Analysis of Blue Marlin (*Makaira nigricans*) Catch Rates in the Hawaii-based Longline Fishery with a Generalized Additive Model and Commercial Sales Data

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Abstract

Blue marlin, *Makaira nigricans*, represents a major challenge for the Pacific Islands Fisheries Science Center (PIFSC) of NOAA Fisheries because misidentifications of istiophorids are known to be present to an as yet undetermined extent in the logbook data used to monitor the Hawaii-based longline fishery. This paper presents corrected catch rates for blue marlin, obtained by developing a generalized additive model (GAM) of blue marlin catch rates from environmental and operational data gathered by fishery observers and then applying the model coefficients fishery-wide to the logbook reports from unobserved trips to serve as a comparison standard. The aforementioned results were then verified against sales records from the public fish auction that serves as the principal outlet for the landings of this fleet.

The GAM included nine significant predictors and explained 41.1% of the deviance of blue marlin catch rates. The first six entries yielded 95% of its explanatory power. The initial application of the GAM coefficients to the unobserved sets was summarized by

$$\log_e(Y+1) = 0.0693 + 0.6265 \log_e(X+1)$$

where Y represents the logbook value for catch per set and X represents the GAM prediction ($F_{1,87275}$ = 13,530, P=0; R^2 = 0.134; s^2_{y*x} = 0.2051). The residuals from this regression were used in a detailed data evaluation, which demonstrated that a very substantial fraction (39%) of the questionable data was associated with a small minority of the permitted vessels (7%).The GAM coefficients were then applied to the corrected data, and the results were summarized by

$$\log_e(Y+1) = 0.0369 + 0.6205 \log_e(X+1)$$

where Y represents the logbook value (catch per set) and X represents the GAM prediction. The corrections yielded decreases in the y-intercept and variance estimate (0.1624) and increases in the coefficient of determination (R^2 = 0.161) and test statistic ($F_{1,87275}$ = 16,430, P=0). The point estimate from this more accurate and precise regression indicated that the blue marlin nominal total for kept fish was inflated by approximately 19.8%. Additional results include time series plots of catch rates and totals and assessments of releases.

It is concluded that one of the major challenges in a relatively small and carefully monitored fishery, identification and enumeration of billfishes, can be effectively addressed by the integrated use of observer and commercial sales data. As such, considerable improvements in logbook data accuracy are attainable.

Introduction

Blue marlin, *Makaira nigricans*, represents a major monitoring challenge for the Pacific Islands Fisheries Science Center (PIFSC) of NOAA Fisheries because misidentifications of istiophorids are known to be present to an as yet undetermined extent in the daily longline logbook reports that must be submitted upon landing fish for sale in Honolulu[1]. The misidentifications are believed to consist primarily of logbook reports of the other species as blue marlin, but neither the overall misidentifications problem nor the specific problems involving particular species (e.g., striped marlin reported as blue marlin, or black marlin reported as blue marlin) have been quantified.

This paper presents corrected catch rates for blue marlin in the Hawaii-based longline fishery, obtained by developing a generalized additive model (GAM) of blue marlin catch rates from environmental and operational data gathered by fishery observers (Walsh and Kleiber 2001) and then applying the model coefficients fishery-wide to the logbook reports from unobserved trips to serve as a comparison standard (Walsh et al. 2002). The latter authors demonstrated that a GAM could complement observer coverage to estimate underreporting and characterize reporting biases with blue shark, *Prionace glauca*, the predominant bycatch species in this fishery. This paper demonstrates adaptation of these methods for use when the major factor affecting data quality is the accuracy of identifications among much less numerous but far more valuable species. Specifically, this paper relies heavily upon the use of sales records from the public fish auction that serves as the principal outlet for the landings of this fleet as an independent data source to verify analytical results. Because this paper presents an integrated use of observer, logbook, and commercial sales data, it should prove to be of general interest to scientists and managers involved in fishery monitoring.

Materials and methods

Data Sources

The Hawaii Longline Observer Program (HLLOP) was established in March 1994 to monitor interactions between the longline fishery and sea turtles (DiNardo 1993). The observers also record species-specific tallies of the catch and a large suite of environmental and operational details from each set (Fisheries Observer Management, 1998). Because the observers receive specialized training at the outset of employment and thorough debriefings after trips, their records are believed to be generally accurate.

Federally mandated commercial logbook reports 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 deployed by the fleet. The reports provide species-

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[1] Ito, R.Y. and W.A. Machado. 2001. Annual report of the Hawaii-based longline fishery for 2000. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Southwest Fish. Sci. Cent. Admin. Rep. H-01-07, 55 p.

specific tallies of the catch and a subset of the environmental and operational parameters recorded by the observers.

Sales records (i.e., numbers, pounds sold, and dollar value by species) 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. HDAR, in turn, provides these data to the PIFSC. Before 2000, PIFSC or HDAR personnel attended the auction twice weekly (out of six auction working days) to gather data. Sales records were used to verify species identifications when errors were suspected in either the observer or logbook data sets, in which case the numbers of fish logged as kept on any particular trip were compared to the numbers sold. The UFA data were considered definitive because their personnel are very experienced and because price differences among species necessitate careful identification of the fish. We regard this assumption concerning identifications as justified on the basis of long association. When electronically provided or directly recorded auction data were not available for particular trip(s), possible misidentifications were checked by comparing logbook records to monthly sales receipts submitted by fishermen to HDAR. It should be noted that it was not possible to check considerable numbers of questionable trips against sales records before 2000. One reason was that many fishermen in this fleet are mobile in terms of their employment, which can preclude matching sales receipts to particular trips.

Study Duration and Observer Coverage

This study encompassed the 100-month period March 1994-June 2002, with 9242 sets deployed on 774 observed trips. The observer coverage rate through 1999 was approximately 5%, followed by increases to 11% in 2000 and 23% in 2001.

GAM Development

A GAM of catch rates (catch per set) was developed by forward selection using a cubic splines algorithm (Walsh et al. 2002). Direct observer measurements of environmental and operational variables (e.g., hook numbers, fishing positions, catch rates of two co-occurring tunas) were used as predictors, along with weekly mean sea surface temperatures from the NOAA Operational Environmental Spacecraft. Each was allotted 30 nonlinear degrees of freedom. Catch per set was the dependent variable. Because the procedure does not accommodate missing predictor values, it was necessary to delete 6.5% of the sets that had one or more missing predictor value(s) and an additional 0.4% of the sets with extreme predictor values that were highly influential. One trip was deleted because the observer was incapacitated, and an additional 2.1% of the sets were deleted on the basis of comparisons to the UFA sales records (see Results, below). This left 8397 sets, or 90.9% of the observer data, to fit the GAM. The underlying probability distribution of catch per set was assumed to be the Poisson so logarithms were the link function. The fitting procedure involved evaluating each candidate predictor at each fitting stage and entering into the model the predictor that minimized the Akaike Information Criterion (AIC) and residual deviance. Sequential F-tests were used to ensure that all terms were significant, with a $P<0.05$ entry criterion. The model fit was depicted by a time series plot of the monthly mean catch rates reported by the observers with the corresponding monthly mean backtransformed catch rates from the GAM. GAM development and all other statistical procedures described herein were conducted in S-PLUS Version 6.1.2 (2002).

Logbook Data Sample Size

The fleet deployed 91,452 sets on 8473 unobserved trips during the study period, equivalent to 10,974 sets on 1017 trips per year. Of the total, 3.7% of the sets had one or more missing predictor value(s), which precluded application of the GAM coefficients (see below). It was also necessary to delete another 1.0% of the sets because their predictor ranges exceeded those in the observer data. The resulting sample size for the initial application of the GAM was 87,277 sets, equivalent to 95.4% of the unobserved longline effort during the study period.

GAM Application and Comparison of Predictions to Logbook Reports

The fitted GAM coefficients were applied to the unobserved logbook sets with the 'predict.gam' function in S-PLUS, followed by checks against the archived original logbook forms or auction sales data as necessary in order to detect likely misidentifications. The process was initiated by transforming reported and predicted blue marlin catch rates to $\log_e(x+1)$, computing a regression of the transformed logbook catches on the corresponding GAM predictions, and then using the studentized residuals (SR) (Draper and Smith 1980; Cook and Weisberg 1982) in a multi-stage data editing procedure analogous to that in Walsh et al. (2002). The first stage entailed identifying all trips with two or more large SR (i.e., SR$\geq|2|$) and then comparing the numbers of kept blue marlin and other billfishes to numbers sold at the auction. The second entailed assessing all trips since 2000, when full UFA data became available, undertaken by vessels that had exhibited systematic discrepancies in identifications from the auction at least five times. A third criterion for assessing the accuracy of identifications for trips without sales data was predicated upon the circumstantial evidence of vessel history and seasonality. Specifically, trips with three or more large SR undertaken from October through March by vessels that had exhibited systematic discrepancies from UFA three or more times were also judged to be in error. This judgment was based upon results from the first criterion, which indicated that trips in the summer and early autumn months with large positive SR generally reflected high blue marlin catches, whereas those with multiple large positive SR from October through March always reflected apparent misidentifications. The fourth criterion entailed checks on trips with any sets with SR$\geq|3|$, based on the expectation that very large SR might be associated with recording, transcription, or other types of errors. The fifth criterion was predicated upon the known rarity of black marlin in this fishery and the suspected proclivity of certain individuals to log excessive numbers. Trips with three or more black marlin and any large SR that had not been previously evaluated were examined to assess whether these reports reflected misidentifications. The sixth criterion entailed checks on trips undertaken by vessels that had logged 50 or more black marlin during the study period, regardless of the SR, when previous criteria had revealed within-vessel patterns of misidentification. The seventh and final criterion, which was intended to detect under- or nonreporting, entailed checks on trips for which the combined totals for blue marlin, striped marlin, and shortbill spearfish exhibited a shortfall of 10 or more relative to the GAM predicted trip totals for blue marlin. Because auction data were not always available or comprehensible for seemingly questionable trips, the corrections applied to blue marlin logbook data should be regarded as conservative and not comprehensive. Also, when numbers of fish kept exceeded those sold, the corrections were intended to approximate blue marlin as accurately as possible, so the shortfall would tend to be concentrated in the other species.

In cases of apparent systematic misidentifications, logbook trip totals for blue marlin and other billfishes were corrected in proportion to sales records (if available). Many trips exhibited 100% apparent misidentifications (e.g., all billfish logged as blue marlin but all sales reported as striped marlin), but when this was not the case, marlin numbers were changed for selected sets to yield the estimated correct totals. When sales records were not available (e.g., the third criterion, above), trip totals were corrected in proportion to the mean fleetwide ratio of striped marlin:blue marlin caught from October-March (3.5:1) after deleting results from those vessels previously determined to be prone to systematic misidentifications.

The GAM coefficients were then applied to this corrected data set. The regression of logbook catch rates on GAM predictions was assessed in terms of its coefficient of determination, parameter estimates, *F*-test, variance estimate, and residuals plots. The monthly means and sums were computed from the uncorrected logbook data, corrected logbook data, and GAM predictions and plotted as time series to depict the effects of data correction and the correspondence of the three trajectories.

Results

Observer Coverage and Fishing Effort

Observer effort (Table 1) changed considerably in both allocation among set types and coverage rates during the study period. Swordfish, *Xiphias gladius*, sets were the focus of observer coverage in 1994 because these were expected to have the highest sea turtle interaction rates. In 1995, however, observer allocation was revised to approximate fleetwide effort more closely. The levels and allocation of observer coverage among set types then remained roughly constant through 1999, with an average of 36% of the active vessels carrying an observer at least once per year. An increase in coverage that began in 2000 permitted observer coverage aboard 55% of the active vessels that year, 93% in 2001, and 92% in the first half of 2002.

Fleetwide fishing effort also changed markedly from 1994-2002. After peaking at 6040 tonnes in 1993, swordfish landings declined by 48% in 1994 and an additional 10% in 1995 (Ito and Coan 1999). Decreased swordfish-directed effort in 1995 was associated with these declining catch rates. Tuna-targeted effort then began to dominate fleetwide activity, representing 64% of all sets from 1995-2000. Swordfish-targeted activity was closed in 2000 to minimize longline interactions with sea turtles (National Marine Fisheries Service 2003). The result was that nearly all fishing targeted tunas in 2001 and 2002.

Nominal Catch Statistics

The most important aspect of the uncorrected billfish catch statistics for this study (Table 2) was that logbook reports apparently listed excess blue marlin. The observer catch rates were less than those from the logbooks on observed sets, which in turn were less than those from the unobserved sets. This was true in all set types. Black marlin were probably also overreported, and to a far greater extent than blue marlin, because the former species is known to be rare in this fishery.

The uncorrected billfish catch statistics exhibited three other noteworthy features. The first was that blue marlin, striped marlin, and shortbill spearfish catch rates varied among set types, with the lowest rates on swordfish sets. Second, the percent contribution of each species relative to the total catch as reported by the observers was less than the corresponding value for the logbooks on both observed and unobserved sets. This reflects the tendency of some captains to treat the logbook form as a landings report, rather than a total catch report with full species diversity. Finally, the higher mean catch rates for striped marlin and shortbill spearfish in logbooks from unobserved than observed trips were artefactual and reflected disproportional observer coverage relative to fleetwide effort. For example, in six of the nine (whole or partial) calendar years, the mean catch rates reported in logbooks from observed trips for tuna sets were greater than those from unobserved trips, as was expected. There was, however, relatively low observer coverage of tuna-directed fishing early in the study period, particularly in 1995 when 20.5% of the nominal striped marlin catch was harvested. The result was that the mean values from the logbooks on unobserved sets were more strongly affected than the corresponding nominal statistics from observed sets.

Blue Marlin Catch Rates on Observed Sets

The preliminary data evaluation revealed that marlins were systematically misidentified by observers on 2.1%, in the logbooks on 3.2%, and in both observer and logbook reports on 1.2% of the observed trips. Among the 16 observers in the first category, half made the errors on their first or second trip, and two others on their third after previously reporting only three and 10 marlins, respectively. There were no apparent instances of repeated systematic errors by observers. In contrast, the logbook reports in question were provided by two vessels that exhibited systematic errors twice and two others that did so three times. The GAM was fitted after deleting the trips with identifiable systematic errors (Figure 1), with the relationship between logbook (Y) and observer (X) catch records expressed by

$$\log_e(Y+1) = 0.0668 + 0.7901 \log_e(X+1) \qquad (R^2 = 0.512, N = 8397) \qquad \text{Equation 1.}$$

Both regression parameters were influenced by positive logbook values above the expected 45° slope associated with observer reports of zeroes or very low values when auction data were unavailable for verification.

GAM of Blue Marlin Catch Rates

The GAM (Table 3) included nine significant predictors and explained 41.1% of the deviance of blue marlin catch rates. The first six entries yielded 95% of its explanatory power. The fit of the model (Figure 2) is depicted by the monthly mean blue marlin catch rates reported by the observers and the corresponding corrected values throughout the study period. The observer catch rates were greater than the corrected values in mid-1995, mid-1996, and very noticeably in mid-1997. Thereafter, the GAM-corrected monthly means generally tracked closely or slightly above the mean catch rates from the observers. Their correlation was highly significant (r=0.946; df = 96; P = 0), which indicated that the GAM coefficients could reasonably be applied to the logbook predictor values to generate predictions for use in evaluation of unobserved trips.

Application of the GAM to Blue Marlin Catch Rates from Unobserved Trips

The initial application of the GAM coefficients to the unobserved sets was summarized by

$$\log_e(Y+1) = 0.0693 + 0.6265 \log_e(X+1) \qquad \text{Equation 2}$$

where Y represents the logbook value for catch per set and X represents the GAM prediction ($F_{1,87275}$ = 13,530, P=0; R^2 = 0.134; s^2_{y*x} = 0.2051). There were 5361 large SR, which represented 6.1% of the unobserved sets. The preponderance (96.5%) were positive, reflecting higher reported than predicted values, such as occurred when other species were misidentified as blue marlin, particularly near the origin.

The detailed data evaluation (Table 4) revealed two major features of the blue marlin logbook catch data. First, a very substantial fraction (39%) of the large SR was disproportionately associated with a small minority of the permitted vessels (7%), which indicated that the records from these vessels were habitually in error. The second feature was the scope of the misidentifications problem. For example, the first criterion, which led to checks on 36% of the large SR, revealed that 18% of the nominal catch of blue marlin was misidentified. The preponderance involved striped marlin and some shortbill spearfish logged as blue, inflating the nominal blue marlin catch total, but other blue marlin were logged as black, reducing the blue marlin catch total and thereby acting as a countervailing influence. Criteria 2-5 revealed that an additional 2% of the nominal blue marlin catch was misidentified, with striped marlin logged as blue once again the principal source of inaccuracy. In contrast, Criteria 6-7 primarily led to corrections of other species that had been logged as black marlin, which raised the blue marlin total. The noteworthy feature of the final category, checked and accepted data, was that 79% of the sets were deployed from April through September. The entire suite of checks indicated that the blue marlin nominal total for kept fish was inflated by approximately 19.8%.

The GAM coefficients were then applied to the corrected data (Table 5), which are presented as trip totals in Figure 3 (N = 8417 longline trips), and the results were summarized by

$$\log_e(Y+1) = 0.0369 + 0.6205 \log_e(X+1) \qquad \text{Equation 3}$$

where Y represents the logbook value (catch per set) and X represents the GAM prediction. The corrections yielded decreases in the y-intercept and variance estimate (0.1624) and increases in the coefficient of determination (R^2 = 0.161) and test statistic ($F_{1,87275}$ = 16,430, P=0). The point estimate for the total blue marlin catch was 34,580 fish.

The monthly mean blue marlin catch rates (Figure 4) exhibited highly significant correlations between the GAM predictions and both the corrected (r = 0.888; d.f. = 98; P = 0) and uncorrected logbook data (r = 0.787; d.f. = 98; P = 0), although the three trajectories did not track closely on two occasions. The uncorrected mean rates peaked in September 1995, caused largely by misidentifications of striped marlin on four trips by four vessels, which collectively inflated the monthly mean by 1.0 blue marlin per set. The GAM predictions peaked in July-August 1997, but this reflected very low observer coverage (1.1% of the deployed sets). The monthly catch totals (Figure 6) again demonstrated that the greatest effect of the corrections occurred in the autumn of 1995. There were also misidentifications in the fourth quarter of 2001 equivalent to 19% of the nominal annual and 52% of the nominal quarterly catch totals, but the availability of full auction data allowed reconciliation of the sums of the GAM predictions and corrected logbook data to within 0.5%.

Releases

This fishery was characterized by low blue marlin release rates. The mean release rate reported by the observers was 0.03 per set for all sets, and 1.2 per set when one or more releases were reported. The mean release rate in the logbooks from observed sets was 0.01 per set, and 1.2 per set when the release value was positive. The mean from unobserved sets was also 0.01 per set, and 0.9 per set when releases were reported. The releases from unobserved trips included 13% that were misidentified, from four trips by two vessels.

Effects on Other Species' Nominal Catch Statistics

The corrections of blue marlin logbook data necessitated substantial minimum changes from the striped marlin and black marlin nominal catch totals. Correction of 2.7% of the longline sets indicated that the striped marlin catch total was at least 8.2% greater than reported, whereas correction of only 0.4% of the sets yielded a -14.2% change in the black marlin total. The nominal catch total for shortbill spearfish would increase by 1.0% in response to correction of 0.4% of the sets.

Discussion

This study has documented that one of the major challenges in a relatively small and carefully monitored fishery, identification and enumeration of billfishes, can be effectively addressed by the integrated use of observer and commercial sales data. As such, considerable improvements in logbook data accuracy are attainable.

The results have revealed several important features of both the observer and logbook data. Regarding the former, it is apparent that job experience is probably the most important factor regarding data quality. Regarding the latter, the results demonstrated that a small number of vessels (or captains) who habitually submit erroneous reports can have very substantial effects on the official catch statistics that are compiled directly from the logbooks. The results also revealed both the types and extent of the misidentifications problem in this fishery, and demonstrated that use of the residuals tends to detect real errors and not simply random variation. It is therefore concluded that the analyses described herein, characterized by detailed integrated use of observer and commercial sales data, represent a useful study in logbook data quality control.

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Table 1. Summary of effort data from the Hawaii-based longline fishery used in the development and application of a GAM of blue marlin catch per set. Entries are the numbers of trips, vessels, sets, and percentages of set types in observer and logbook reports.

	Observer data (all data)						Logbook data (all data)					
Year	Vessels	Trips	Longline sets	Set types			Vessels	Trips	Longline sets	Set types		
				SF	M	T				SF	M	T
1994 - 2002	143	774	9242	6.4	15.3	78.4	173	8473	91,452	10.5	22.0	67.5

	Observer data (data used in GAM development)						Logbook data (data used in GAM application)					
Year	Vessels	Trips	Longline sets	Set types			Vessels	Trips	Longline sets	Set types		
				SF	M	T				SF	M	T
1994 - 2002	143	724	8397	6.8	16.6	76.6	173	8417	87,277	10.4	22.2	67.5
1994	45	47	484	48.1	17.4	34.5	121	803	7757	40.0	12.4	47.6
1995	43	47	526	13.1	36.1	50.8	110	1079	11,045	15.0	24.5	60.4
1996	47	52	617	9.4	43.1	47.5	104	1047	10,929	9.6	31.4	59.1
1997	33	37	461	11.5	46.2	42.3	105	1083	11,319	8.8	26.3	64.9
1998	40	47	542	11.3	32.7	56.0	115	1092	11,776	9.3	26.7	64.0
1999	36	39	430	12.8	28.6	58.6	120	1098	12,260	5.9	26.4	67.7
2000	69	107	1233	2.8	20.0	77.2	124	988	9622	4.9	27.3	67.8
2001	94	213	2297	0.4	4.0	95.6	101	803	8573	0.0	3.2	96.8
2002	89	156	1807	0.0	0.0	100.0	97	424	3996	0.0	0.4	99.6

Table 2. Summary of catches, percent contributions to the entire catch of the fishery, mean catches per set, and mean catch per unit effort (CPUE=fish per 1000 hooks) for four istiophorid billfishes taken by the Hawaii-based longline fishery on observed (Obs, *N*=9242) and unobserved (Log (U); *N*=91,452) sets, March 1994-June 2002. Logbook data from observed sets (Log (O)) are provided for comparison. Catch rates are presented pooled and by set types. All data are uncorrected.

		All Set Types				Tuna Sets		Mixed Sets		Swordfish Sets	
Species	Source	Catches	Percentage of Total	Catch/ Set	CPUE	Catch/ Set	CPUE	Catch/ Set	CPUE	Catch/ Set	CPUE
Blue marlin	Obs	3768	0.9	0.41	0.30	0.43	0.27	0.44	0.52	0.11	0.13
	Log (O)	4544	1.5	0.49	0.37	0.50	0.32	0.58	0.69	0.16	0.19
	Log (U)	46762	1.6	0.51	0.46	0.49	0.35	0.70	0.86	0.27	0.31
Black marlin	Obs	67	<0.1	0.01	0.01	0.01	<0.01	0.01	0.02	<0.01	<0.01
	Log (O)	260	0.1	0.03	0.02	0.03	0.02	0.02	0.03	0.01	0.02
	Log (U)	5620	0.2	0.06	0.05	0.07	0.04	0.06	0.07	0.03	0.03
Shortbill spearfish	Obs	7401	1.7	0.80	0.48	0.96	0.55	0.27	0.29	0.10	0.13
	Log (O)	6544	2.1	0.71	0.42	0.86	0.48	0.23	0.25	0.05	0.07
	Log (U)	68161	2.3	0.75	0.47	1.02	0.60	0.25	0.26	0.05	0.06
Striped marlin	Obs	11207	2.6	1.21	0.81	1.32	0.76	0.97	1.13	0.50	0.63
	Log (O)	9739	3.1	1.05	0.70	1.16	0.67	0.76	0.89	0.42	0.54
	Log (U)	107259	3.7	1.17	0.88	1.39	0.87	0.86	1.04	0.44	0.56

Table 3. Analysis of deviance of a nine-variable GAM of blue marlin catch rates (catch per set). The reductions in the Akaike Information Criterion (AIC) and residual deviance, degrees of freedom, and the *F* test and associated significance are presented for each term.

Predictor Variable	ΔAIC	ΔResidual Deviance	df	F_{enter}	*P*
Date of fishing	2199.48	2257.38	28.9	49.173	0
Begin-set time	823.33	879.79	29.2	21.174	0
SST (°C)	600.65	661.50	30.4	15.679	0
Longitude	143.14	202.64	29.7	5.167	0
Latitude	100.09	159.85	29.9	4.135	$3.1*10^{-13}$
Hooks/set	57.54	115.97	29.2	3.109	$3.5*10^{-8}$
Vessel length	27.69	87.77	30.0	2.346	$4.5 *10^{-5}$
Yellowfin tuna/set	15.98	77.01	30.5	2.037	0.0006
Bigeye tuna/set	4.46	63.97	29.8	1.738	0.008

Null deviance = 10958.46, df = 8396.

Residual deviance = 6452.58, df = 8128.32.

Pseudo-R^2 = (10958.46-6452.58)/10958.46
= 0.411

Table 4. Summary of logbook data editing after the initial GAM application (N = 87277 longline sets). Initial data are the numbers of sets with large studentized residuals (i.e., SR≥|2|), kept blue marlin from these sets, vessels with various SR totals, and trips with one or more large SR. Sequentially edited data entries include numbers of unobserved trips, sets, and vessels at each criterion, the numbers of kept fish reported in the logbooks with the corresponding numbers sold, and the percent change from the nominal initial total (43,747 kept blue marlin).

Initial Data

Sets with Large SR	Blue Marlin on Large SR Sets	Trips with Large SR	Trips with ≥2 Large SR	Vessels with Large SR	Vessels with ≤50 Large SR	Vessels with 51-99 Large SR	Vessels with ≥100 Large SR
5361	23,363	2161	1106	151	120	19	12

Checked, Corrected Data

Criterion	Trips	Vessels	Sets	Large SR	Blue Marlin		Striped Marlin		Shortbill Spearfish		Black Marlin		∆ Blue Marlin (%)
					Log	Sold	Log	Sold	Log	Sold	Log	Sold	
Direct checks against sales data, ≥2 large SR per trip.	356	72	4166	1955	10,572	2590	3448	11,058	2790	3320	242	42	-18.2
Direct checks against sales data; all trips (1/00-6/02) by vessels with ≥5 prior discrepancies against sales data.	12	7	138	40	181	47	40	165	56	73	3	0	-0.3
Trips by vessels with prior auction discrepancies (≥5X); October-March; ≥3 large SR per trip.	14	7	149	79	423	85	30	338	173	173	4	0	-0.8

Table 4, continued.

Checked, Corrected Data

Criterion	Trips	Vessels	Sets	Large SR	Blue Marlin Log	Blue Marlin Sold	Striped Marlin Log	Striped Marlin Sold	Shortbill Spearfish Log	Shortbill Spearfish Sold	Black Marlin Log	Black Marlin Sold	△ Blue Marlin (%)
SR≥|3|	9	2	88	44	266	20	7	253	116	116	0	0	-0.6
Black marlin (≥3 per trip + SR)	12	10	123	41	223	93	187	407	126	162	157	0	-0.3
≥50 Black marlin per vessel during study	31	8	335	8	105	183	318	423	175	281	285	1	0.2
Possible underreporting	10	8	117	12	46	155	50	50	52	45	102	0	0.2

Checked, Uncorrected Data

Criterion	Trips	Vessels	Sets	Large SR	Blue Marlin Log	Blue Marlin Sold	Striped Marlin Log	Striped Marlin Sold	Shortbill Spearfish Log	Shortbill Spearfish Sold	Black Marlin Log	Black Marlin Sold	△ Blue Marlin (%)
Direct checks against sales data	97	45	1007	261	2250	2212	797	830	436	476	0	2	----

Table 5. Regression of logbook reports of blue marlin catches per set on GAM predictions after transforming both variables to $\log_e(X+1)$[a].

	d.f.	Value	Sum of Squares	Standard Error	Mean Square	t	F	P	R^2
Source of variation									
Regression	1		2721.903		2721.903		6801.870	0.000	
Residuals	87275		14171.019		0.162				
Parameter									
Intercept		0.0369		0.0019		19.2963		0.000	0.161
Coefficient		0.6205		0.0048		129.4734		0.000	

[a] 95% CI (regression coefficient): 0.6111 - 0.6299.

Figure Legends

Figure 1. Blue marlin catch totals per trip on observed trips as reported in logbooks in relation to the corresponding observer reports from March 1994 through June 2002.

Figure 2. Correspondence between GAM-corrected and uncorrected monthly mean blue marlin catch rates from March 1994 through June 2002.

Figure 3. GAM-corrected, log-transformed blue marlin catch totals per trip as reported in logbooks in relation to GAM predictions from March 1994 through June 2002.

Figure 4. Monthly mean blue marlin catch per set estimated by the GAM, and from both the corrected and uncorrected logbook data from March 1994 through June 2002.

Figure 5. Monthly blue marlin catch totals estimated by the GAM, and from both the corrected and uncorrected logbook data from March 1994 through June 2002.