STANDARDIZED CATCH RATES FOR BIGEYE TUNA (*Thunnus obesus*) FROM THE PELAGIC LONGLINE FISHERY IN THE NORTHWEST ATLANTIC AND THE GULF OF MEXICO.

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SUMMARY

Two indices of abundance of bigeye tuna from the United States pelagic longline fishery in the Atlantic are presented for the period 1981-2001: an index of number of fish per number of hooks (thousand) estimated from numbers of bigeye tuna caught and reported in the Pelagic logbooks data; and, a biomass index (dress weight) per number of hooks (thousand) estimated from the weight-out data. 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.

RÉSUMÉ

Le présent document fournit deux indices d'abondance du thon obèse de la pêcherie palangrière pélagique des Etats-Unis opérant dans l'Atlantique pour la période 1981-2001 : un indice du nombre de poissons par nombre d'hameçons (mille) estimé à partir du nombre de thons obèses capturés et déclarés dans les carnets de bord des pêcheurs pélagiques ; et un indice de biomasse (poids manipulé) par nombre d'hameçons (mille) estimé à partir des données de poids au débarquement. La procédure d'analyse de standardisation a inclus les variables suivantes : année, zone, saison, caractéristiques des engins (baguettes lumineuses, longueur de la ligne principale, densité des hameçons, etc.) et caractéristiques de la pêche (type d'appât, mode opérationnel et espèces-cibles). L'indice standardisé a été estimé à l'aide de Modèles linéaires généralisés selon une approche du modèle delta-lognormal.

RESUMEN

Se presentan dos índices de abundancia del patudo para la pesquería de palangre pelágico de Estados Unidos en el Atlántico durante el período 1981-2001: un índice del número de peces por número de anzuelos (mil) estimado a partir del número de patudos capturados y comunicados en los datos de los cuadernos de pesca de la pesquería pelágica, y un índice de biomasa (peso canal) por número de anzuelos (mil) estimado a partir de los datos de peso durante el desembarque. El procedimiento de análisis de estandarización incluía las siguientes variables año, zona, temporada, características del arte (bastones luminosos, longitud de la línea principal, densidad de anzuelos, etc.) y características de la pesca (tipo de cebo, procedimiento de las operaciones y especies objetivo). El índice estandarizado se estimó utilizando los Modelos Lineales Mixtos Generalizados en el marco de un enfoque de modelo delta-lognormal.

KEYWORDS

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

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1 INTRODUCTION

Information on the relative abundance of tunas 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 several tunas species including bigeye (Cramer and Ortiz 1998, Ortiz et al. 2000). This report documents the analytical methods applied to the available US longline fleet data through 2001, and presents correspondent standardized CPUE indices for the Atlantic bigeye tuna stock unit. Catch in numbers and effort data were obtained from the Pelagic Longline Logbook (PLL) reports data that reports catch and effort information for each longline set. While biomass catch information was gathered from the Weight-out Pelagic data, which records carcass weight per vessel trip.

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 2001, and includes analyses of variability associated 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 Pelagic Longline 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 including bigeye are the main target species for the US Pelagic Longline fleet. Longline fishers are also required to submit trip level summary of individual carcasses weight for the main market species. This constitutes the Weight-out database, which started in 1981.

The Pelagic Longline Logbook data comprises a total of 208,805 record-sets from 1986 through 2001. Each record contains information of catch by 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 sets, bigeye tuna was reported as being caught in 62,639 sets (30%). Logbooks only record numbers of fish. As per the recommendation of the SCRS Species Group, indices of abundance should be reported both in weight and numbers of fish, when possible. The weight-out data comprises a total 32,626 from 1981 through 2001. Each record represents information of catch by vessel-trip, including date, geographical area of the catch (Fig 1), catch in numbers and weight for swordfish, tunas, and other market species, and fishing effort (total number of hooks per set, and number of sets per trip).

The pelagic 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 (Fig 2). Eight geographical areas of longline fishing have been frequently used for classification (Fig 1). 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, and the 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, 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 bigeye tuna 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%.

Relative indices of abundance for bigeye 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 of bigeye tuna for the Logbook and the weight-out data 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.

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). 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 bigeye, respectively from the Logbook and the weight-out data analyses, respectively. In the case of bigeye tuna, 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 bigeye tuna, the expected probability of capture at least one fish was mainly associated with area, and target factors including year*area, and year*OP interactions. Bigeye tuna catch rates of positive sets were mainly explained by the year, area, quarter 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 show that for bigeye tuna the proportion of positive sets was explained by the year, area, season, and the interactions of year*area year*OP. The mean catch rate for sets with bigeye tuna catch was best explained by the main effects of year, area, season, OP, and the interactions year*area, year*OP. **Table 4** shows the evaluation of mixed model formulations of bigeye tuna standardization procedure. All interactions that included the year factor were treated as random interactions. Diagnostic plots for the final model positive lognormal fit component are shown in **Figures 4 and 5**.

Standardized CPUE for bigeye are shown in **Tables 5 and 6** and **Figure 6**. Coefficients of variation for the bigeye tuna analysis range from 13 to 16% for the PLL data; and 20 and 40% for the weight-out data.

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Table 1. Deviance table analyses of bigeye tuna catch rates from the Logbook data US Pelagic longline fishery from 1987 to 2001. Percent of total deviance refers to the deviance explained by the full model; *p* value refers to the Chi-square probability between consecutive models.

Bigeye Tuna Logbook Catch (Numbers of fish)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
1	1	54722.007			
Year	14	53256.035	1465.97	14.0%	< 0.001
Year Area	8	47446.41	5809.62	55.3%	< 0.001
Year Area Season	3	46565.278	881.13	8.4%	< 0.001
Year Area Season Op	6	45856.062	709.22	6.8%	< 0.001
Year Area Season Op Lghtc	3	45647.045	209.02	2.0%	< 0.001
Year Area Season Op Lghtc Mngarea2	1	45631.67	15.37	0.1%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Mngarea2	14	45429.526	202.14	1.9%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Lghtc	42	45387.645	244.02	2.3%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Season	42	45257.728	373.94	3.6%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Op	84	45121.164	510.51	4.9%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Area	112	44225.828	1405.84	13.4%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	p
1	1	91768.138			
Year	14	90931.385	836.75	1%	< 0.001
Year Area	8	41130.575	49800.81	83%	< 0.001
Year Area Season	3	38624.076	2506.50	4%	< 0.001
Year Area Season Op	6	37585.101	1038.97	2%	< 0.001
Year Area Season Op Lghtc	3	37321.831	263.27	0%	< 0.001
Year Area Season Op Lghtc Mngarea2	1	36318.404	1003.43	2%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Mngarea2	14	35890.635	427.77	1%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Season	42	35082.776	1235.63	2%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Lghtc	42	35020.673	1297.73	2%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Op	84	34188.510	2129.89	4%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Area	112	31584.765	4733.64	8%	< 0.001

Table 2. Deviance table analysis of bigeye tuna catch rates from the weight out US pelagic longline fleet 1981-2001. Percent of total deviance refers to the deviance explained by the full model; *p* value refers to the Chi-square probability between consecutive models.

Bigeye tuna biomass CPUE Index from Weight-out data

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
1	1	10025.1485			
Year	19	9605.2024	419.95	10.3%	< 0.001
Year Area	7	8312.29695	1292.91	31.6%	< 0.001
Year Area Op	6	8163.09018	149.21	3.6%	< 0.001
Year Area Op Targ	3	6815.95692	1347.13	32.9%	< 0.001
Year Area Op Targ Qtr	3	6500.71254	315.24	7.7%	< 0.001
Year Area Op Targ Qtr Area*Op	31	6358.00641	142.71	3.5%	< 0.001
Year Area Op Targ Qtr Year*Targ	57	6324.61609	176.10	4.3%	< 0.001
Year Area Op Targ Qtr Year*Qtr	55	6314.21352	186.50	4.6%	< 0.001
Year Area Op Targ Qtr Op*Qtr	18	6279.73647	220.98	5.4%	< 0.001
Year Area Op Targ Qtr Area*Qtr	19	6270.13156	230.58	5.6%	< 0.001
Year Area Op Targ Qtr Area*Targ	21	6259.98878	240.72	5.9%	< 0.001
Year Area Op Targ Qtr Year*Op	104	6189.88805	310.82	7.6%	< 0.001
Year Area Op Targ Qtr Year*Area	108	5929.59546	571.12	13.9%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	p
1	1	10392.257			
Year	19	10308.183	84.07	1%	< 0.001
Year Area	7	5650.576	4657.61	68%	< 0.001
Year Area Qtr	3	5499.686	150.89	2%	< 0.001
Year Area Qtr Targ	3	4314.486	1185.20	17%	< 0.001
Year Area Qtr Targ Op	6	4138.312	176.17	3%	< 0.001
Year Area Qtr Targ Op Year*Targ	57	3955.197	183.12	3%	< 0.001
Year Area Qtr Targ Op Year*Qtr	57	3915.607	222.70	3%	< 0.001
Year Area Qtr Targ Op Year*Op	105	3734.857	403.45	6%	< 0.001
Year Area Qtr Targ Op Year*Area	116	3590.942	547.37	8%	< 0.001

Table 3. Analysis of mixed model formulations for bigeye catch rates from the Logbook data US Pelagic longline fleet. Likelihood ratio tests the difference of –2 REM loglikelihood between two nested models.

	Bigeye tuna GLMixed Model	Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Proportion Positives						
	Year Area OP Season	6552	29027.1	29029.1	29035.9		
	Year Area OP Season *Year*Area*	6552	28663.1	28667.1	28673	364	0.0000
*	Year Area OP Season *Year*Area Year*OP*	6552	28653.1	28659.1	28667.8	10	0.0016
	Positives catch rates						
	Year Area Season OP	60604	155300.8	155302.8	155311.8		
	Year Area Season OP *Year*Area*	60604	153846.3	153850.3	153856.1	1454.5	0.0000
*	Year Area Season OP *Year*Area Year*OP*	60604	153687.6	153693.6	153702.3	158.7	0.0000

Table 4. Analysis of mixed model formulations for bigeye catch rates from the weight out US Pelagic longline fleet. Likelihood ratio tests the difference of –2 REM loglikelihood between two nested models.

	Bigeye tuna (dressed wgt) GLMixed Model	Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Proportion Positives						
*	Year Area Target OP Qtr	3009	12045.9	12047.9	12053.8		
	Year Area Target OP Qtr *Year*Area*	3009	12104.4	12108.4	12114.4	-58.5	#NUM!
	Year Area Target OP Qtr *Year*Area Year*OP*	3009	12065.5	12071.5	12080.4	38.9	0.0000
	Positives catch rates						
	Year Area OP Target Qtr	6526	17911	17913	17919.7		
	Year Area OP Target Qtr *Year*Area*	6526	17636.1	17640.1	17645.9	274.9	0.0000
	Year Area OP Target Qtr *Year*Area Year*OP*	6526	17625.2	17631.2	17639.9	10.9	0.0010
	Year Area OP Target Qtr *Year*Area Year*OP Area*Targ*	6526	17502.8	17510.8	17522.4	122.4	0.0000
	Year Area OP Target Qtr *Year*Area Year*OP Area*Targ OP*Qtr*	6526	17372.5	17382.5	17397	130.3	0.0000
*	Year Area OP Target Qtr *Year*Area Year*OP Area*Targ OP*Qtr Year*Qtr*	6526	17364.3	17376.3	17393.8	8.2	0.0042

Table 5. Nominal and standard catch rates of bigeye tuna from the Logbook US Pelagic longline fleet. Catch rates express as numbers of fish per thousand hooks.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Numb obs	Index	Upp CI 95%	Low CI 95%
1987	3.84	4.33	0.148	0.642	10835	1.75	1.34	0.74
1988	3.02	3.15	0.156	0.490	10437	1.27	0.99	0.53
1989	3.25	3.26	0.148	0.485	14078	1.32	1.01	0.56
1990	2.77	2.27	0.160	0.362	13940	0.91	0.72	0.38
1991	2.76	2.30	0.158	0.362	13599	0.93	0.73	0.39
1992	2.07	1.89	0.163	0.308	13757	0.76	0.60	0.32
1993	2.49	2.22	0.158	0.350	13550	0.89	0.70	0.37
1994	2.48	2.19	0.157	0.342	13982	0.88	0.69	0.37
1995	2.20	1.98	0.156	0.309	14866	0.80	0.62	0.34
1996	1.76	2.18	0.154	0.334	15346	0.88	0.68	0.37
1997	2.23	1.97	0.157	0.309	14321	0.79	0.62	0.33
1998	2.46	2.09	0.155	0.325	11593	0.84	0.66	0.36
1999	2.81	2.77	0.154	0.428	11242	1.12	0.87	0.47
2000	1.75	2.01	0.162	0.326	11195	0.81	0.64	0.34
2001	2.37	2.61	0.153	0.398	10333	1.05	0.81	0.44

Table 6. Nominal and standard catch rates of bigeye tuna from the weight out US Pelagic longline fleet. Biomass catch rates express as dressed weight (lbs) per thousand hooks.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Numb obs	Index	Upp CI 95%	Low CI 95%
1982	283.81	441.20	0.397	175.010	106	1.99	4.28	0.93
1983	338.36	399.64	0.291	116.140	153	1.80	3.19	1.02
1984	334.62	321.82	0.269	86.485	176	1.45	2.46	0.86
1985	248.15	292.16	0.261	76.139	178	1.32	2.20	0.79
1986	311.37	368.47	0.232	85.309	324	1.66	2.63	1.05
1987	232.77	335.13	0.214	71.854	740	1.51	2.31	0.99
1988	155.94	301.58	0.208	62.787	944	1.36	2.06	0.90
1989	152.92	277.14	0.208	57.748	745	1.25	1.89	0.83
1990	152.23	212.33	0.207	43.858	805	0.96	1.44	0.64
1991	157.50	215.44	0.209	44.942	1223	0.97	1.47	0.64
1992	113.50	135.29	0.205	27.772	1769	0.61	0.92	0.41
1993	134.45	141.64	0.204	28.860	2015	0.64	0.96	0.43
1994	124.02	119.01	0.203	24.216	2134	0.54	0.80	0.36
1995	113.89	111.76	0.204	22.748	2253	0.50	0.75	0.34
1996	104.43	100.07	0.226	22.602	286	0.45	0.71	0.29
1997	109.79	108.18	0.224	24.258	326	0.49	0.76	0.31
1998	73.44	118.64	0.250	29.609	182	0.54	0.88	0.33
1999	185.60	227.03	0.226	51.368	210	1.03	1.60	0.66
2000	63.23	107.37	0.268	28.758	173	0.48	0.82	0.29
2001	124.39	95.85	0.250	23.984	141	0.43	0.71	0.26

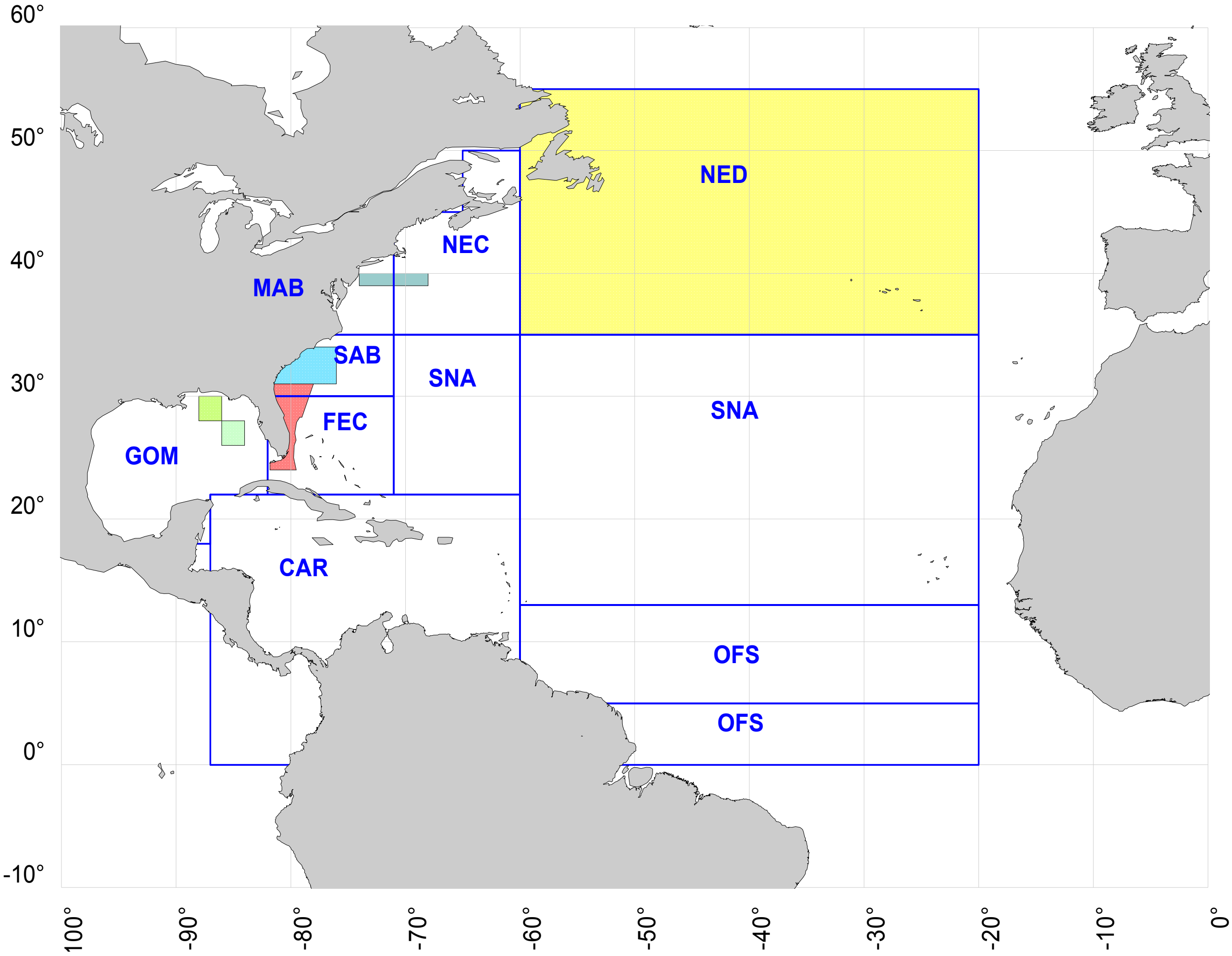
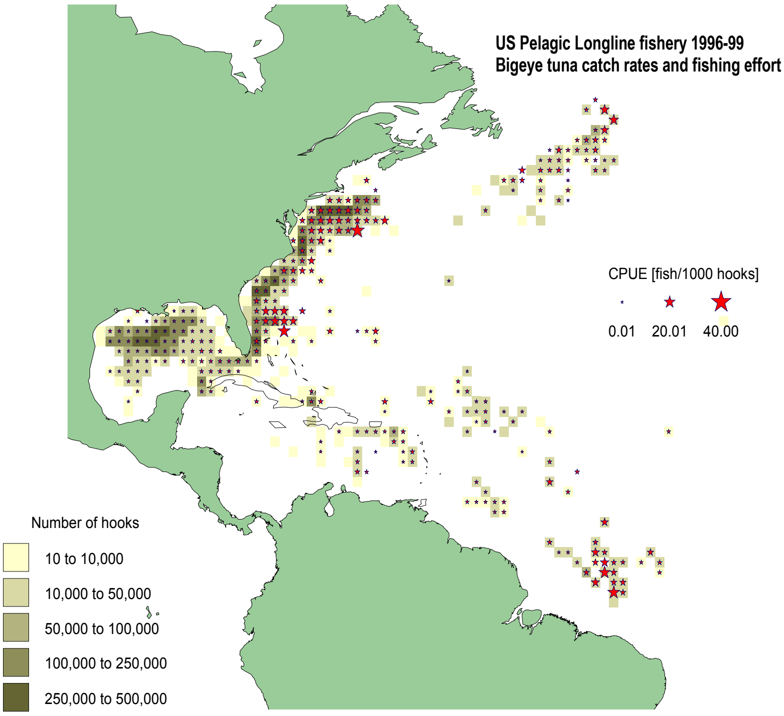


Figure 1 Geographic area classification for the US Pelagic longline fishery: CAR Caribbean, GOM Gulf of Mexico, FEC Florida east coast, SAB south Atlantic bight, MAB mid Atlantic bight, NEC north east coastal, NED north east distant waters, SNA Sargasso area, and OFS offshore waters. Shaded areas represent the current time-area closures affecting the pelagic longline fisheries. Permanent closures: the DeSoto area in the Gulf of Mexico, and the Florida east coast area. Time-area closures: the Charleston Bump in the SAB area closed Feb-Apr, the Bluefin tuna protected area in the MAB and NEC areas closed Jun, and the Grand Banks in the NED area closed from Oct 10/00 to Apr 9/01.



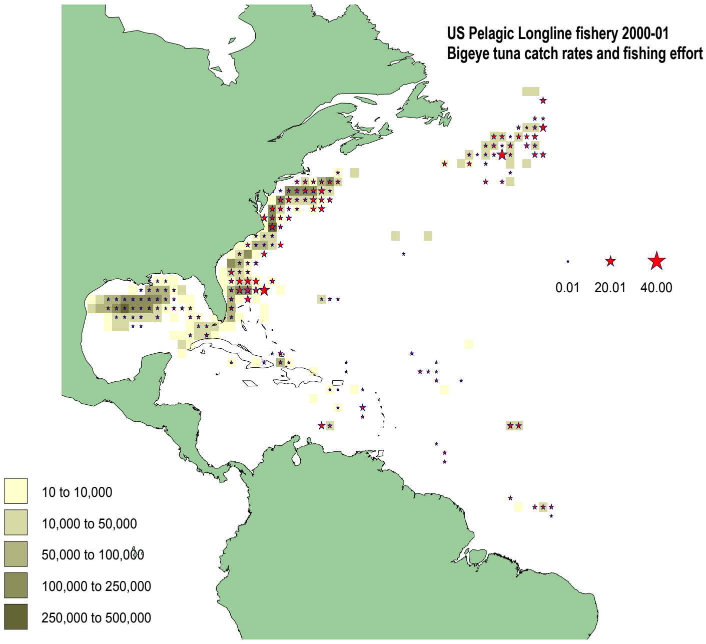
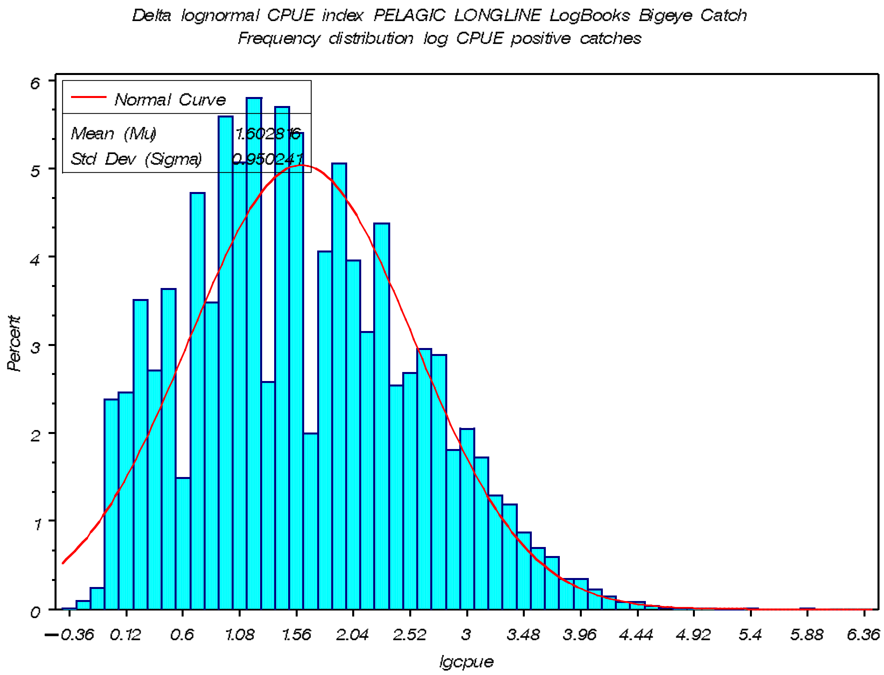


Figure 2 Geographic distribution of fishing effort (total number of hooks) [shade areas], and mean catch rates (numbers of fish/1000 hooks) [start symbols] of bigeye tuna by 1° squared degree from the Weight-out data for the periods of 1996-1999 (left) and 2000-2001 (right). The plotted data represents mean lat-lon for trips for which latitude longitude information was available at the set level on the Pelagic Logbook data.



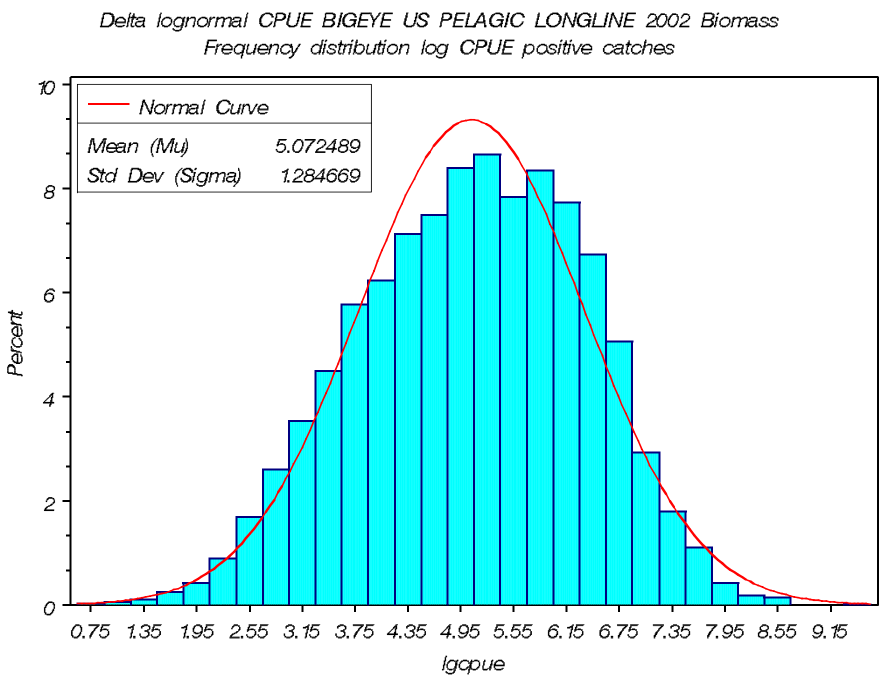


Figure 3. Frequency distribution of nominal catch rates for bigeye tuna from the US Pelagic longline fishery from the Logbook data (fish per 1000 hooks) and from the weight out data (dress weight per 1000 hooks).

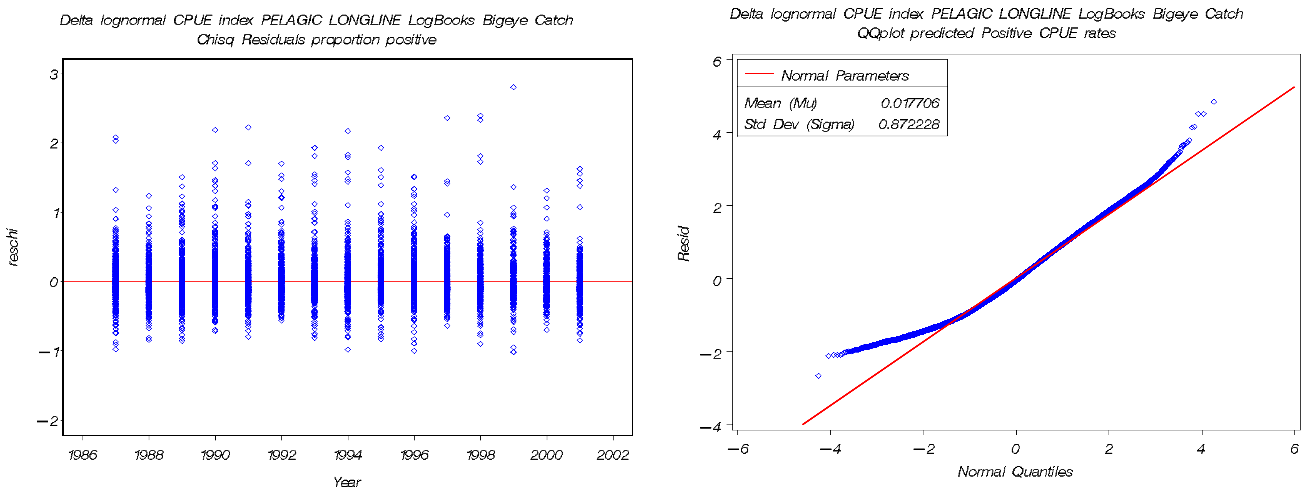


Figure 4. Diagnostic plots for the delta lognormal model fit to the logbook US Pelagic lonline data. Left, distribution of residual by year from the binomial assumed error distribution for the proportion of positive set. Right, cumulative normalized residual plots from the lognormal assumed error distribution of positive sets for bigeye tuna.

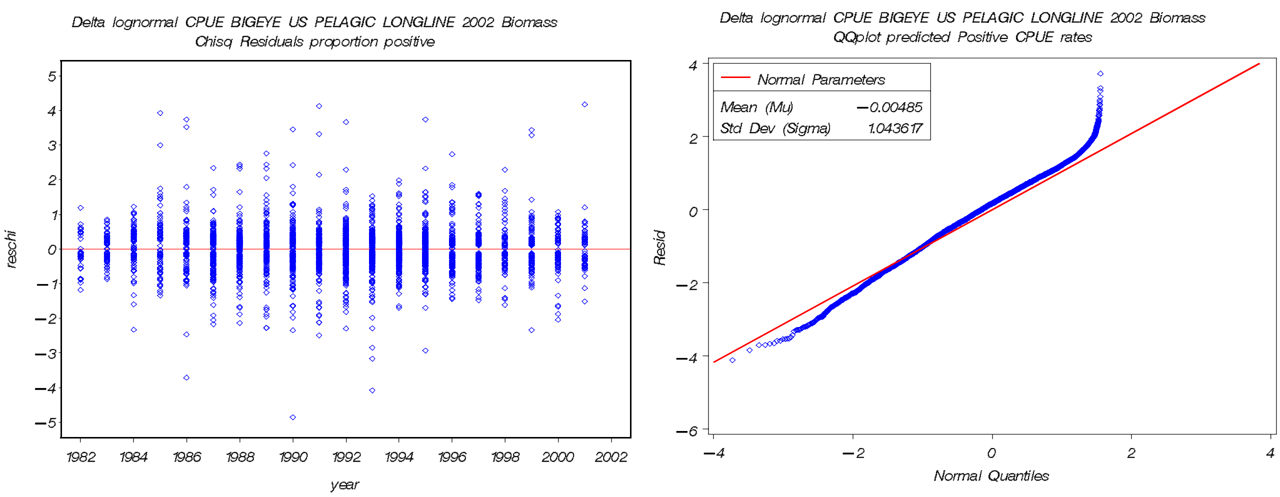
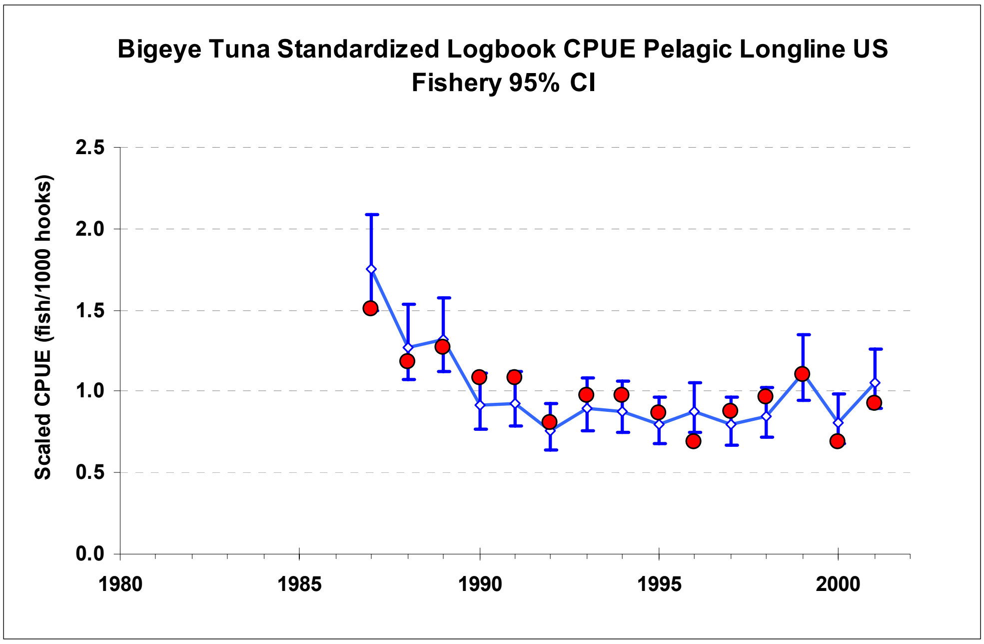


Figure 5. Diagnostic plots for the delta lognormal model fit to the weight out US Pelagic lonline data. Left, distribution of residual by year from the binomial assumed error distribution for the proportion of positive set Right, cumulative normalized residual plots from the lognormal assumed error distribution of positive sets for bigeye tuna.



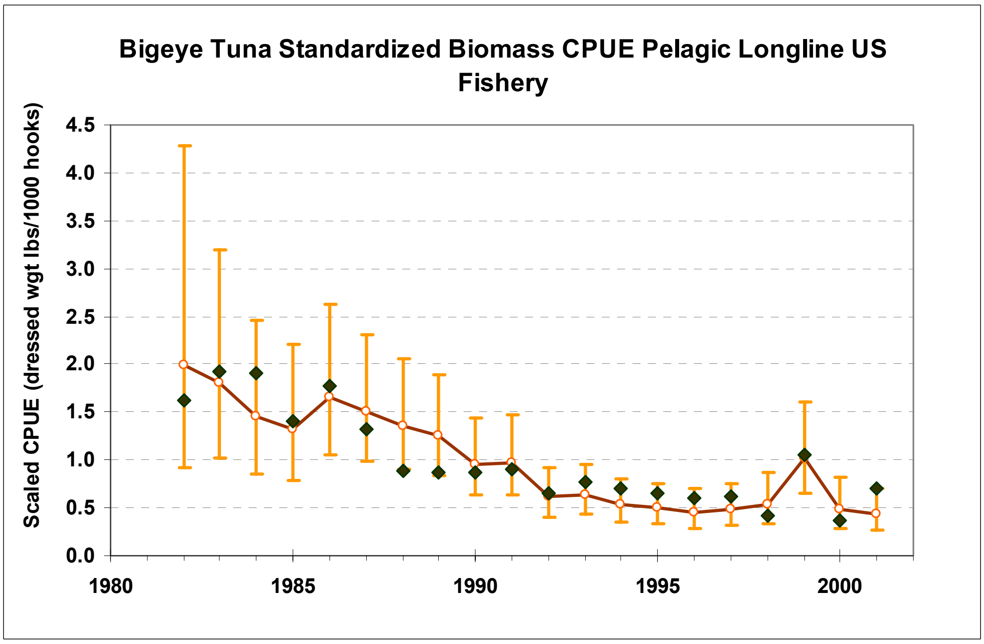


Figure 6. Nominal and standard catch rates for bigeye from the US Pelagic longline fishery. Top, logbook data reported as number of fish per thousand hooks. Bottom, weight out data reported as dress weight (lbs) per thousand hooks.