SCRS/02/065

STANDARDIZED CATCH RATES FOR WHITE MARLIN (*Tretapturus albidus*) AND BLUE MARLIN (*Makaira nigricans*) FROM THE PELAGIC LONGLINE FISHERY IN THE NORTHWEST ATLANTIC AND THE GULF OF MEXICO.

Mauricio Ortiz and Gerald P. Scott[1]

SUMMARY

Indices of abundance of white and blue marlin from the United States pelagic longline fishery in the Atlantic are presented for the period 1986-2000/2001. The index of weight (kg) per number of hooks (thousand) was estimated from numbers of marlins caught and reported in the logbooks submitted by commercial fisherman, and from mean annual weight estimated by scientific observers aboard longline (Pelagic Observer Program) vessels since 1992. The standardization analysis procedure included the following variables; year, area, season, gear characteristics (light sticks, main line length, hook density, etc) and fishing characteristics (bait type, operations procedure, and target species). The standardized index was estimated using Generalized Linear Mixed Models under a delta lognormal model approach.

KEYWORDS

Catch/effort, abundance, longline, Fish catch statistics, logbooks, Multivariate analyses

1. INTRODUCTION

Information on the relative abundance of marlins is necessary to tune stock assessment models. Data collected from the US longline fleet has been used to develop standardized catch per unit of effort (CPUE) indices of abundance for billfish species including blue and white marlin (Ortiz and Scott 2001, Cramer 1998). This report documents the analytical methods applied to the available US longline fleet data through 2000 (logbooks) and 2001 (Observers), and presents correspondent standardized CPUE indices for the Atlantic white and blue marlin stock units. Catch in numbers and effort data were obtained from the Pelagic Longline Logbook (PLL) reports data, while size information was gathered from the Pelagic Observer Program (POP). The US longline fleet operates over a wide geographical range of the western North Atlantic Ocean and although billfish are not now targeted nor landed by the US fleet, this bycatch constitutes a component of fishery mortality on these stocks that can be quantified.

2. MATERIALS AND METHODS

Hoey and Bertolino (1988) described the main features of the fleet and numerous authors (Hoey et al. 1989, Scott et al. 1993, Cramer and Bertolino 1998, Ortiz et al. 2000) have reviewed the available catch and effort data from the US Pelagic Longline fishery. The present report updates the catch and effort information through 2000 and 2001 (observers) and includes analyses of variability associated

[1] U.S. Department of Commerce National Marine Fisheries Service Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, Florida 33149 U.S.A. email Mauricio.Ortiz@noaa.gov

with random factor interactions particularly for interactions that include the *Year* effect, following the suggestion of the statistics and methods working group of the SCRS in 1999.

Logbook records from the US Longline Pelagic fleet have been collected since 1986. From 1986 to 1991, submission of logbooks was voluntary, and thereafter, submission of logbook reports became mandatory. Swordfish, yellowfin, and other tunas are the main target species for the US Pelagic Longline fleet. Marlins are not retained by the U.S. fleet, although catch records of these and other by-catch species are recorded on logbooks. Since 1992, trained observers have recorded detailed information on gear characteristics, fishing operations as well morphometric and biological information from a target sub-sample level of 5% of the US longline Pelagic effort (Lee and Brown 1998). These constitute the Pelagic Observer Program (POP) data, which provide size and weight information on marlins caught by longline operations

The Pelagic Longline Logbook data comprises a total of 238,188 record-sets from 1986 through 2000 (data for year 2001 was unavailable at the time of this report). Each record contains information of catch by trip/set, including: date and time, geographical location, catch in numbers of targeted and bycatch species, and fishing effort (as number of hooks per set). Of these trips, white marlin was reported as being caught in 21,557 sets (9.0%), while blue marlin was reported in 22,603 sets (9.5%).

Logbooks only record numbers of fish. As per the recommendation of the SCRS Billfish Species Group, indices of abundance should be reported both in weight and numbers of fish, when possible. In order to convert number of fish to weight, size information on blue and white marlin caught by the US longline fleet was retrieved from the POP. The POP covers about 5% of the total annual U.S. Atlantic pelagic longline trips, but POP data are available only since 1992. Figure 1 shows box plots of the size distribution for blue and white marlin, respectively from the POP data by year. The number of blue and white marlin measured was 1,227 and 2,065, respectively. Mean size was estimated for year-area-season stratum if at least 20 fish were measured per cell, if not mean size of year area or year stratum was used. Conversion from mean length size to weight used the current size-weight relationships for combined sex (Prager et al. 1995). For years prior to 1992, the mean size value from 1992 was applied.

The longline fishing grounds for the US fleet extends from the Grand Banks in the North Atlantic to latitudes of 5-10° south, off the South America coast, including the Caribbean Sea and the Gulf of Mexico. Eight geographical areas of longline fishing were used for classification (Fig 2). These include: the Caribbean, Gulf of Mexico, Florida East coast, South Atlantic Bight, Mid-Atlantic Bight, New England coastal, Northeast distant waters, the Sargasso Sea - North central Atlantic, and Southern Offshore area. Calendar quarters were used to account for seasonal fishery distribution through the year (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec). Other factors included in the analyses of catch rates included; the use of light-sticks and the density of light-sticks, type of bait (alive or dead), and a variable named operations procedure (OP), which is a categorical classification of US longline vessels based on their fishing configuration, type and size of the vessel, and main target species and area of operation(s).

Fishing effort is reported in terms of the total number of hooks per trip and number of sets per trip. As number of hooks per set varies, catch rates were calculated as number of marlin caught per 1000 hooks. The U.S. Atlantic longline fleet targets mainly swordfish and yellowfin tuna, but other tuna species are also targets including bigeye tuna and albacore (to a lesser extent, some of the trips-sets target other pelagic species including sharks, dolphin and small tunas). A target variable was defined based on the proportion of the number of swordfish caught to the total number of fish per set, with four discrete target categories corresponding to the ranges 0-25%, 25-50%, 50-75%, and 75-100%. As marlins are not a targeted species by the US longline fleet, this measure of targeting was investigated to allow evaluation of targeting towards swordfish or tunas.

For the PLL data, relative indices of abundance for sailfish were estimated by a GLM approach assuming a delta-lognormal model distribution. The delta model fits separately the proportion of positive sets assuming a binomial error distribution and the mean catch rate of sets where at least one marlin was caught assuming a lognormal error distribution. The standardized index is the product of these model-estimated components. The log-transformed frequency distribution for white marlin and blue marlin are shown in figure 3, respectively. The estimated proportion of successful sets per stratum is assumed to be the result of *r* positive sets of a total *n* number of sets, and each one is an independent Bernoulli-type realization. The estimated proportion is a linear function of fixed effects and interactions. The logit function was used as a link between the linear factor component and the binomial error. For sets that caught at least one marlin (positive observations), estimated CPUE rates were assumed to follow a lognormal error distribution (lnCPUE) of a linear function of fixed factors and random effect interactions, particularly when the *Year* effect was within the interaction.

For the POP data relative indices of abundance for marlins were also estimated by a GLM approach assuming a delta lognormal distribution. In previous report a comprehensive evaluation of the relationship between marlins catch rates and multiple factors from the POP data were performed (Ortiz and Scott, 2001). The POP data includes information from 1992 through 2001. The present analysis follows the same factors and categorization of continuous variables as selected in previous report, including: year, area, OP (operations procedure), target species (as specified by the captain prior to the set), season (quarterly months), light-sticks (0, 0-0.75, and > 0.75 light-sticks per hook), hook density, rattlers, surface lights, main line material (1= nylon, 2 = others), hook manufacture (three categories), hook type (circle hooks, J-type hooks, and unknown), hook size (7/0-10/0, 11/0-16/0, and unknown), weather condition (Clear/cloudy, Rain/snow, Severe, Unknown), distance between gangions (< 30 fathoms, ≥ 30 fathoms), main line length (< 30 NM, ≥ 30 NM), bait kind (including mackerel, herring, squid, sardine, scad, artificial lures, unknown, and several mixed combination of these types), and bait type (classifying sets as live bait only, dead bait, and mixed).

A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability. Because, the difference of deviance between two consecutive (nested) models follows a χ^2 (Chi-square) distribution, this statistic was used to test for the significance of an additional factor in the model. The number of additional parameters associated with the added factor minus one corresponds to the number of degrees of freedom in the χ^2 test (McCullagh and Nelder, 1989 pp 393). Deviance analysis tables are presented for both data series, each table includes the deviance for the proportion of positive observations (*i.e.* positive trips/total trips), and the deviance for the positive catch rates. Final selection of explanatory factors was conditional to: a) the relative percent of deviance explained by adding the factor in evaluation (normally factors that explained more than 5% were selected), b) the χ^2 test of significance, and c) the Type-III test significance within the final specified model.

Once a set of fixed factors was specified, possible interactions were evaluated, and in particular interactions between the *Year* effect and other factors. Selection of the final mixed model was based on the Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion (SBC), and a chi-square test of the difference between the [–2 loglikelihood statistic] between successive model formulations (Littell et al. 1996). Relative indices for the delta model formulation were calculated as the product of the year effect least square means (LSmeans) from the binomial and the lognormal model components. The LSmeans estimates use a weighted factor of the proportional observed margins in the input data to account for the un-balanced characteristics of the data. LSmeans of lognormal positive trips were bias corrected using Lo et al., (1992) algorithms. Analyses were done using the GLIMMIX and MIXED procedures from the SAS® statistical computer software (SAS Institute Inc. 1997).

3. RESULTS AND DISCUSSION

Table 1 and 2 show the deviance analysis for blue and white marlin, respectively from the POP data analyses. In the case of blue marlin, the fixed effects of year, area, and season were the major factors that explained the probability of capture of at least one blue marlin. For the mean catch rate of positive sets, the fixed effects of year, area, and OP, and the interactions year*area and year*OP were more significant. For white marlin, the expected probability of capture at least one fish was mainly associated with year, area, and season factors including year*area, year*OP and area*season interactions. White marlin catch rates of positive sets were mainly explained by the year, area, and OP factors.

Once a set of fixed factors was selected, we evaluated first level random interactions between the year and other effects. Table 3 shows the results from the random test analyses. All three-selection criteria used (AIC, SBC and 2 residual log likelihood) showed agreement for the best model selection.

The deviance analyses of the Pelagic Longline Logbook data are show in Table 4 and 5. For blue marlin the proportion of positive sets was explained by the area, season, target and the interaction of year*area. The mean catch rate for sets with blue marlin catch was best explained by the main effects of year, area, OP, and the interactions year*area, year*OP. In the case of white marlin, the proportion of positive sets was best explained by the area, season, OP, target, and the interactions year*OP, year*area, and area*season. While mean catch rates of positive sets was best explained by the factors year, area, OP, light sticks and the interactions year*area, year*OP, area*season. Table 6 shows the evaluation of mixed model formulations of blue and white marlin standardization procedure. All interactions that included the year factor were treated as random interactions.

Standardized CPUE for blue marlin are shown in Table 7 and Figure 4. Coefficients of variation for the blue marlin analysis of the PLL data range from 21 to 31%. For white marlin standardized CPUE are shown in Table 8 and Figure 4, coefficients of variation range from 24% to 31%. For comparison, standardized CPUE were also estimated using number of fish per thousand hooks as dependent variable in the Pelagic Longline Logbook dataset. Model formulations were the same as the final models for the weight analyses in terms of explanatory variables and interactions (Table 9 and 10). Overall the trends were similar to the ones observed in the weight CPUE series. In order to have a more rigorous comparison, both weight and number of fish CPUE series were normalized to a mean zero and one standard deviation (Fig 5). For blue and white marlin, the weight and number CPUE series follow similar trend, the major difference between the series occurs in 1996 in the case of blue marlin.

A comparison of the standardized CPUE series from the PLL and the POP data is shown in Figure 6 for blue and white marlin, respectively. In this plot, the standard CPUE series are scaled to the respective mean of the overlapping years (1992-2000); In general, confidence intervals were much larger for the POP data (Table 11 and 12). White marlin shows a closer correlation between the PLL and the POP standardized CPUEs, than does blue marlin; overall the white marlin trend is marginally different for the 1995 and 1997 years only, although the confidence bounds generally completely overlap.

REFERENCES

CRAMER, J. 1998. Large Pelagic Logbook catch rate indices for Billfish. Col. Vol. Sci. Pap. ICCAT, 47:301-307.

CRAMER, J. and A. Bertolino. 1998. Standardized catch rates for swordfish (*Xiphias gladius*) from the U.S. longline fleet through 1997. Col. Vol. Sci. Pap. ICCAT, 49(1):449-456.

HOEY, J.J. and A. Bertolino. 1988. Review of the U.S. fishery for swordfish, 1978 to 1986. Col. Vol. Sci. Pap. ICCAT, 27:256-266.

HOEY, J.J., R. Conser and E. Duffie. 1989. Catch per unit effort information from the U.S. swordfish fishery. Col. Vol. Sci. Pap. ICCAT, 29:195-249.

LEE, D.W. and C.J. Brown. 1998. SEFSC Pelagic Observer Program Data Summary for 1992-1996. NOAA Tech. Memo. NMFS-SEFSC-408, 21 pp.

LITTELL, R.C., G.A. Milliken, W.W. Stroup, and R.D Wolfinger. 1996. SAS® System for Mixed Models, Cary NC, USA:SAS Institute Inc., 1996. 663 pp.

LO, N.C., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

MCCULLAGH, P. and J.A. Nelder. 1989. Generalized Linear Models 2nd edition. Chapman & Hall.

ORTIZ, M. J. Cramer, A. Bertolino and G. P. Scott. 2000. Standardized catch rates by sex and age for swordfish (*Xiphias gladius*) from the U.S. Longline Fleet 1981-1998. Col. Vol. Sci. Pap. ICCAT, 51:1559-1620.

ORTIZ, M and G. P. Scott. 2001. Standardized catch rates for blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) from the pelagic longline fishery in the northwest Atlantic and the Gulf of Mexico. Col. Vol. Sci. Pap. ICCAT, 53:231-248.

PRAGER, M.H., E. D. Prince and D. W. Lee. 1995. Empirical length and weight conversion equation: for blue marlin, white marlin, and sailfish from the North Atlantic Ocean. *Bull of Mar. Sci*. 56(1):201-210.

SAS Institute Inc. 1997, SAS/STAT® Software: Changes and Enhancements through Release 6.12. Cary, NC, USA:Sas Institute Inc., 1997. 1167 pp.

SCOTT, G. P., V. R. Restrepo and A. R. Bertolino. 1993. Standardized catch rates for swordfish (*Xiphias gladius*) from the US longline fleet through 1991. Col. Vol. Sci. Pap. ICCAT, 40(1):458-467.

Table 1. Deviance analysis table of explanatory variables in the delta lognormal model for blue marlin catch rates from the Observer Pelagic Program data. Percent of total deviance refers to the deviance explained by each factor in reference to the full model; *p* value refers to the 5% Chi-square probability between two consecutive models.

BLUE MARLIN OBSERVER PELAGIC PROGRAM DATA

Model factors positive catch rates values	d. f.	Deviance	Change in deviance	% of total deviance	*p*
1	_	480.70			
Year	9	448.59	32.1	8.8%	< 0.001
… + Area	6	334.45	114.1	31.3%	< 0.001
… + Season	3	326.26	8.2	2.2%	0.042
… + Op	7	283.83	42.4	11.6%	< 0.001
… + Targetsp	4	275.73	8.1	2.2%	0.088
… + Lghtc	2	275.54	0.2	0.1%	0.909
… + Ratlr	1	275.06	0.5	0.1%	0.488
… + Srflite	1	272.37	2.7	0.7%	0.101
… + Mainmat	1	272.36	0.0	0.0%	0.917
… + Hkbrand	3	270.30	2.1	0.6%	0.559
… + Hktype	2	269.31	1.0	0.3%	0.610
… + Hksize	2	268.69	0.6	0.2%	0.733
… + Weatherc	3	268.07	0.6	0.2%	0.892
… + Gangdisc	1	265.82	2.3	0.6%	0.133
… + Baitknd	17	253.74	12.1	3.3%	0.795
… + Bait	2	252.42	1.3	0.4%	0.517
… + Year*Area	52	211.01	41.4	11.4%	0.854
… + Year*Season	26	198.64	12.4	3.4%	0.989
… + Area*Season	16	190.84	7.8	2.1%	0.955
… + Year*Op	47	169.74	21.1	5.8%	1.000
… + Area*Op	19	163.58	6.2	1.7%	0.998
… + Season*Op	16	156.00	7.6	2.1%	0.960
… + Year*Targetsp	23	147.67	8.3	2.3%	0.998
… + Area*Targetsp	12	138.55	9.1	2.5%	0.693
… + Season*Targetsp	8	136.14	2.4	0.7%	0.966
… + Op*Targetsp	8	133.15	3.0	0.8%	0.935
… + Year*Lghtc	17	125.52	7.6	2.1%	0.974
… + Area*Lghtc	10	123.31	2.2	0.6%	0.995
… + Season*Lghtc	5	119.72	3.6	1.0%	0.610
… + Op*Lghtc	8	117.34	2.4	0.7%	0.967
… + Targetsp*Lghtc	3	116.42	0.9	0.3%	0.820

Model factors proportion positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	_	2189.83			
Year	9	2096.68	93.2	12.9%	< 0.001
… + Area	6	1887.06	209.6	29.1%	< 0.001
… + Season	3	1776.16	110.9	15.4%	< 0.001
… + Op	7	1767.86	8.3	1.2%	0.306
… + Targetsp	4	1758.30	9.6	1.3%	0.049
… + Lghtc	2	1756.23	2.1	0.3%	0.355
… + Ratlr	1	1756.09	0.1	0.0%	0.710
… + Srflite	1	1752.84	3.2	0.5%	0.072
… + Mainmat	1	1752.58	0.3	0.0%	0.607
… + Hkbrand	3	1749.01	3.6	0.5%	0.312
… + Hktype	2	1747.77	1.2	0.2%	0.538
… + Hksize	2	1721.67	26.1	3.6%	< 0.001
… + Weatherc	3	1720.34	1.3	0.2%	0.723
… + Gangdisc	1	1713.91	6.4	0.9%	0.011
… + Year*Mainmat	6	1702.87	11.0	1.5%	0.087
… + Area*Op	22	1687.10	26.8	3.7%	0.218
… + Year*Lghtc	18	1676.30	37.6	5.2%	0.004
… + Year*Targetsp	30	1637.85	76.1	10.6%	< 0.001
… + Year*Season	26	1621.67	92.2	12.8%	< 0.001
… + Area*Season	17	1532.39	181.5	25.2%	< 0.001
… + Year*Op	54	1506.32	207.6	28.9%	< 0.001
… + Year*Area	53	1470.28	243.6	33.9%	< 0.001

Table 2. Deviance analysis table of explanatory variables in the delta lognormal model for white marlin catch rates from the Observer Pelagic Program data. Percent of total deviance refers to the deviance explained by each factor in reference to the full model; *p* value refers to the 5% Chi-square probability between two consecutive models.

WHITE MARLIN OBSERVER PELAGIC PROGRAM DATA

Model factors positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	_	546.45			
Year	9	525.92	20.5	6.5%	0.015
… + Area	6	474.01	51.9	16.4%	< 0.001
… + Season	3	469.01	5.0	1.6%	0.172
… + Op	7	445.54	23.5	7.4%	0.001
… + Targetsp	4	434.75	10.8	3.4%	0.029
… + Lghtc	2	430.67	4.1	1.3%	0.130
… + Ratlr	1	429.92	0.7	0.2%	0.387
… + Srflite	1	425.96	4.0	1.3%	0.046
… + Mainmat	1	424.17	1.8	0.6%	0.181
… + Hkbrand	3	422.88	1.3	0.4%	0.733
… + Hktype	2	418.92	4.0	1.3%	0.138
… + Hksize	2	418.87	0.1	0.0%	0.973
… + Weatherc	3	414.51	4.4	1.4%	0.225
… + Gangdisc	1	410.22	4.3	1.4%	0.038
… + Baitknd	16	390.92	19.3	6.1%	0.253
… + Bait	2	389.38	1.5	0.5%	0.463
… + Year*Area	52	340.56	48.8	15.4%	0.600
… + Year*Season	26	324.74	15.8	5.0%	0.941
… + Area*Season	14	317.17	7.6	2.4%	0.910
… + Year*Op	42	293.98	23.2	7.3%	0.992
… + Area*Op	15	285.29	8.7	2.7%	0.893
… + Season*Op	17	277.20	8.1	2.6%	0.965
… + Year*Targetsp	25	266.22	11.0	3.5%	0.993
… + Area*Targetsp	11	256.12	10.1	3.2%	0.521
… + Season*Targetsp	9	253.30	2.8	0.9%	0.971
… + Op*Targetsp	9	250.80	2.5	0.8%	0.981
… + Year*Lghtc	18	242.33	8.5	2.7%	0.971
… + Area*Lghtc	10	240.04	2.3	0.7%	0.994
… + Season*Lghtc	5	237.03	3.0	1.0%	0.698
… + Op*Lghtc	10	232.69	4.3	1.4%	0.931
… + Targetsp*Lghtc	5	230.45	2.2	0.7%	0.816

Model factors proportion positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	_	2843.70			
Year	9	2702.11	141.6	13.0%	< 0.001
… + Area	6	2508.79	193.3	17.7%	< 0.001
… + Season	3	2264.90	243.9	22.3%	< 0.001
… + Op	7	2249.08	15.8	1.4%	0.027
… + Targetsp	4	2231.24	17.8	1.6%	0.001
… + Lghtc	2	2207.09	24.1	2.2%	< 0.001
… + Ratlr	1	2207.08	0.0	0.0%	0.923
… + Srflite	1	2186.25	20.8	1.9%	< 0.001
… + Mainmat	1	2173.12	13.1	1.2%	< 0.001
… + Hkbrand	3	2164.37	8.7	0.8%	0.033
… + Hktype	2	2160.76	3.6	0.3%	0.164
… + Hksize	2	2160.53	0.2	0.0%	0.890
… + Weatherc	3	2151.71	8.8	0.8%	0.032
… + Gangdisc	1	2135.41	16.3	1.5%	< 0.001
… + Year*Mainmat	6	2121.38	14.0	1.3%	0.029
… + Year*Lghtc	18	2088.34	47.1	4.3%	< 0.001
… + Year*Season	26	2061.36	74.1	6.8%	< 0.001
… + Area*Op	22	2061.21	74.2	6.8%	< 0.001
… + Year*Targetsp	30	2041.97	93.4	8.6%	< 0.001
… + Year*Op	54	1937.95	197.5	18.1%	< 0.001
… + Year*Area	53	1916.58	218.8	20.0%	< 0.001
… + Area*Season	17	1752.07	383.3	35.1%	< 0.001

Table 3. Analyses of delta lognormal mixed model formulations for blue and white marlin catch rates from the Observer Pelagic Program data. Likelihood ratio tests the difference of –2 REM log likelihood statistic between two nested models.

Blue Marlin	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Proportion Positives					
Year Area Season OP	1534.1	1536.1	1540.1		
Year Area Season OP *Year*Area*	1497.1	1501.1	1505.6	37	0.0000
Year Area Season OP *Year*Area Year*Season*	1493.2	1499.2	1505.9	3.9	0.0483
Year Area Season OP *Year*Area Year*Season Area*Season*	1482.5	1490.5	1499.4	10.7	0.0011
Positive Catch					
Year Area OP Mainlength	1453	1455	1459.7		
Year Area OP Mainlength *Year*Area*	1437.2	1441.2	1445.7	15.8	0.0001
Year Area OP Mainlength *Year*Area Year*OP*	1420.7	1424.7	1429.2	16.5	0.0000

White Marlin	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Proportion Positives					
Year Area Season OP	4150.1	4152.1	4156.9		
Year Area Season OP *Year*Area*	4099.3	4103.3	4107.7	50.8	0.0000
Year Area Season OP *Year*Area Year*OP*	4097.8	4103.8	4110.5	1.5	0.2207
Positive Catch					
Year Area OP Target	2258.5	2260.5	2265.5		
Year Area OP Target *Year*Area*	2218.6	2222.6	2227	39.9	0.0000
Year Area OP Target *Year*Area Year*OP*	2199.3	2205.3	2212	19.3	0.0000

Table 4. Deviance analysis tables of explanatory variables in the delta lognormal model for blue marlin catch rates from the Pelagic Longline Logbook data. Percent of total deviance refers to the deviance explained by each factor in reference to the full model; p value refers to the 5% Chi-square probability between two consecutive models

Pelagic Longline Logbook data for Blue marlin

Model factors positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	_	11091.83			
Year	14	10664.70	427.1	10.4%	< 0.001
Year Area	8	8425.37	2239.3	54.7%	< 0.001
Year Area Season	3	8321.26	104.1	2.5%	< 0.001
Year Area Season Op	8	7669.87	651.4	15.9%	< 0.001
Year Area Season Op Targ2	3	7618.80	51.1	1.2%	< 0.001
Year Area Season Op Targ2 Lghtc	3	7563.62	55.2	1.3%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty	2	7485.60	78.0	1.9%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Targ2	42	7414.16	71.4	1.7%	0.003
Year Area Season Op Targ2 Lghtc Baitty Year*Season	40	7393.72	91.9	2.2%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Baitty	22	7388.54	97.1	2.4%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Op	48	7381.72	103.9	2.5%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Season	22	7375.54	110.1	2.7%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Lghtc	42	7360.01	125.6	3.1%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Op	92	7146.10	339.5	8.3%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Area	108	6998.92	486.7	11.9%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1		43259.1			
Year	14	42540.4	718.7	3.6%	< 0.001
Year Area	8	31718.9	10821.5	54.7%	< 0.001
Year Area Season	3	30088.9	1630.0	8.2%	< 0.001
Year Area Season Op	8	29547.3	541.7	2.7%	< 0.001
Year Area Season Op Targ2	3	25577.9	3969.4	20.1%	< 0.001
Year Area Season Op Targ2 Lghtc	3	25387.2	190.7	1.0%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty	2	25284.4	102.8	0.5%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Baitty	23	25076.1	208.3	1.1%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Targ2	42	24927.0	357.4	1.8%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Season	40	24867.6	416.8	2.1%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Lghtc	42	24853.2	431.2	2.2%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Op	61	24515.2	769.1	3.9%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Season	24	24050.1	1234.2	6.2%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Area	111	23638.6	1645.7	8.3%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Op	98	23464.1	1820.2	9.2%	< 0.001

Table 5. Deviance analysis table of explanatory variables in the delta lognormal model for white marlin catch rates from the Pelagic Longline Logbook data. Percent of total deviance refers to the deviance explained by each factor in reference to the full model; *p* value refers to the 5% Chi-square probability between two consecutive models

Pelagic Longline Logbook data for White marlin

Model factors positive catch rates values	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
1	–	9608.4			
Year	14	9210.5	398.0	19.6%	< 0.001
Year Area	8	8559.4	651.1	32.0%	< 0.001
Year Area Season	3	8473.2	86.2	4.2%	< 0.001
Year Area Season Op	8	8018.2	455.0	22.4%	< 0.001
Year Area Season Op Targ2	3	7997.6	20.6	1.0%	< 0.001
Year Area Season Op Targ2 Lghtc	3	7879.1	118.4	5.8%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty	2	7804.1	75.0	3.7%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Targ2	42	7777.4	26.7	1.3%	0.969
Year Area Season Op Targ2 Lghtc Baitty Year*Season	40	7757.5	46.6	2.3%	0.218
Year Area Season Op Targ2 Lghtc Baitty Year*Baitty	22	7741.3	62.8	3.1%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Lghtc	42	7740.4	63.8	3.1%	0.017
Year Area Season Op Targ2 Lghtc Baitty Area*Season	23	7708.4	95.8	4.7%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Op	49	7689.2	114.9	5.7%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Op	91	7617.7	186.4	9.2%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Area	109	7575.4	228.7	11.3%	< 0.001

Model factors proportion positives	**d.f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
1		41263.7			
Year	14	40780.1	483.6	3.0%	< 0.001
Year Area	8	35932.5	4847.6	29.7%	< 0.001
Year Area Season	3	32872.8	3059.7	18.8%	< 0.001
Year Area Season Op	8	31266.8	1605.9	9.8%	< 0.001
Year Area Season Op Targ2	3	27640.9	3625.9	22.2%	< 0.001
Year Area Season Op Targ2 Lghtc	3	27570.3	70.6	0.4%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty	2	27510.8	59.5	0.4%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Targ2	42	27392.4	118.4	0.7%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Lghtc	42	27256.6	254.2	1.6%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Baitty	23	27249.0	261.8	1.6%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Season	40	27013.8	497.0	3.0%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Op	61	26595.5	915.3	5.6%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Area	111	26048.1	1462.7	9.0%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Year*Op	98	25789.1	1721.7	10.6%	< 0.001
Year Area Season Op Targ2 Lghtc Baitty Area*Season	24	24959.5	2551.4	15.6%	< 0.001

Table 6. Analyses of delta lognormal mixed model formulations for blue and white marlin catch rates from the Pelagic Longline Logbook data. Likelihood ratio tests the difference of –2 REM log likelihood statistic between two nested models.

	Blue Marlin Model	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Proportion Positives					
	Year Area Season OP Targ2	26226.5	26228.5	26235.2		
	Year Area Season OP Targ2 Year*Area	26136	26140	26145.8	90.5	0.0000
*	Year Area Season OP Targ2 Year*Area Year*OP	25438.8	25444.8	25453.5	697.2	0.0000
	Year Area Season OP Targ2 Year*Area Year*OP Area*Season	25514	25522	25533.6	-75.2	N/A
	Positive Catch					
	Year Area OP Lights	40124.8	40126.8	40134.8		
	Year Area OP Lights Year*Area	38920.5	38924.5	38930.3	1204.3	0.0000
	Year Area OP Lights Year*Area Year*OP	38682.1	38688.1	38696.8	238.4	0.0000
	Year Area OP Lights Year*Area Year*OP Area*OP	38530.8	38538.8	38550.3	151.3	0.0000
*	Year Area OP Lights Year*Area Year*OP Area*OP Year*Lights	38370.5	38380.5	38394.9	160.3	0.0000

	White Marlin Model	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Proportion Positives					
	Year Area Season OP Targ2	27772.2	27774.2	27781		
	Year Area Season OP Targ2 Year*Area	27546.4	27550.4	27556.2	225.8	0.0000
	Year Area Season OP Targ2 Year*Area Year*OP	27337.6	27343.6	27352.2	208.8	0.0000
	Year Area Season OP Targ2 Year*Area Year*OP Area*Season	27274.5	27282.5	27294.1	63.1	0.0000
*	Year Area Season OP Targ2 Year*Area Year*OP Area*Season Area*OP	26522.4	26532.4	26546.9	752.1	0.0000
	Positive Catch					
	Year Area Season OP Targ2	39808.6	39810.6	39818.6		
	Year Area Season OP Targ2 Year*Area	39758.5	39462.5	39468.2	50.1	0.0000
	Year Area Season OP Targ2 Year*Area Year*OP	39305	39311	39319.7	453.5	0.0000
	Year Area Season OP Targ2 Year*Area Year*OP Area*Season	39167.3	39175.3	39186.8	137.7	0.0000
*	Year Area Season OP Targ2 Year*Area Year*OP Area*Season Area*OP	39031	39041	39055.4	136.3	0.0000

Table 7. Blue marlin nominal and standard catch rate series (kg/1000 hooks) from the Pelagic Longline Logbook data. The index column is the scaled to the maximum value of the CPUE series.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Index	Upp CI 95%	Low CI 95%
1986	19.29	15.91	30.5%	4.85	1.33	2.42	0.73
1987	20.61	10.97	23.4%	2.57	0.92	1.46	0.58
1988	20.55	9.93	23.6%	2.34	0.83	1.32	0.52
1989	18.38	12.57	22.2%	2.79	1.05	1.63	0.68
1990	17.76	13.33	22.2%	2.96	1.12	1.73	0.72
1991	16.22	11.71	23.0%	2.69	0.98	1.54	0.62
1992	18.86	15.89	21.7%	3.45	1.33	2.04	0.87
1993	26.00	18.47	21.7%	4.01	1.55	2.38	1.01
1994	22.02	14.39	22.2%	3.19	1.21	1.87	0.78
1995	26.09	12.63	22.9%	2.90	1.06	1.66	0.67
1996	28.28	12.56	23.0%	2.89	1.05	1.66	0.67
1997	19.57	9.41	23.3%	2.19	0.79	1.25	0.50
1998	10.94	7.38	23.4%	1.73	0.62	0.98	0.39
1999	10.57	7.61	24.2%	1.84	0.64	1.03	0.40
2000	12.07	6.36	24.8%	1.58	0.53	0.87	0.33

Table 8. White marlin nominal and standard catch rate series (kg/1000 hooks) from the Pelagic Longline Logbook data. The index column is the scaled to the maximum value of the CPUE series.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Index	Upp CI 95%	Low CI 95%
1986	10.52	9.38	30.2%	2.84	2.72	4.91	1.50
1987	7.02	4.12	24.6%	1.01	1.19	1.94	0.74
1988	5.43	3.43	25.6%	0.88	0.99	1.64	0.60
1989	6.87	4.27	24.4%	1.04	1.24	2.00	0.76
1990	5.50	3.55	25.0%	0.89	1.03	1.68	0.63
1991	5.82	3.38	25.5%	0.86	0.98	1.62	0.59
1992	6.74	4.11	24.5%	1.01	1.19	1.93	0.73
1993	6.47	3.43	24.7%	0.85	0.99	1.61	0.61
1994	6.34	2.82	25.2%	0.71	0.82	1.34	0.50
1995	6.14	2.47	25.8%	0.64	0.71	1.19	0.43
1996	4.96	2.14	26.0%	0.56	0.62	1.03	0.37
1997	5.04	1.99	26.4%	0.53	0.58	0.97	0.34
1998	4.77	2.48	25.8%	0.64	0.72	1.19	0.43
1999	5.10	2.77	26.3%	0.73	0.80	1.35	0.48
2000	2.93	1.45	28.0%	0.41	0.42	0.73	0.24

Table 9. Blue marlin nominal and standard catch rate series (number of fish/1000 hooks) from the Pelagic Longline Logbook data. The index column is the scaled to the maximum value of the CPUE series.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Index	Upp CI 95%	Low CI 95%
1986	0.454	0.373	36.6%	0.968	1.968	0.476
1987	0.483	0.262	30.0%	0.681	1.225	0.378
1988	0.483	0.240	30.8%	0.623	1.139	0.341
1989	0.434	0.304	27.7%	0.789	1.358	0.458
1990	0.425	0.323	27.4%	0.838	1.435	0.489
1991	0.383	0.285	28.9%	0.740	1.304	0.420
1992	0.447	0.385	25.9%	1.000	1.666	0.600
1993	0.483	0.347	26.4%	0.902	1.518	0.536
1994	0.428	0.275	28.2%	0.713	1.240	0.410
1995	0.342	0.189	31.6%	0.490	0.909	0.265
1996	0.354	0.169	32.5%	0.438	0.827	0.232
1997	0.271	0.138	34.8%	0.358	0.703	0.182
1998	0.201	0.130	35.5%	0.337	0.671	0.169
1999	0.179	0.126	37.0%	0.327	0.669	0.160
2000	0.214	0.114	38.9%	0.297	0.629	0.140

Table 10. White marlin nominal and standard catch rate series (number of fish/1000 hooks) from the Pelagic Longline Logbook data. The index column is the scaled to the maximum value of the CPUE series.

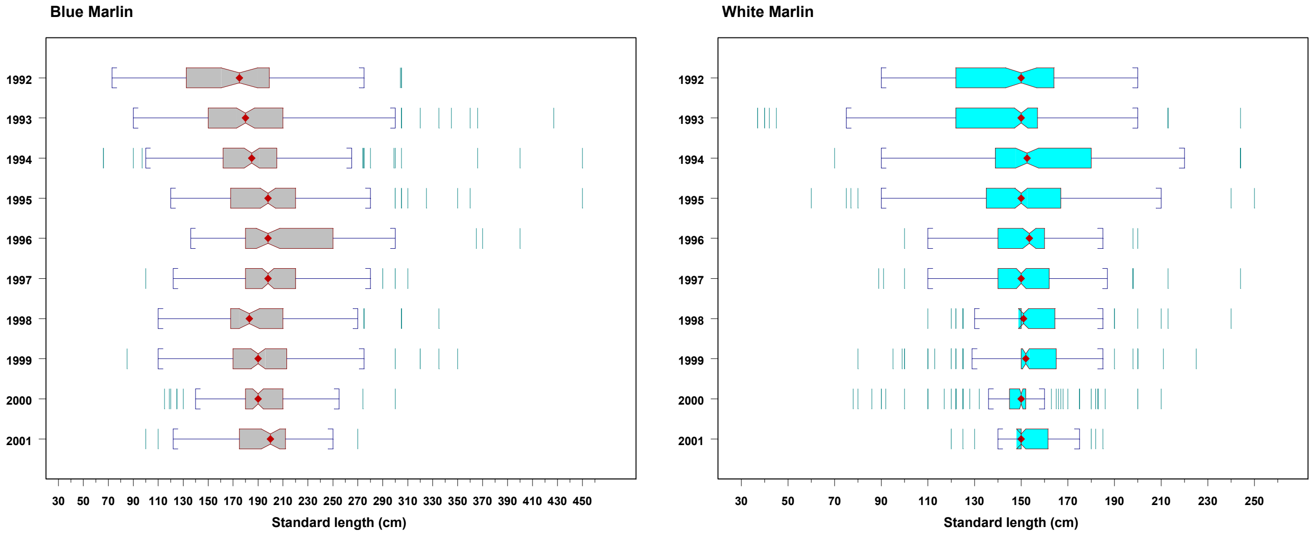
Year	Nominal CPUE	Standard CPUE	Coeff Var	Index	Upp CI 95%	Low CI 95%
1986	0.609	0.548	34.1%	1.000	1.940	0.516
1987	0.403	0.234	31.0%	0.428	0.783	0.233
1988	0.313	0.196	33.3%	0.358	0.685	0.187
1989	0.392	0.246	30.5%	0.449	0.814	0.247
1990	0.317	0.204	32.2%	0.371	0.696	0.198
1991	0.334	0.193	33.1%	0.352	0.670	0.184
1992	0.386	0.235	30.7%	0.428	0.780	0.235
1993	0.393	0.210	31.5%	0.383	0.708	0.207
1994	0.308	0.141	35.1%	0.258	0.510	0.131
1995	0.312	0.132	36.4%	0.241	0.488	0.119
1996	0.257	0.110	38.4%	0.201	0.421	0.096
1997	0.253	0.099	40.1%	0.180	0.391	0.083
1998	0.218	0.115	37.9%	0.209	0.435	0.101
1999	0.253	0.137	36.9%	0.249	0.509	0.122
2000	0.162	0.080	44.9%	0.146	0.344	0.062

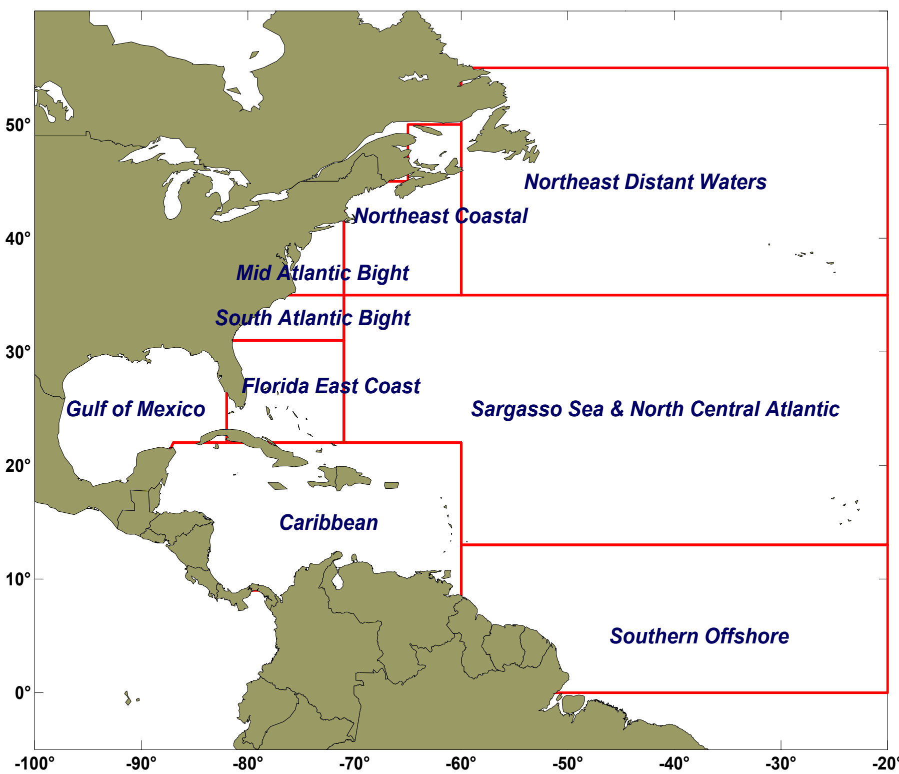
Table 11. Nominal and standard CPUE (kg/1000 hooks) for blue marlin from the Pelagic Observer Program.

Year	N Obs	Nominal CPUE	Standard CPUE	Coeff Var	Low CI	Upp CI
1992	329	21.54	24.42	31.5%	13.19	45.20
1993	803	26.65	21.87	28.6%	12.49	38.31
1994	629	20.56	17.06	31.3%	9.25	31.45
1995	683	37.51	26.02	30.0%	14.46	46.81
1996	361	61.00	38.56	30.8%	21.12	70.38
1997	455	43.87	33.65	31.0%	18.35	61.72
1998	287	24.03	19.65	32.8%	10.37	37.21
1999	411	34.09	23.63	32.4%	12.56	44.44
2000	459	28.52	20.59	32.1%	11.01	38.49
2001	758	8.20	9.97	36.7%	4.89	20.30

Table 12. Nominal and standard CPUE (kg/1000 hooks) for white marlin from the Pelagic Observer Program.

Year	N Obs	Nominal CPUE	Standard CPUE	Coeff Var	Low CI	Upp CI
1992	329	14.08	11.27	31.9%	6.05	21.00
1993	803	13.81	10.53	27.3%	6.16	17.99
1994	629	11.02	7.12	30.9%	3.89	13.02
1995	683	18.53	13.18	27.1%	7.74	22.43
1996	361	12.12	9.96	30.1%	5.53	17.97
1997	455	16.15	10.27	30.7%	5.63	18.73
1998	287	15.30	11.00	31.1%	5.99	20.21
1999	411	21.43	13.98	28.2%	8.04	24.32
2000	459	13.15	6.63	32.9%	3.49	12.58
2001	758	3.34	3.28	37.7%	1.58	6.80


Blue Marlin
White Marlin
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
30 50 70 90 110 130 150 170 190 210 230 250 270 290 310 330 350 370 390 410 430 450
Standard length (cm)
30 50 70 90 110 130 150 170 190 210 230 250
Standard length (cm)


Northeast Distant Waters
Northeast Coastal
Mid Atlantic Bight
South Atlantic Bight
Florida East Coast
Gulf of Mexico
Sargasso Sea & North Central Atlantic
Caribbean
Southern Offshore
50°
40°
30°
20°
10°
0°
-100° -90° -80° -70° -60° -50° -40° -30° -20°

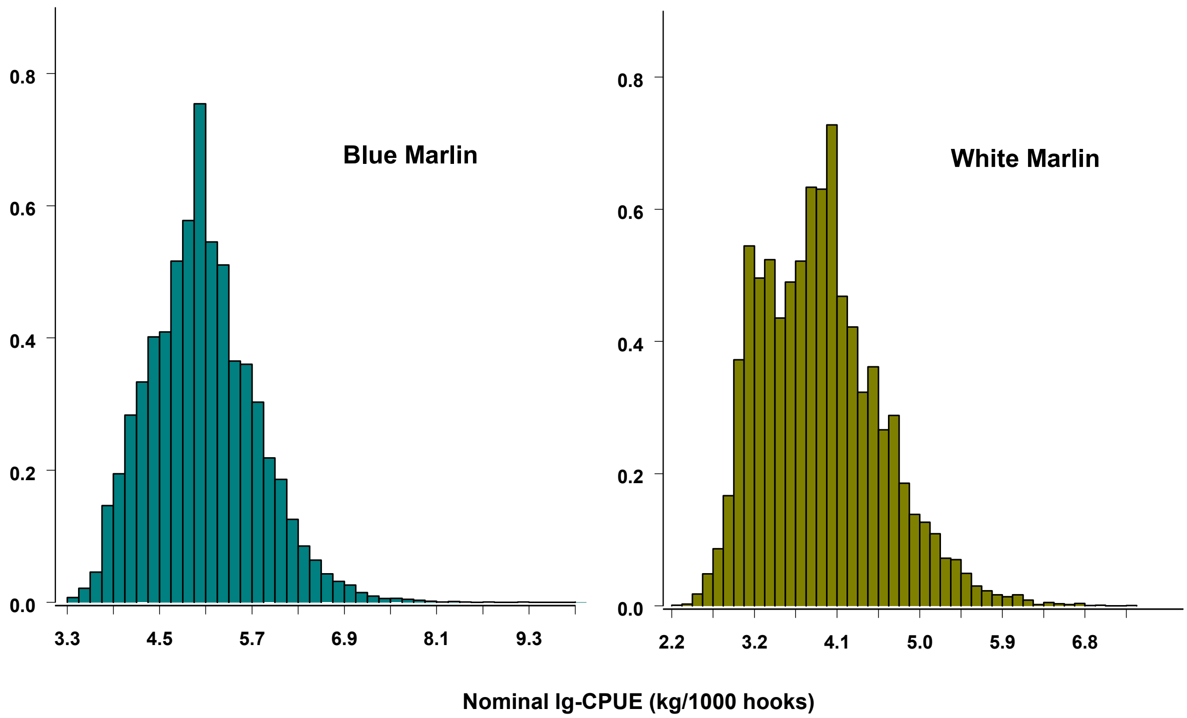
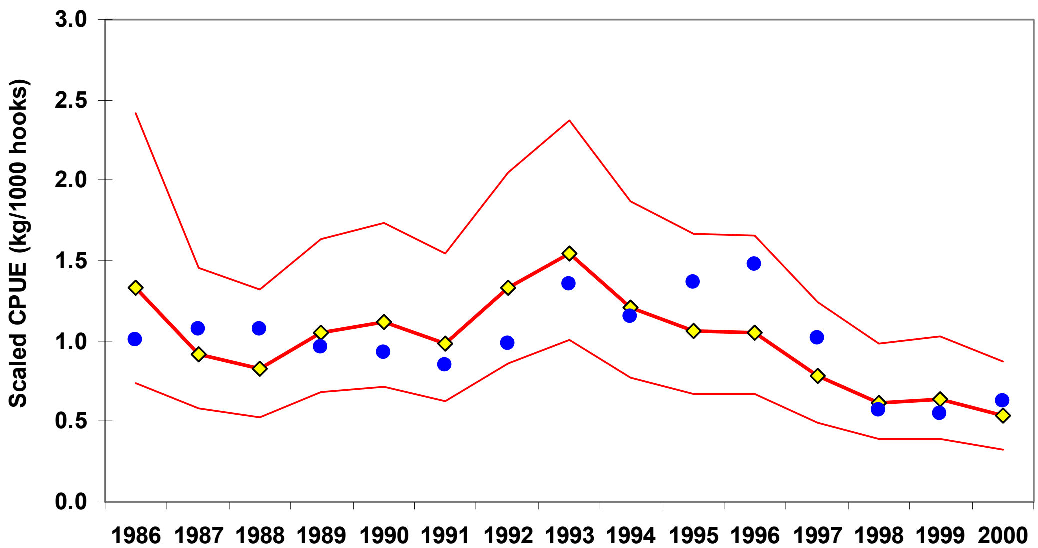
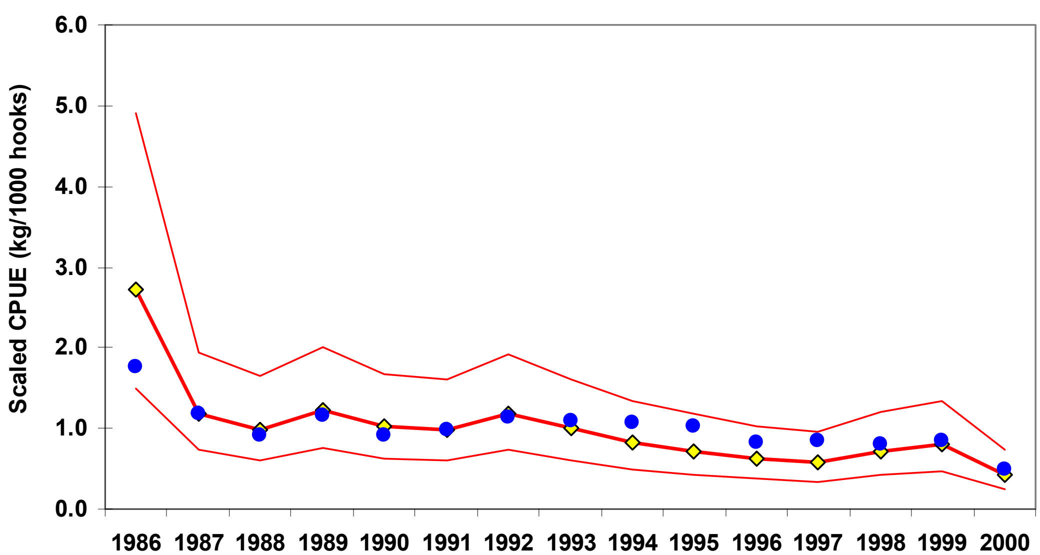


Figure 3. Frequency distribution of log-transformed nominal CPUE values for trip/sets that caught blue marlin (right) or white marlin (left) from the Pelagic Longline US fleet from 1986 through 2000.

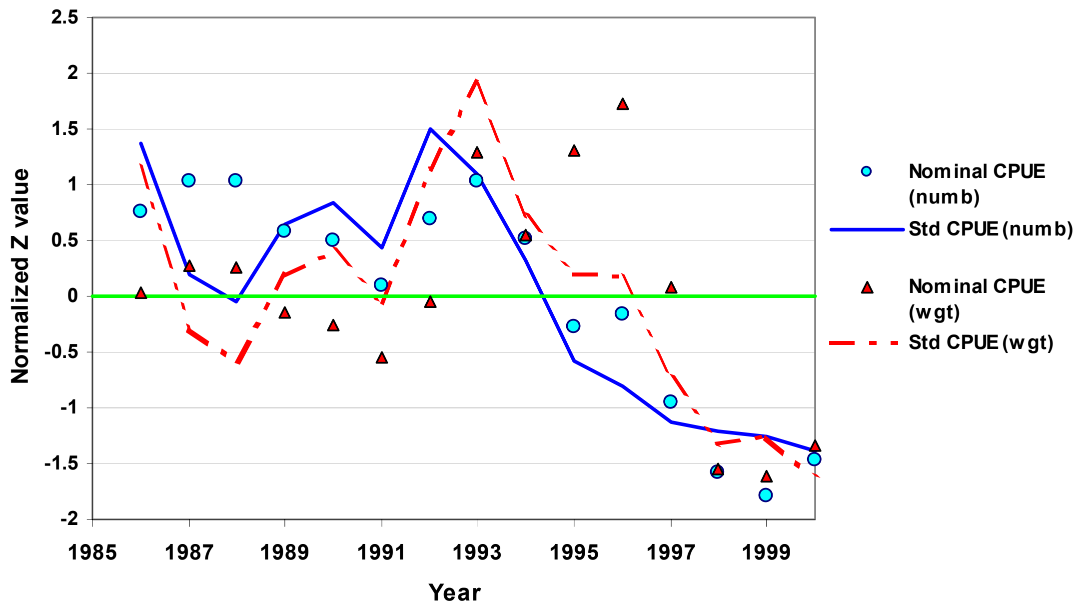
Blue Marlin Standardized CPUE Pelagic Longline US Fishery



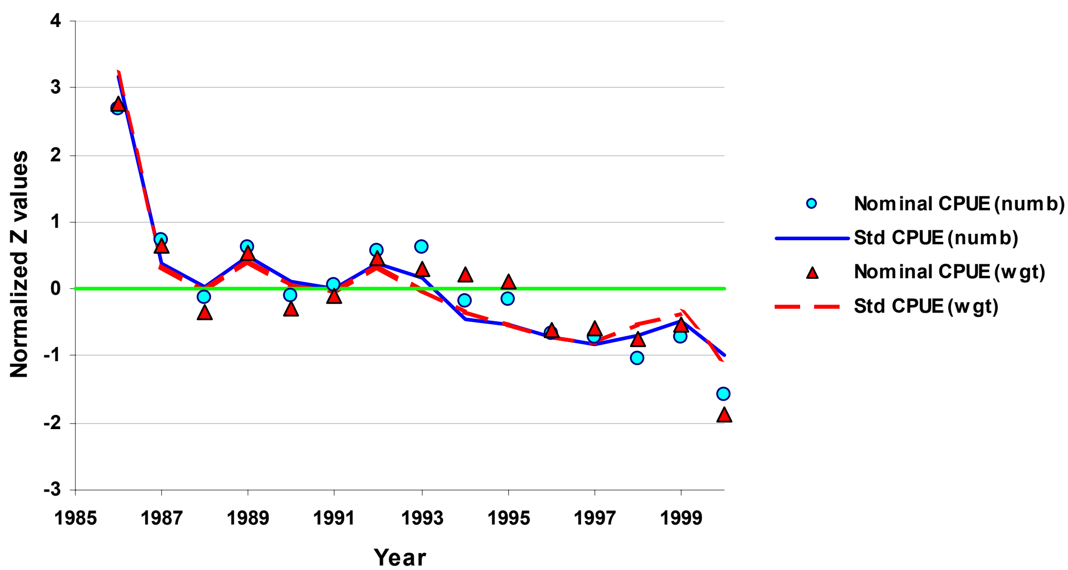
White Marlin Standardized CPUE Pelagic Longline US Fishery

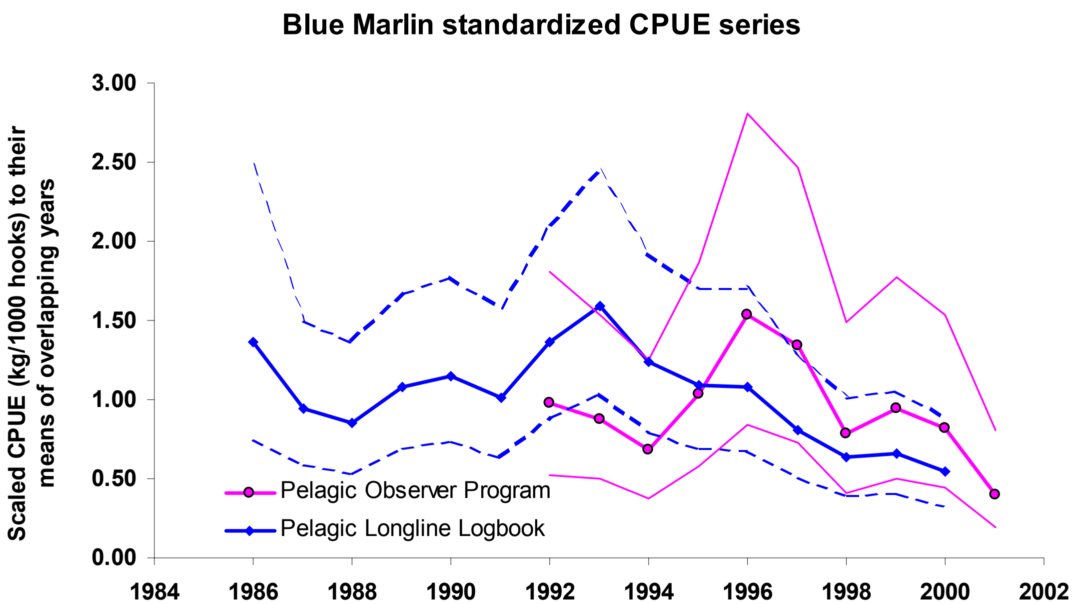


Comparison of Weight and Number CPUE index for Blue marlin

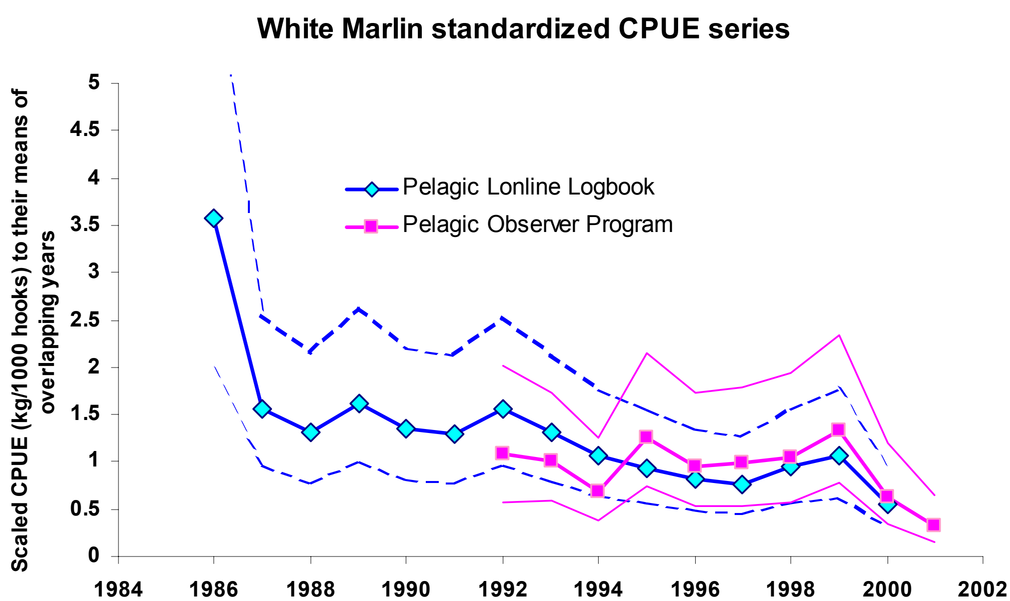


Comparison of Weight and Number CPUE index for White marlin





Blue Marlin standardized CPUE series
Scaled CPUE (kg/1000 hooks) to their means of overlapping years
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Pelagic Observer Program
Pelagic Longline Logbook



White Marlin standardized CPUE series
Scaled CPUE (kg/1000 hooks) to their means of overlapping years
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Pelagic Lonline Logbook
Pelagic Observer Program