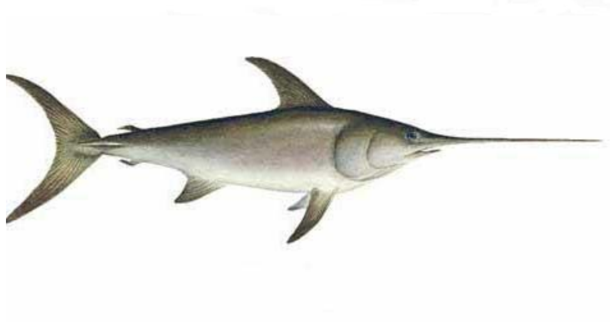
International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

ISC/08/BILLWG-1/01

Model selection for standardizing striped marlin catch-per-unit-effort in the Hawaii-based longline fishery

Jon Brodziak
NOAA Fisheries
Pacific Islands Fisheries Science Center
2570 Dole St., Honolulu, HI, 96822, USA

William Walsh
Joint Institute of Marine and Atmospheric Research
NOAA Fisheries
Pacific Islands Fisheries Science Center
2570 Dole St., Honolulu, HI, 96822, USA



[1]Working document submitted to the ISC Billfish Working Group Workshop, January 8-15, 2008, Honolulu, Hawaii, USA. Document not to be cited without authors' written permission.

Model selection for standardizing striped marlin catch-per-unit effort in the Hawaii-based longline fishery

Jon Brodziak and William Walsh

Pacific Islands Fisheries Science Center, Honolulu, HI 96822-2326
Email: Jon.Brodziak@NOAA.GOV

Striped marlin (*Tetrapturus audax*) are captured primarily as incidental catch in the Hawaii-based longline fishery. Striped marlin catches in this fishery average about 400 t per year, or roughly 2/3 of the total striped marlin catch by US fisheries in the western Pacific region (Dalzell and Boggs 2003). A time series of standardized striped marlin catch-per-unit effort (CPUE) has been developed using fisheries observer data collected in this fishery since 1994 (ISC 2007). This CPUE series was used as a relative abundance index in the most recent North Pacific striped marlin stock assessment (Piner et al. 2007).

In March 2007, the ISC Marlin and Swordfish Working Groups recommended development of a standardized CPUE series for striped marlin in the Hawaii-based longline fishery that would incorporate yearly and quarterly effects. It was also recommended that the CPUE series include an estimate of variance. In this working paper, we refine the CPUE standardization approach developed by Brodziak and Walsh (2007) and apply it to compare alternative generalized linear models (GLMs) to produce standardized CPUE estimates and their precision by year and quarter.

To do this, we fit a total of 40 alternative GLMs to the set of 13,737 observed set during 1994 through the first quarter of 2004. This set of GLMs represented the Cartesian product of three hypotheses about the appropriate spatial scale (n=4), the set of predictors (n=5), and the appropriate seasonal effect (n=2). The spatial scale hypotheses (S_k) were identical to those investigated by Brodziak and Walsh (2007). The first hypothesis (S_1) was that spatial scale could be modeled using separate latitudinal and longitudinal effects where latitude and longitude were categorized as factors in 1˚ bins. The second hypothesis (S_2) treated longitude the same as hypothesis S_1 but modeled latitude as a 2^{nd} order polynomial. The third hypothesis (S_3) modeled latitude as a 2^{nd} order polynomial and longitude as a continuous linear effect. The fourth hypothesis (S_4) modeled latitude and longitude using the four quadrants (Q1-Q4) defined by the median set location of all observed striped marlin sets (Figure 1).

The set of predictor hypotheses (P_k) were also identical to those investigated by Brodziak and Walsh (2007). Using R or S-PLUS formula notation with "Y" equal to the number of striped marlin per set, the null GLM formula was

(1.1) $$glm\left(Y \sim year + season + hooks + poly(SST,2) + S + permit\right)$$

where the baseline CPUE predictors were year, season (month or quarter, see below), hooks, SST, permit, and one of the spatial scale hypotheses S. The first hypothesis (P_1) was that the set of predictors included the null GLM plus vessel length, moon phase, and set time; this was the full model. The second hypothesis (P_2) was the null GLM plus vessel length and moon phase. The third hypothesis (P_3) was that the set of predictors was the null GLM plus vessel length. The fourth hypothesis (P_4) was the null GLM. The fifth hypothesis (P_5) was that the predictors included the null GLM plus vessel length and set time.

The seasonal effect hypotheses (H_k) were that season was most appropriately modeled as either a quarter (H_Q) or a month (H_M) effect.

In previous analyses (Walsh et al. 2005, Brodziak and Walsh 2007), the striped marlin catch count data were modeled by an overdispersed Poisson distribution and approximated using the robust Poisson family as implemented in S-PLUS. In this application, we fit the overdispersed Poisson model using a quasi-likelihood GLM with variance function (V) equal to the mean (μ) and link function equal to $\log(\mu)$ in order to directly calculate the overdispersion parameter (σ^2) (McCullagh and Nelder 1989). As a result, the log-likelihood of the striped marlin catch (y_i) was

(1.2) $$\log L\left(\underline{\mu},\underline{y}\right) = \sum_i \left(y_i \log\left(\mu_i\right) - \mu_i\right)$$

and the scaled deviance function $D(\underline{y}, \underline{\mu})$ was

(1.3) $$D\left(\underline{y},\underline{\mu}\right) = 2\log L\left(\underline{y},\underline{y}\right) - 2\log L\left(\underline{\mu},\underline{y}\right) = 2\sum_i \left(y_i \log\left(y_i / \mu_i \right) - \left(y_i - \mu_i\right)\right)$$

Maximum likelihood estimates (MLE) of model parameters were based on minimizing the deviance for each alternative model.

Model selection criteria to choose a single best model among competing models have been developed by Akaike (*AIC*, 1983), Schwarz (1978), Spiegelhalter et al. (2002) and numerous others (see Burnham and Anderson 2002, for example). One of the more commonly applied model selection criteria is the Bayesian (a.k.a. Schwarz, *BIC*) Information Criterion (Schwarz 1978). The *BIC* can be expressed in terms of deviance (*D*) evaluated at the MLE, and a parameter penalty term which depends on the number of parameters (*p*) and sample size (*N*)

(1.4) $$BIC = D + p \cdot \log\left(N\right)$$

The model with the lowest value of *BIC* among competing models gives the best fit to the data. We used *BIC* to select the best fitting GLM for CPUE standardization (Table 1) since previous work indicated that *BIC* and *AIC* produced very similar estimates of standardized CPUE for striped marlin using the Hawaii-based longline data set (Brodziak and Walsh 2007). We also applied Bayesian model averaging to the set of probable models to provide a sensitivity analysis to model selection uncertainty (Brodziak and Legault 2005, Brodziak and Walsh 2007).

Model selection results indicated that the most probable model was (S_3, P_1, H_M). This model explained approximately 38% of model deviance using 191 parameters, roughly 77 units of deviance per parameter, with an estimated overdispersion parameter of σ^2=2.23. In this case, the spatial dimension was modeled using a quadratic submodel for latitude and a linear submodel for longitude. The set of predictors included all of the potential explanatory variables and the seasonal effect was modeled using month. All of the explanatory variables were significant based on F-tests ($P<0.05$) although some predictors explained a small percentage of the overall deviance (Table 2). Overall, the most important explanatory variables were year, month, vessel length, sea surface temperature and latitude (Figures 2.1-2.5).

The most probable model was used to predict striped marlin catch and its variance on unobserved sets in the Hawaii-based longline fishery during 1994 through the first quarter of 2004. Information on 103,745 unobserved sets was collected from reported logbook data for predicting striped marlin CPUE and calculating quarterly standardized CPUE and its precision (Table 3). During this period, the majority of sets of longline hooks were unobserved although there was an increasing trend in fraction of total sets observed (Figure 3). A comparison of the nominal CPUE from the observed hooks and the predicted CPUE from unobserved hooks indicated that the two series exhibited similar trends (Figure 4.1). However there were some notable differences between observed and predicted CPUE, e.g., the fourth quarter of 1997. As a result of these differences, the angular deviation (θ) between the observed (x) and predicted CPUE (y) vectors was about 18 degrees where $\cos(\theta) = \langle x, y\rangle / \sqrt{\langle x, x\rangle \langle y, y\rangle}$. A comparison of the nominal CPUE from the observed sets and the standardized CPUE computed from observed and unobserved sets also indicated that these series exhibited similar trends (Figure 4.2). In this case, the angular deviation between the nominal and standardized CPUE was 17 degrees. Last, a comparison of the estimated standardized CPUE from the most probable model and the model average estimate of standardized CPUE indicated that the model selection uncertainty was relatively unimportant (Figure 4.3) for the set of alternative models investigated using the striped marlin catch data from the Hawaii-based longline fleet.

References

Akaike, H. 1983. Information measures and model selection. International Statistical Institute 44:277-291.

Brodziak, J. and C. Legault. 2005. Model averaging to estimate rebuilding targets for overfished stocks. Can. J. Fish. Aquat. Sci. 62:544-562.

Brodziak, J., and W. Walsh. 2007. Aspects of model selection for generalized linear models applied to striped marlin in the Hawaii-based longline fishery. Pelagic Longline Catch Rate Standardizations Workshop, Honolulu, HI. Working Paper 1, 68 p.

Burnham, K., and D. Anderson. 2002 Model selection and multimodel inference, 2nd ed. Springer Verlag, NY, 488 p.

Dalzell, P. and C. Boggs. 2003. Pelagic fisheries catching blue and striped marlin in the WS Western Pacific Islands. Mar. Freshw. Res. 54:419-424.

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean [ISC]. 2007. Report of the marlin and swordfish working group joint workshop. Intercessional Workshop, March 19-26, 2007, Institute of Oceanography, National Taiwan University, Taipei, Taiwan, 51 p.

McCullagh, P., and J. Nelder. 1989. Generalized linear models. Chapman & Hall, New York, 511 p.

Piner, K., R. Conser, G. Dinardo, and J. Brodziak. 2007. Stock synthesis 2 sensitivity runs for striped marlin assessment WG 2007. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/MARWG-SWORWG-1/Working Paper 2.

Schwarz, G. 1978. Estimating the dimension of model. Ann. Stat. 6:461-464.

Spiegelhalter, D.J., N. Best, B. Carlin, and A. van der Linde. 2002. Bayesian measures of model complexity and fit. J. Royal. Stat. Soc., Ser. B 64:1-34.

Walsh, W.A., R.Y. Ito, K. E. Kawamoto, and M. McCracken. 2005. Analysis of logbook accuracy for blue marlin in the Hawaii-based longline fishery with a generalized additive model and commercial sales data. Fish. Res. 75:175-192.

Table 1. Model selection results for alternative CPUE standardization models using residual deviance, number of parameters, and the Bayesian information criterion.

Alternative Model												
Spatial Hypothesis	Predictor Hypothesis	Seasonal Hypothesis	Residual Deviance	Model Deviance	Percent Deviance Explained	Deviance per Parameter	Degrees of Freedom	Number of Parameters P	BIC	Δ BIC	Relative Likelihood	Model Probability
S_1	P_1	H_M	23168.0	15279.7	40%	57.9	13472	264	25683.3	121.4	0.00000	0.00
S_1	P_2	H_M	23182.4	15265.3	40%	58.0	13473	263	25688.2	126	0.00000	0.00
S_1	P_3	H_M	23200.6	15247.1	40%	58.4	13475	261	25687.3	125.4	0.00000	0.00
S_1	P_4	H_M	23274.2	15173.5	39%	59.0	13479	257	25722.8	160.8	0.00000	0.00
S_1	P_5	H_M	23187.1	15260.6	40%	58.2	13474	262	25683.3	121.4	0.00000	0.00
S_2	P_1	H_M	23490.4	14957.3	39%	65.0	13506	230	25681.8	119.8	0.00000	0.00
S_2	P_2	H_M	23507.3	14940.4	39%	65.2	13507	229	25689.2	127.2	0.00000	0.00
S_2	P_3	H_M	23524.3	14923.4	39%	65.7	13509	227	25687.1	125.1	0.00000	0.00
S_2	P_4	H_M	23588.3	14859.4	39%	66.6	13513	223	25713.0	151.0	0.00000	0.00
S_2	P_5	H_M	23508.3	14939.4	39%	65.5	13508	228	25680.6	118.6	0.00000	0.00
S_3	**P_1**	**H_M**	**23742.2**	**14705.5**	**38%**	**77.0**	**13545**	**191**	**25562.0**	**0**	**1.00000**	**0.51**
S_3	**P_2**	**H_M**	**23754.3**	**14693.4**	**38%**	**77.3**	**13546**	**190**	**25564.6**	**2.6**	**0.26684**	**0.14**
S_3	**P_3**	**H_M**	**23773.8**	**14673.9**	**38%**	**78.1**	**13548**	**188**	**25565.0**	**3.1**	**0.21474**	**0.11**
S_3	P_4	H_M	23837.6	14610.1	38%	79.4	13552	184	25590.7	28.7	0.00000	0.00
S_3	**P_5**	**H_M**	**23762.6**	**14685.1**	**38%**	**77.7**	**13547**	**189**	**25563.4**	**1.4**	**0.49055**	**0.25**
S_4	P_1	H_M	24629.1	13818.6	36%	72.3	13545	191	26448.9	887.0	0.00000	0.00
S_4	P_2	H_M	24630.7	13817.0	36%	72.7	13546	190	26441.0	879.0	0.00000	0.00
S_4	P_3	H_M	24653.0	13794.7	36%	73.4	13548	188	26444.2	882.2	0.00000	0.00
S_4	P_4	H_M	24716.0	13731.8	36%	74.6	13552	184	26469.1	907.1	0.00000	0.00
S_4	P_5	H_M	24651.6	13796.1	36%	73.0	13547	189	26452.3	890.4	0.00000	0.00
S_1	P_1	H_Q	24109.2	14338.5	37%	56.0	13480	256	26548.3	986.4	0.00000	0.00
S_1	P_2	H_Q	24132.7	14315.0	37%	56.1	13481	255	26562.3	1000.3	0.00000	0.00
S_1	P_3	H_Q	24151.8	14295.9	37%	56.5	13483	253	26562.3	1000.4	0.00000	0.00
S_1	P_4	H_Q	24214.1	14233.6	37%	57.2	13487	249	26586.5	1024.5	0.00000	0.00
S_1	P_5	H_Q	24129.6	14318.1	37%	56.4	13482	254	26549.6	987.7	0.00000	0.00
S_2	P_1	H_Q	24548.1	13899.6	36%	62.6	13514	222	26663.2	1101.3	0.00000	0.00
S_2	P_2	H_Q	24578.6	13869.2	36%	62.8	13515	221	26684.2	1122.2	0.00000	0.00
S_2	P_3	H_Q	24596.3	13851.5	36%	63.2	13517	219	26682.8	1120.9	0.00000	0.00
S_2	P_4	H_Q	24646.5	13801.2	36%	64.2	13521	215	26695.0	1133.0	0.00000	0.00
S_2	P_5	H_Q	24567.0	13880.7	36%	63.1	13516	220	26663.1	1101.1	0.00000	0.00
S_3	P_1	H_Q	24789.8	13657.9	36%	74.6	13553	183	26533.4	971.4	0.00000	0.00
S_3	P_2	H_Q	24815.9	13631.8	35%	74.9	13554	182	26550.0	988.0	0.00000	0.00
S_3	P_3	H_Q	24833.6	13614.1	35%	75.6	13556	180	26548.6	986.6	0.00000	0.00
S_3	P_4	H_Q	24884.8	13562.9	35%	77.1	13560	176	26561.7	999.8	0.00000	0.00
S_3	P_5	H_Q	24808.9	13638.8	35%	75.4	13555	181	26533.4	971.4	0.00000	0.00
S_4	P_1	H_Q	25984.6	12463.1	32%	68.1	13555	183	27728.2	2166.2	0.00000	0.00
S_4	P_2	H_Q	25997.6	12450.1	32%	68.4	13556	182	27731.6	2169.7	0.00000	0.00
S_4	P_3	H_Q	26018.8	12428.9	32%	69.0	13558	180	27733.8	2171.8	0.00000	0.00
S_4	P_4	H_Q	26064.2	12383.5	32%	70.4	13562	176	27741.1	2179.1	0.00000	0.00
S_4	P_5	H_Q	26006.4	12441.3	32%	68.7	13557	181	27730.9	2169.0	0.00000	0.00

Table 2. Analysis of deviance table for the best fitting GLM (S_3, P_1, H_M) .

	Degrees of Freedom	Null Deviance
NULL	13736	38447.7

Explanatory Variable	Number of Parameters	Deviance Explained	Percent Deviance Explained	Deviance per Parameter	Residual Degrees of Freedom	Residual Deviance	F Statistic	P-Value
year	10	4397.077	11.4%	440	13726	34050.63	197.3326	0
month	11	3994.956	10.4%	363	13715	30055.67	162.9874	0
hooks	1	591.954	1.5%	592	13714	29463.72	265.6579	0
SST	2	1873.914	4.9%	937	13712	27589.8	420.4887	0
latitude	2	1066.732	2.8%	533	13710	26523.07	239.3646	0
longitude	1	330.949	0.9%	331	13709	26192.12	148.5236	0
vessel length	157	2354.556	6.1%	15	13552	23837.57	6.7305	0
permit	4	63.752	0.2%	16	13548	23773.82	7.1527	9.5E-06
moon phase	2	19.49	0.1%	9.7	13546	23754.33	4.3733	0.012627
set time	1	12.169	0.0%	12	13545	23742.16	5.4612	0.019457

Table 3. Predicted, observed, and standardized striped marlin CPUE in the Hawaii-based longline fishery, 1994-2004.

	Angle with Nominal	18.2	0	17.1	17.2	17.3
Year	Quarter	Predicted Catch per Thousand Hooks	Observed (Nominal) Catch per Thousand Hooks	Lower 95% Standardized Catch per Thousand Hooks	Standardized Catch per Thousand Hooks	Upper 95% Standardized Catch per Thousand Hooks
1994	1	0.412	0.493	0.391	0.422	0.453
1994	2	0.797	1.277	0.788	0.821	0.855
1994	3	0.481	0.629	0.459	0.486	0.513
1994	4	1.401	1.080	1.327	1.388	1.450
1995	1	1.501	1.239	1.423	1.488	1.553
1995	2	1.420	1.812	1.385	1.437	1.490
1995	3	0.810	0.768	0.771	0.808	0.845
1995	4	2.563	3.249	2.484	2.583	2.683
1996	1	1.225	1.849	1.206	1.257	1.308
1996	2	1.244	1.130	1.193	1.237	1.281
1996	3	0.506	0.557	0.483	0.508	0.533
1996	4	1.668	1.451	1.591	1.659	1.728
1997	1	0.983	0.928	0.942	0.980	1.019
1997	2	0.930	1.266	0.910	0.944	0.977
1997	3	0.415	1.074	0.405	0.425	0.445
1997	4	1.614	0.513	1.511	1.577	1.643
1998	1	0.837	0.962	0.804	0.841	0.879
1998	2	0.745	0.227	0.708	0.736	0.763
1998	3	0.352	0.601	0.351	0.367	0.383
1998	4	1.381	1.217	1.313	1.371	1.429
1999	1	0.632	0.470	0.597	0.626	0.655
1999	2	0.621	1.117	0.616	0.638	0.661
1999	3	0.266	0.472	0.257	0.269	0.282
1999	4	0.934	0.725	0.887	0.925	0.962
2000	1	0.222	0.413	0.224	0.233	0.243
2000	2	0.212	0.545	0.218	0.226	0.235
2000	3	0.068	0.203	0.075	0.078	0.081
2000	4	0.337	0.285	0.305	0.318	0.332
2001	1	0.858	0.861	0.826	0.859	0.891
2001	2	0.666	0.957	0.679	0.706	0.733
2001	3	0.240	0.388	0.256	0.267	0.278
2001	4	1.118	1.255	1.112	1.148	1.184
2002	1	0.342	0.466	0.370	0.381	0.392
2002	2	0.296	0.290	0.284	0.294	0.305
2002	3	0.122	0.103	0.113	0.117	0.122
2002	4	0.516	0.415	0.478	0.493	0.508
2003	1	1.079	1.011	1.030	1.064	1.097
2003	2	0.909	0.843	0.863	0.894	0.925
2003	3	0.344	0.371	0.339	0.351	0.362
2003	4	1.445	1.925	1.527	1.570	1.614
2004	1	1.113	0.984	1.036	1.076	1.116

Figure 1. Median location of sets with some striped marlin catch versus all observed sets in Hawaii-based longline fishery, 1994 through Q1 2004.

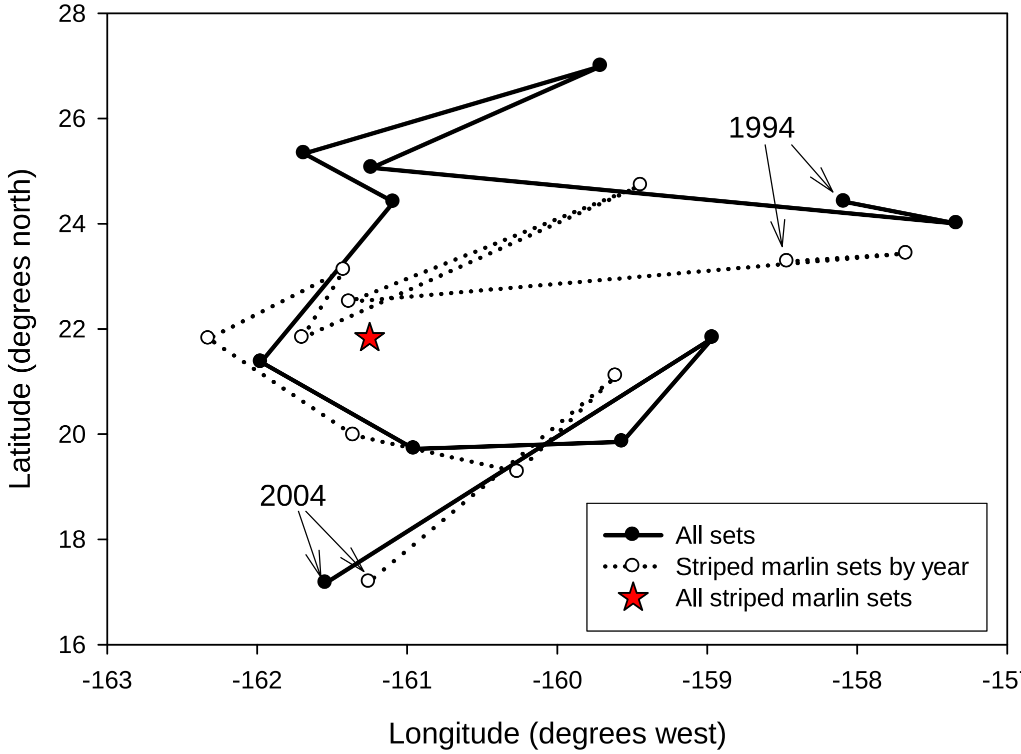


Figure 2.1. Predicted year effect scaled to equal nominal CPUE in 1994 versus nominal observed striped marlin CPUE along with 95% confidence intervals for the predicted values.

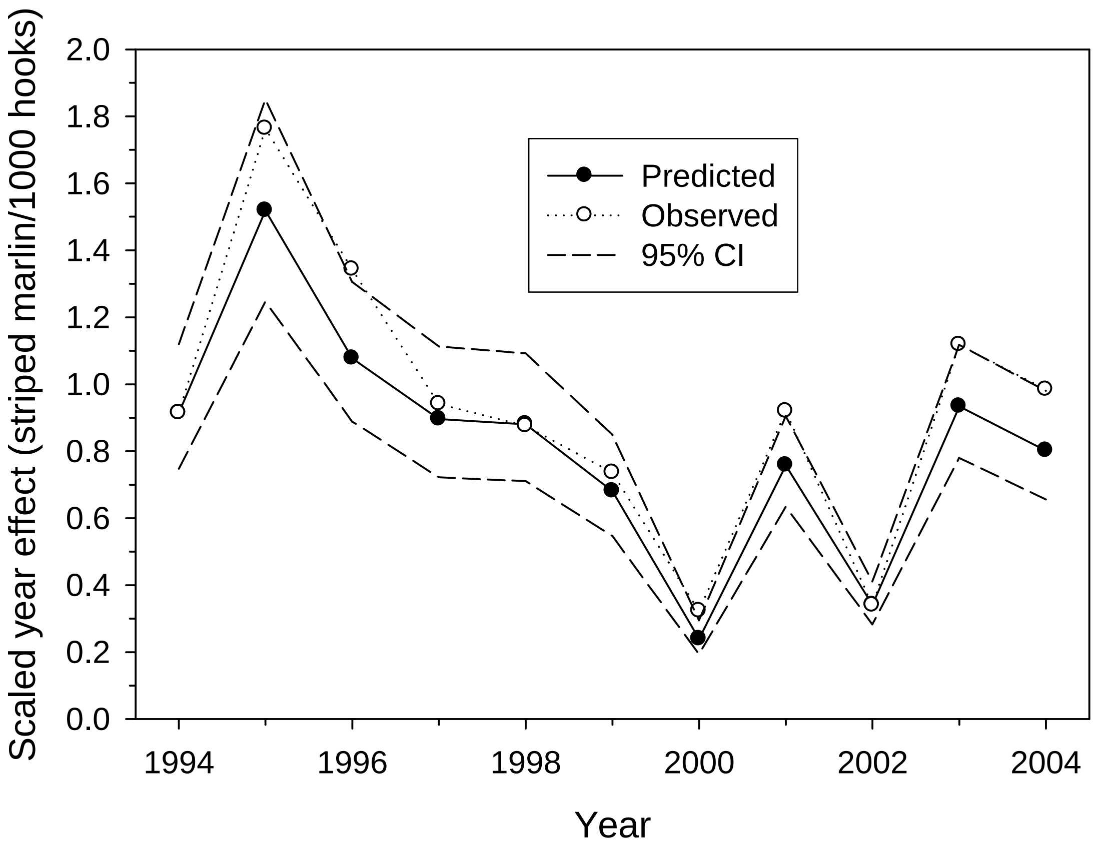


Figure 2.2. Predicted month effect along with 95% confidence intervals for the predicted values.

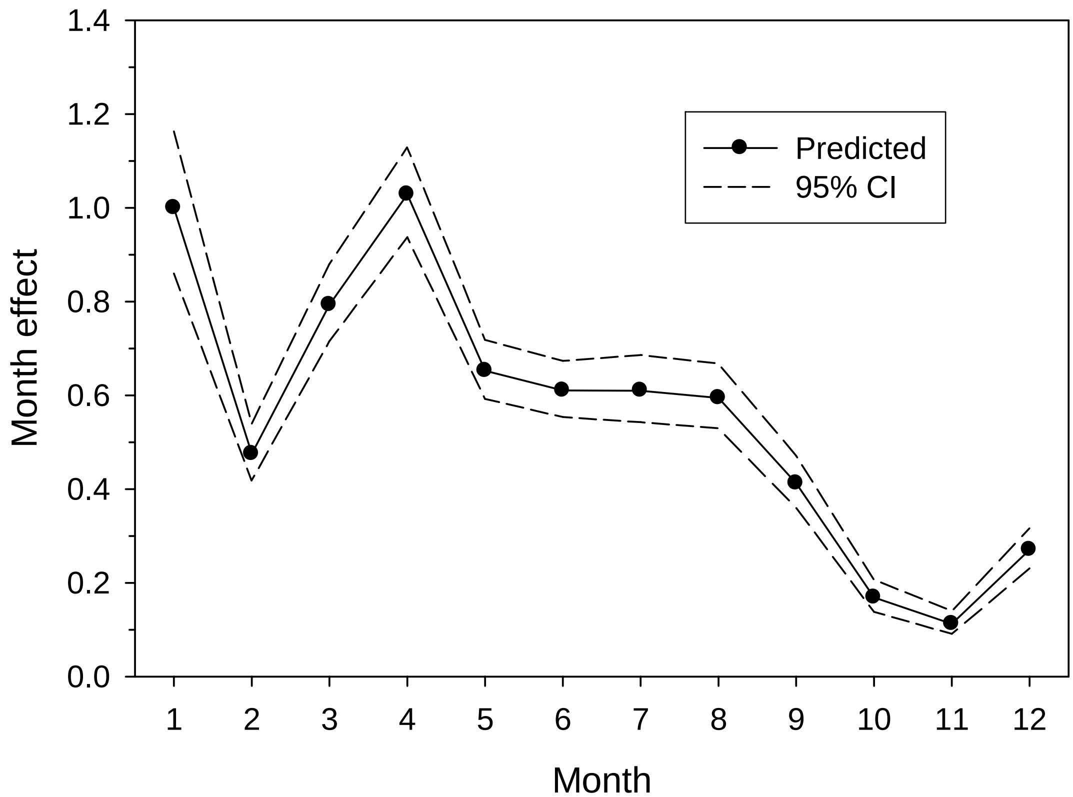


Figure 2.3. Predicted vessel length effect along with 95% confidence intervals for the predicted values.

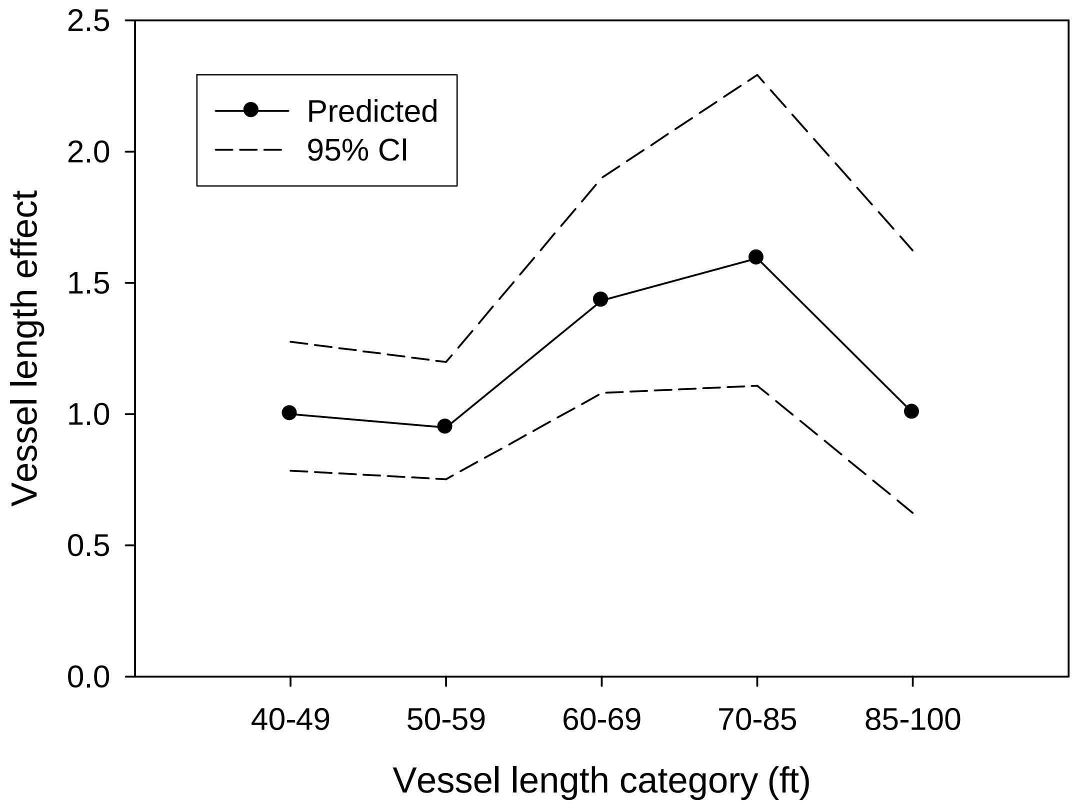


Figure 2.4. Predicted quadratic sea surface temperature (SST) effect along with 95% confidence intervals for the predicted values.

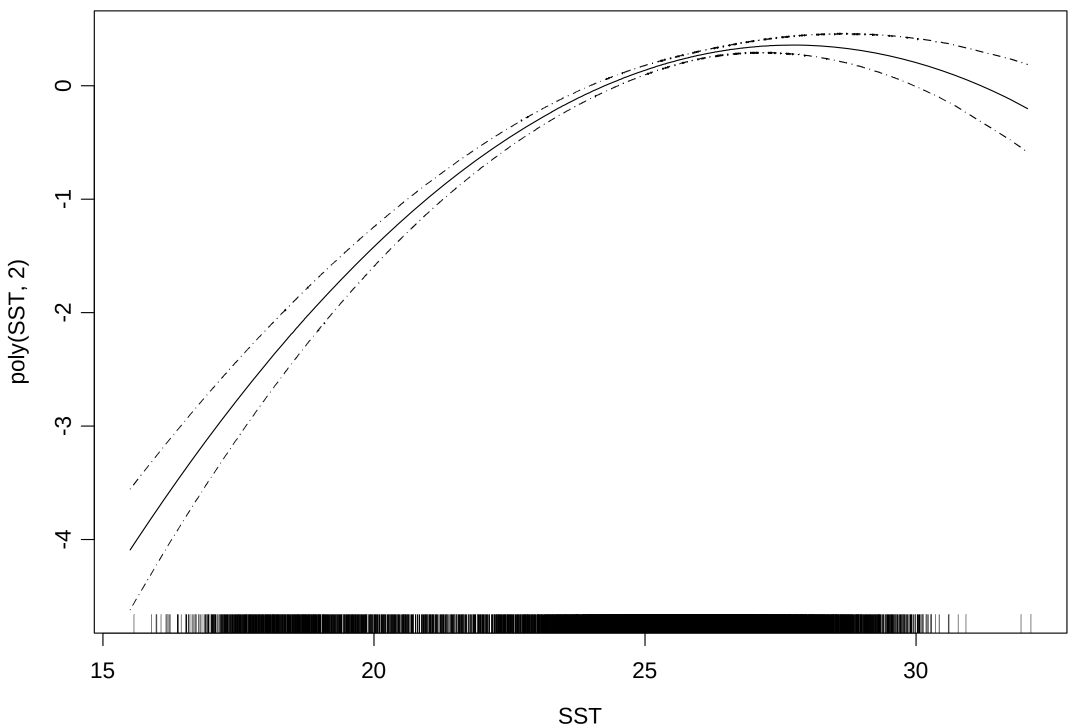


Figure 2.5. Predicted quadratic latitude effect along with 95% confidence intervals for the predicted values.

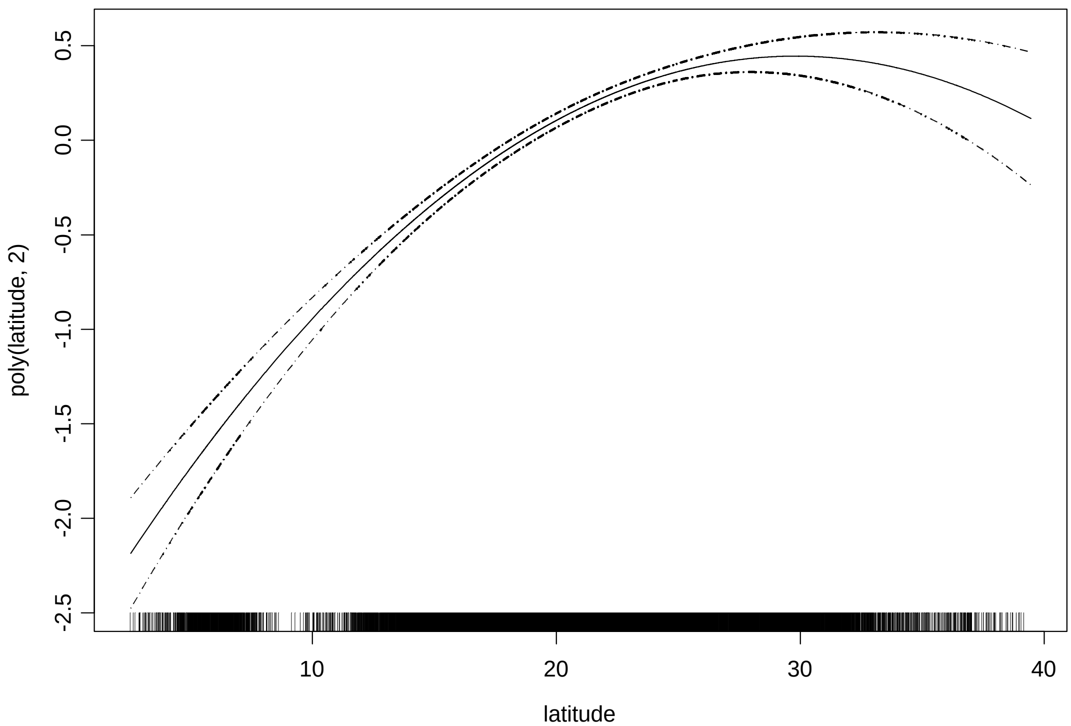


Figure 3. Number of unobserved (logbook) and observed hooks deployed in the Hawaii-based longline fishery during 1994 through the first quarter of 2004 along with the fraction of total hooks monitored by fisheries observers.

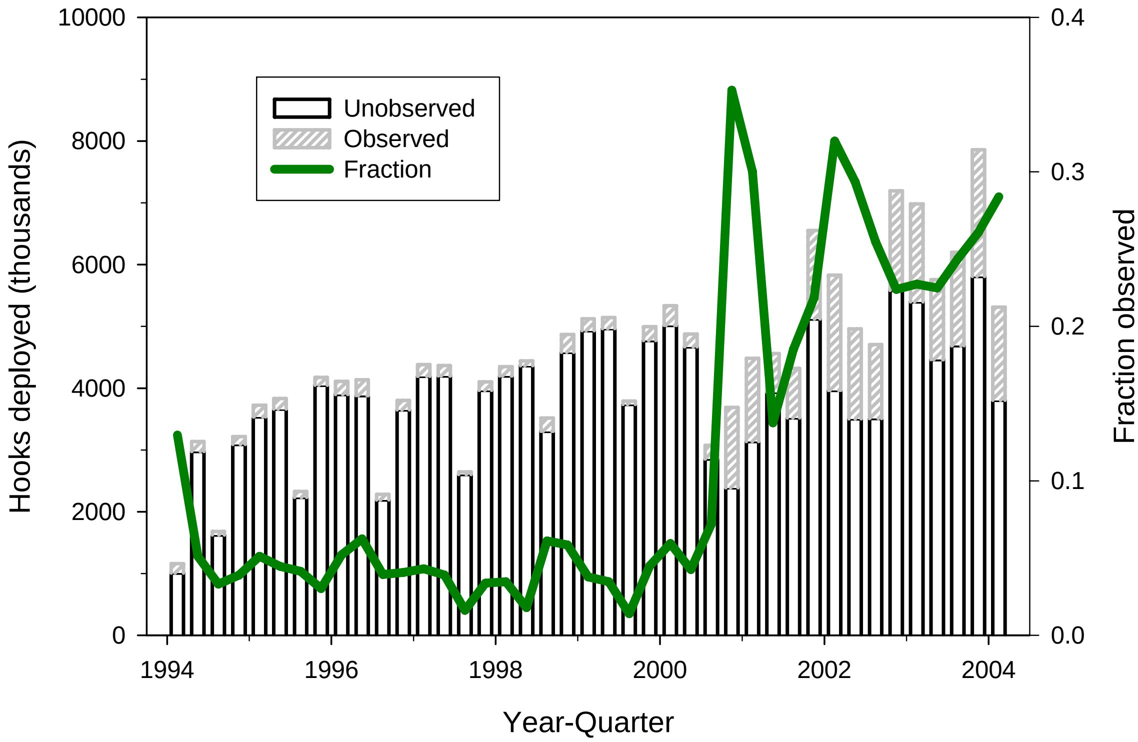


Figure 4.1. Comparison of trends in observed and predicted striped marlin CPUE for the Hawaii-based longline fishery during 1994 through the first quarter of 2004.

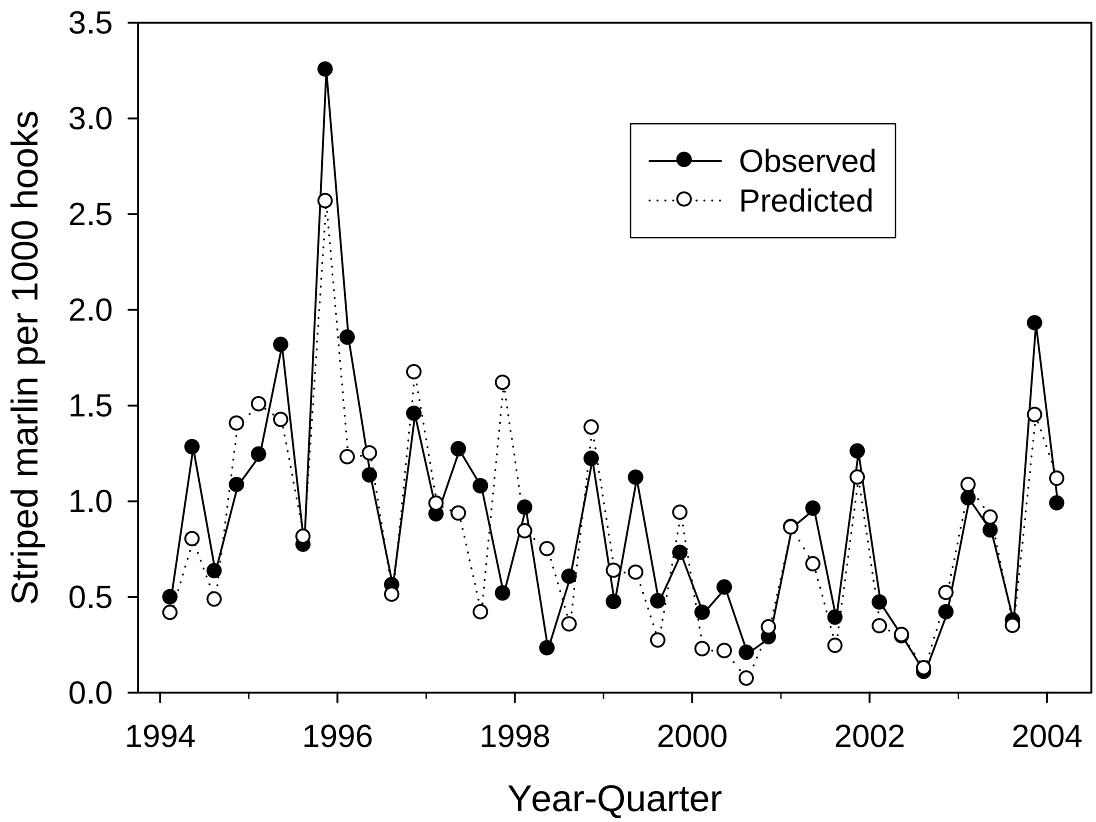


Figure 4.2. Comparison of trends in observed and standardized striped marlin CPUE for the Hawaii-based longline fishery during 1994 through the first quarter of 2004.

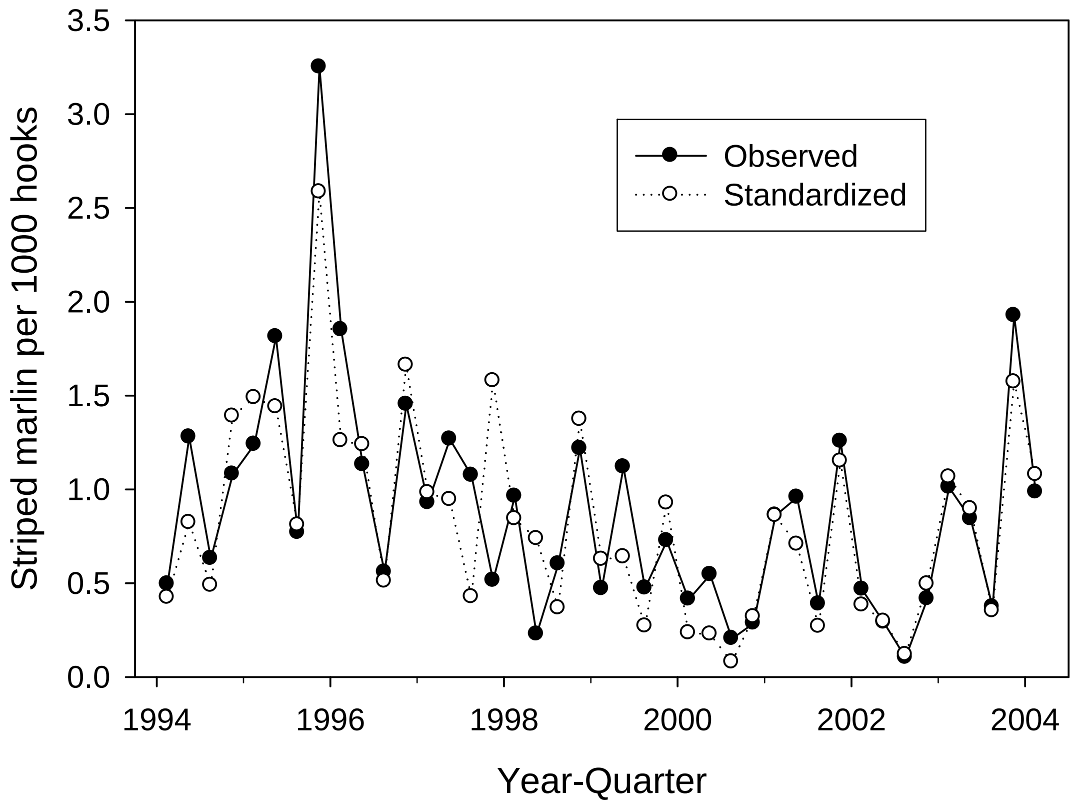


Figure 4.3. Comparison of trends in standardized striped marlin CPUE from the most probable model and the model averaged estimate of standardized CPUE for the Hawaii-based longline fishery during 1994 through the first quarter of 2004 along with approximate 95% confidence intervals for the model averaged estimate.