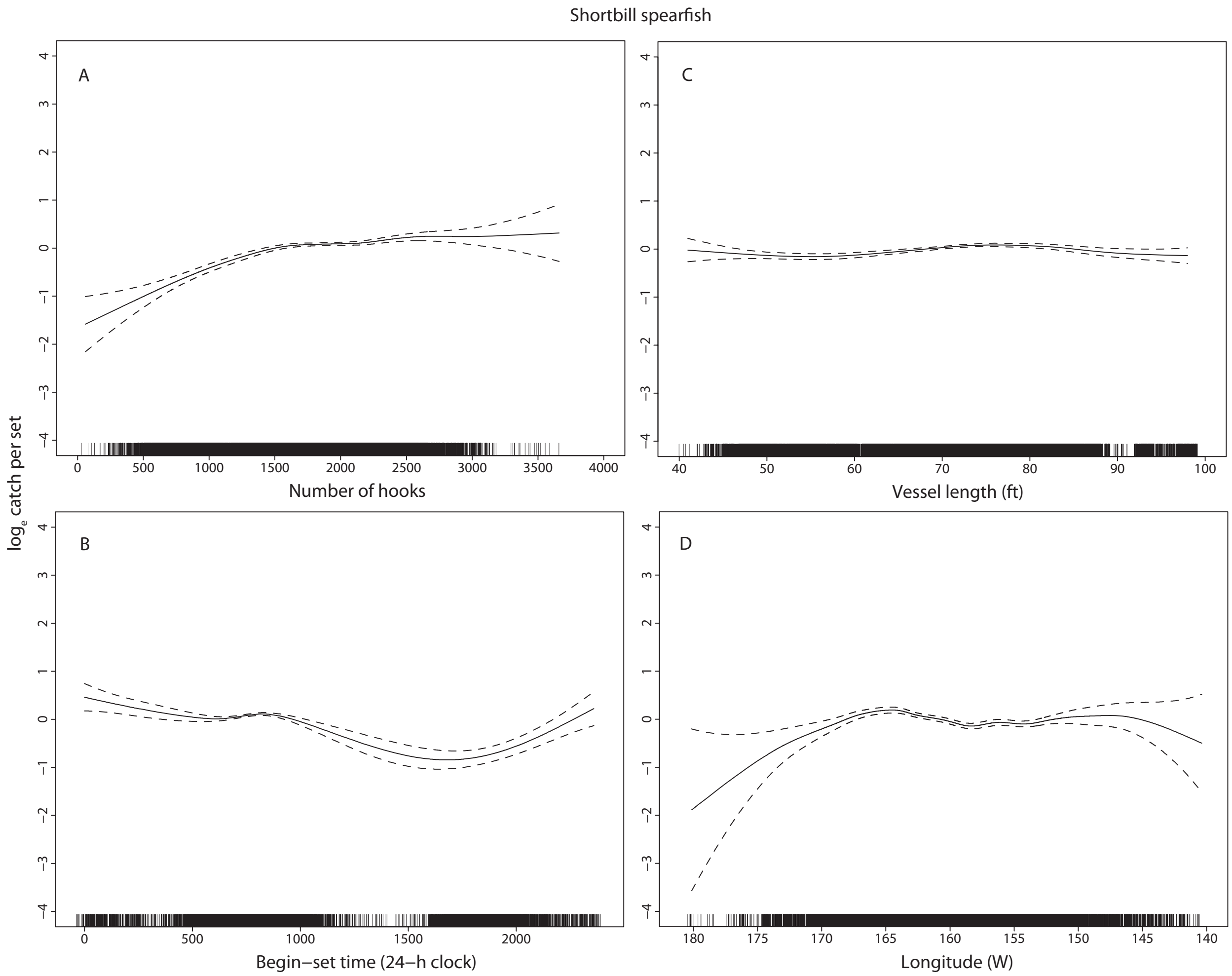

Figure A3.--Smoother traces from a GAM depicting the relationships between shortbill spearfish catches per set and (a) hook numbers per set, (b) begin-set time, (c) vessel length, and (d) longitude.

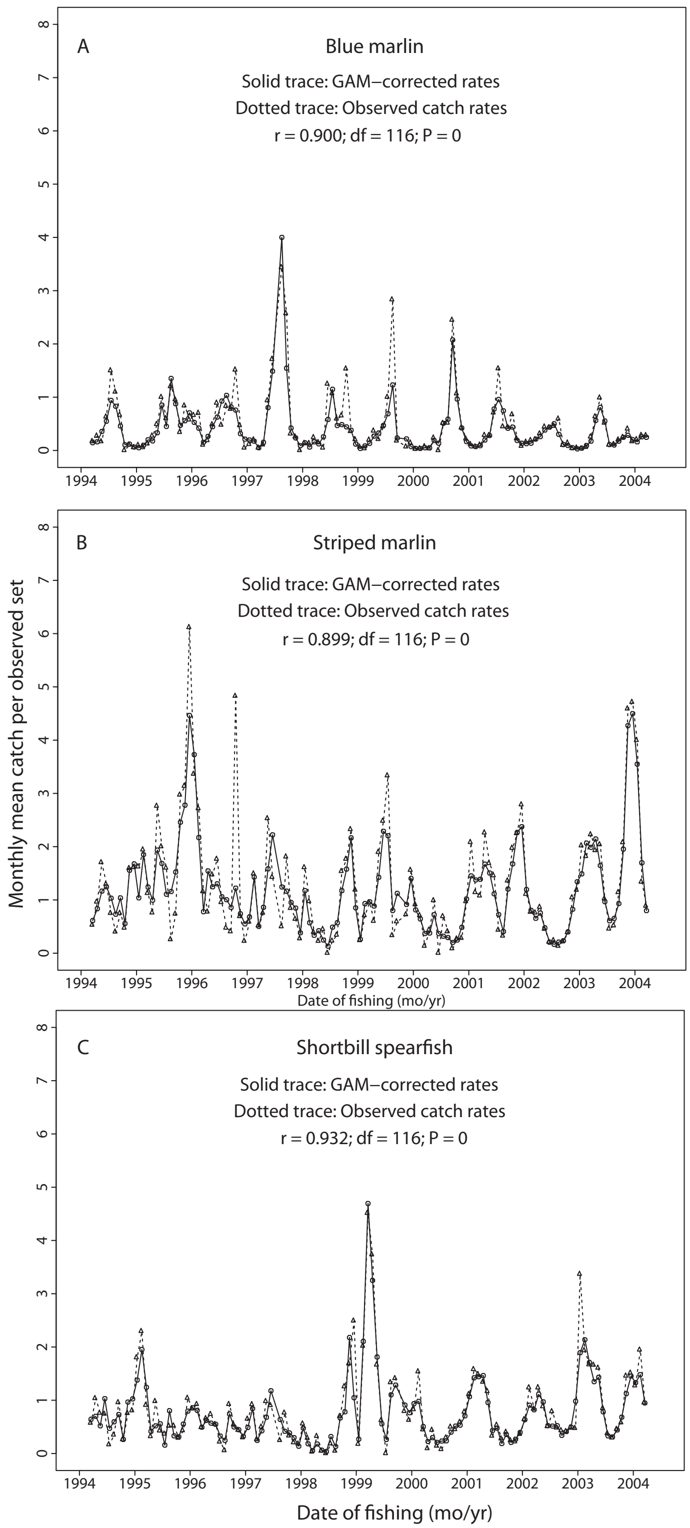

Figure A4.--Time series plots depicting the fit of GAMs for (a) blue marlin, (b) striped marlin, and (c) shortbill spearfish.

Table B1.--Quarterly corrected catch totals and mean weights for striped marlin, blue marlin, and shortbill spearfish by the Hawaii-based longline fishery, March 1994–February 2004.

Year	Quarter	Species						
		Striped marlin			Blue marlin		Shortbill spearfish	
		Corrected catch	Mean weight		Corrected catch	Mean weight	Corrected catch	Mean weight
1994	1	585	NA		125	NA	348	NA
1994	2	3,236	NA		1,019	NA	1,206	NA
1994	3	905	NA		1,779	NA	492	NA
1994	4	3,165	NA		611	NA	1,226	NA
1995	1	4,600	20.5		700	40.5	4,682	15.2
1995	2	5,462	32.8		1,928	71.8	2,296	13.8
1995	3	3,513	25.3		1,835	66.8	639	14.8
1995	4	11,487	26.3		1,596	74.0	1,923	15.6
1996	1	6,046	22.8		990	64.8	2,149	13.6
1996	2	4,755	31.2		1,415	67.7	1,846	13.9
1996	3	2,286	25.4		1,864	73.4	587	14.4
1996	4	3,665	30.9		1,016	64.8	1,533	13.6
1997	1	3,584	24.0		451	57.9	3,658	14.6
1997	2	6,503	34.5		2,451	53.8	1,972	13.2
1997	3	793	34.2		3,237	59.6	581	13.2
1997	4	3,084	27.9		1,119	69.9	1,028	15.3
1998	1	3,144	22.7		457	73.3	1,392	14.9
1998	2	2,716	40.0		1,104	67.0	1,527	14.1
1998	3	1,894	30.0		1,414	73.6	1,471	13.7
1998	4	7,993	27.0		919	71.6	5,309	14.4
1999	1	4,957	22.2		483	51.9	4,642	13.0
1999	2	3,941	30.6		1,308	67.7	6,091	12.2
1999	3	1,836	35.3		1,534	82.2	2,043	14.4
1999	4	4,541	26.1		555	79.2	2,969	16.3

Table B1.--Continued.

Year	Quarter	Species						
		Striped marlin			Blue marlin		Shortbill spearfish	
		Corrected catch	Mean weight		Corrected catch	Mean weight	Corrected catch	Mean weight
2000	1	3,026	22.7		176	73.3	3,095	14.9
2000	2	2,375	40.0		505	67.0	1,850	14.1
2000	3	416	30.0		1,419	73.6	557	13.7
2000	4	1,210	27.0		449	71.6	1,085	14.4
2001	1	2,518	22.7		101	73.3	2,602	14.9
2001	2	2,842	40.0		1,007	67.0	1,693	14.1
2001	3	1,167	30.0		1,567	73.6	850	13.7
2001	4	6,563	27.0		518	71.6	928	14.4
2002	1	2,239	22.2		280	51.9	1,839	13.0
2002	2	1,206	30.6		790	67.7	1,649	12.2
2002	3	280	35.3		607	82.2	840	14.4
2002	4	2,694	26.1		236	79.2	1,843	16.3
2003	1	5,069	22.7		334	73.3	5,743	14.9
2003	2	2,811	40.0		1,350	67.0	2,521	14.1
2003	3	1,681	30.0		422	73.6	1,001	13.7
2003	4	8,837	27.0		727	71.6	2,936	14.4
2004	1	4,565	18.7		509	56.7	2,798	12.6

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