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STANDARDIZED CATCH RATE IN NUMBER AND WEIGHT OF YELLOWFIN TUNA (*Thunnus albacares*) FROM THE UNITED STATES PELAGIC LONGLINE FISHERY 1987-2007

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We present standardized indices of abundance of yellowfin tuna from the United States pelagic longline fishery for the period 1987-2007 in the Atlantic and Gulf of Mexico. The data consists of the number of yellowfin tuna reported by vessel captains in logbooks, and the weight obtained by assigning an average length to the fish caught on each trip based on observer-recorded lengths. Indices are presented in both number of fish (CPUEN) and biomass per fishing effort (CPUEW) measured by the number of hooks set. The standardization procedure evaluated the following factors; year, area, season, gear characteristics (light sticks, main line length, hook density, etc) and fishing characteristics (operations procedure and target species). Standardized indices were estimated using SAS Generalized Linear Mixed Models under a delta lognormal model approach. Indices have declined since 1987 but appear to be increasing since 2003. Length frequencies and changes in median length over time are also reported and there appears to be a slight increase in length in fish in the Gulf of Mexico. Overall the standardized indices show a decrease since 1986 but a rather flat trend since 1992.

KEYWORDS

yellowfin tuna, Abundance indices, observer program, Catch/effort, Catch rate standardization, Generalized linear model, Pelagic fisheries

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1. Introduction

Relative abundance indices are critical indicators of stock status as well as essential inputs into stock assessments. Fishery catch per unit effort (CPUE) indices operate under the basic assumption that catch per unit effort is proportional to stock size. Numerous factors including changes vessel characteristics, fishing locations and methods, stock size and distribution and targeting of alternative species erode this basic relationship and complicate the interpretation of raw CPUE. Provided that data on covariates that influence the relationship between CPUE and abundance exist, these can be incorporated into standardized measures that presumably more accurately reflect population relative abundance (Maunder and Punt 2004).

The report is an update to a paper presented in 2007 at the tropical tunas meeting in Recife (Walter et al 2007) of standardized indices of CPUE in weight and number of yellowfin tuna obtained from pelagic longline logbook data from 1987 to 2007. We use a delta lognormal approach implemented as a generalized linear mixed model in SAS using methodology similar to Ortiz and Diaz (2003). We also present nominal catch rates by geographic area and as a function of various explanatory variables.

2. Materials and Methods

Data for this analysis comes from the United States Atlantic and Gulf of Mexico Pelagic Longline fishery described in detail by Hoey and Bertolino (1988). Swordfish, yellowfin and bigeye tuna are the predominant target species. The pelagic longline fishing grounds of the US fleet extends from the Grand Banks in the North Atlantic to 5-10° south of the Equator, mainly in the Western Atlantic including the Caribbean Sea and the Gulf of Mexico (Fig 1).The fishery has operated under several time-area restrictions since 2000 due to management regulations related to swordfish and other species (Federal Register 2000, Fig 1). These restrictions included two permanent closures to pelagic longline fishing, one in the Gulf of Mexico known as the Desoto Canyon, effective since November 1st 2000, and the second permanent closure was the Florida East Coast effective since March 1st 2001. In addition, three time-area restrictions were also imposed for the pelagic longline gear in the US Atlantic coast: the Charleston Bump, an area off the North Carolina coast closed from February 1st to April 30th starting in 2001 year, The Bluefin tuna protection area off the South New England coast closed from June 1st to June 30th starting in 1999, and the Grand Banks area that was closed from July 17 2001 to January 9 2002 as a result of an emergency rule implementation (Cramer 2002).

Catch and effort data is available from three sources: pelagic logbooks reported daily by vessel captains (Scott et al 1993, Cramer and Bertolino 1998, Ortiz et al 2000), pelagic observer program data collected beginning in 1992 by onboard fishery observers on approximately 4-5% of the Pelagic Longline trips (Lee and Brown 1999). US Pelagic logbook data is available from 1986, however from 1986 to 1991, submission of logbooks was voluntary, and became mandatory in 1992. Weigh-out data collection began in 1981 and observer data collection began in 1992. In this paper we use vessel logbook reports however previous papers have explored the use of dealer weigh-out data and found that it followed a similar trend to logbook reports (Ortiz and Diaz 2004). A companion paper (Brown 2008) presents as standardized index of observer-reported CPUE. This data and further descriptions of the data collection and processing are available from the National Marine Fisheries Service Southeast Fisheries Science Center (http://www.sefsc.noaa.gov/commercialprograms.jsp).

The Pelagic longline Logbook data comprises a total of 304,392 recorded sets from 1986 through 2007. Each record contains information of catch by set, including: date-time, geographical location, catch in numbers of targeted and bycatch species, number of hooks, light stick and various other gear parameters for each set as well as environmental conditions such as temperature. Restricting the data only to sets made after 1987, those with greater than 100 hooks per set, and with complete catch, effort, location and date information, resulted in a total of 247,543 sets, of which 143,079 (58%) reported positive catches of yellowfin tuna.

Length data comes from measurements made by onboard observers who are directed to record lengths of all species brought onboard and to estimate lengths for all released or discarded animals for which it is not possible to physically measure. Measurements for all tuna species are straight-line fork length taken from the tip of the upper jaw to the fork of the tail. If this measurement is not possible due to the fish processing then lengths are measured as the straight length from the anterior insertion of pectoral fin to the fork of tail. In addition observers record sex and weigh the fish if possible. For this study we use only physically recorded lengths rather than estimated lengths.

Dependent variables

Fishing effort is reported as number of hooks per set, and nominal catch rates in number of fish were calculated as number of yellowfin tuna caught per 1000 hooks (**CPUEN**) for each observation. We estimated relative abundances of yellowfin tuna in biomass (**CPUEW**) assigning a mean straight-line fork length of yellowfin tuna by year, area and quarter of the year to each logbook record. Lengths were obtained from the US Pelagic Observer Program (PLOP) measured yellowfin tuna for 1992-2006. Average sizes were transformed to weights using the current length-weight relationship where weight (kg) = 2.1527 x 10^{-5} * length $(cm)^{2.976}$. Caveriviere (1976) (http://www.iccat.es/Documents/SCRS/DetRep/DET_yft.pdf). When the number of fish measured per strata was less than 50, the mean value for the higher strata level was used (i.e. year-area). The PLOP recorded size measurements for 39,175 yellowfin tuna from 1992 to

2007. Although observer coverage was good for most year-area-quarter combinations, the observer size data started in 1992, thus for years 1987-1991 the mean value for 1992-area-quarter was used to convert numbers of fish to biomass of yellowfin tuna. Standardized and nominal catch rates were calculated as kilograms of yellowfin tuna per 1000 hooks.

Factors

Note that this paper is merely an update of the indices through 2007 and that no changes in the methods of standardization were made. Six fixed factors and a random effect of **year** and interactions between the factors were evaluated in the analysis. Eight geographical areas (**area**) of longline fishing have been traditionally used for classification; 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 (Figure 1). Calendar quarters (**season**) 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 and number of light-sticks (**lightc**) expressed as the ratio of light-sticks per hook, and a variable named operations procedures (**OP**), which is a categorical classification of US longline vessels based on their fishing configuration, type and size of vessel, main target species, and area of operation(s).

Fishing effort is reported as number of hooks per set, and nominal catch rates were calculated as number of yellowfin tuna caught per 1000 hooks for each observation. The US Atlantic longline fleet targets mainly swordfish and yellowfin tuna, but other tuna species are also targeted including bigeye tuna and albacore (to a lesser extent, some of the trips-sets target other pelagic species including sharks, dolphin and small tunas). We define targeting (**targ2**) as a categorical variable with four levels 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 fishing practices targeting swordfish generally diverge from those targeting yellowfin this provides an empirical means to determine whether vessels are targeting particular species. Note that there is a record for target species within the PLL database, however it is deemed to be uninformative (L. Beerkircher, *pers comm*.) As the data also spans a series of time-area closures another factor (**Mngarea2**) was used to identifies closure and non-closure areas,

Indices of abundance of yellowfin were estimated by a generalized linear modeling approach assuming a delta lognormal model (Lo et al. 2002). The standardization procedure splits the dependent data into two parts, one of which models the proportion of positive sets which is assumed to have a binomial error distribution. The second part models the mean catch rate (**CPUEN** or **CPUEW**) of successful sets and assumes a lognormal error distribution. The standardized index is the product of the two. Parameterization of the model used the GLM structure where the proportion of successful sets is a linear function of the fixed factors the random **year** effect and random **year**-interaction effects when the **year** term was within the interaction. The logit function was selected as link between the linear factor component and the binomial error.

Analytical approach

Analyses were done using Glimmix and Mixed procedures from the SAS® statistical computer software (SAS Institute Inc, 1997, Littell et al 1996). A step-wise regression procedure was used to determine the set of factors and interactions that significantly explained the observed variability. We used criterion which assumes that the difference in deviance between two consecutive models follows a Chi-square distribution. The deviance is essentially a measure of the residuals explained by the model. Using this statistic, with degrees of freedom equal to the number of additional parameters estimated minus one, a Chi-square test was constructed which indicates if the additional factor is or is not statistically significant (McCullagh and Nelder, 1989). Deviance analysis tables were constructed for both components of the delta model: Proportion of successful trips/sets, and mean catch rate in both numbers and weights of positive trips/sets. Each deviance table includes the deviance explained by the additional factor or interaction, the overall percent explained by each factor, and the Chi-square probability test. Final selection of explanatory factors was conditional to a) the relative percent of deviance explained by the added factor, normally factors that explained more than 5-10% of deviance were included and b) the Chi-square significant test. Once a set of fixed factors was specified, all possible 1st level interactions were evaluated, in particular random interactions between the **year** effect and other factors. The significance of random interactions were evaluated between nested models using three criteria; the likelihood ratio test (Pinheiro and Bates 2000), the Akaike information criteria (AIC), and the Schwarz Bayesian information criteria (BIC) (Littell et al 1996). For the last two criteria smaller values of AIC or BIC indicated best model fit.

Standard indices of abundance were calculated as the product of the year effect least square means (LSmeans) from the binomial and the lognormal components of the delta lognormal model. LSmeans estimates included a weight proportional to the observed margins of the input data, to account for the unbalanced distribution of the data. Lognormal estimates also included a bias back-transformation correction factor as describe by Lo et al (1992). Variances were obtained by the delta method for the approximate variance of the product of two random variables (Zhou 2002).

3. Results and Discussion

For the time period 1987-2007, an average of 11,214longline sets were recorded in the pelagic logbook database. These comprise the most complete records of US pelagic longline CPUE available for the Atlantic and Gulf of Mexico. During this time period, there has been a reduction in the total numbers of vessels in the fishery from a high of 223 to the present value of 85, with a concomitant increase in the number of hooks set per vessel. This has kept overall fishing effort relatively constant, however effort has been displaced from a series of time area closure areas (Figure 1,2). Ortiz and Diaz (2004) conducted a preliminary evaluation of the effects of area closures on nominal catch rates and found that historic catch rates for most closure areas were lower compared to the average rates in non-closure areas. Fishing effort started to reduce in the closure areas as early as 1996-97 prior to the implementation of most closures.

Figure 2 presents the geographic distribution of fishing effort and nominal catch rates for yellowfin tuna from the Pelagic logbooks for two time periods: from 1990 through 2000 (top panel) and for 2001-02 years (bottom panel). The plotted values are the annual thousands of hooks deployed and annual mean catch of fish per 1000 hooks. The plots show the substantial reduction of fishing effort, particularly after the implementation of time/area closures and reduction in nominal catch rates particularly in the Gulf of Mexico region.

A preliminary analysis of catch rates by area indicated declines in CPUE (#/1000 hooks) in the GOM and the Caribbean with slight increases in the MAB and NEC (Figure 4). One putative reason for the decline in catch rates was the prohibition on the use of live bait in the Gulf of Mexico after September 1, 2000, though Brown (2007) found this not to influence catch rates. Concomitant with these decreases in CPUE in the GOM was an increase in the proportion of positive trips (Figure 5) which will tend to stabilize delta-lognormal catch rates that are the product of proportion success and mean CPUE of positive trips. One of the apparent effects of the closure of the Florida Straights to longlining since March 1st 2001 was to displace the remaining fishing effort in the Florida East area to north of the Bahamas where catch rates of yellowfin tuna have increased (Figure 5).

Examination of histograms of log of the CPUEN and CPUEW indicate that both are fairly normally distributed (Figure 6A, B) and examination of the cumulative normalized residuals (Figure 7A,B) also indicated little severe departure from normality. Standardized chi-squared residuals by year also indicate that departures from fitted values appear generally normally and similarly distributed.

Deviance analysis (Table 2) for the pelagic logbook data indicated that the factors **area** and **targ2** were the main factors explaining the observed variability for the successful sets (i.e. positive sets observations). Other factors included were **season**, operations procedure (**op**), **lghtc** and the random effect interactions **year*area**, **year*op**. For the probability of successful sets or proportion of positives, the factors area, **OP** and **targ2** were the most important explanatory variables, other factors included in the model were season, light-sticks, and the random effect interactions **year*area**, **year*op** and **year*season** (Table 3). For the catch in weight, the same factors **season**, **op**, **lghtc**, **targ2** and the random effect interactions **year*area**, **year*op** also were selected (Table 4). Table 5 shows the evaluation of the mixed model formulations for both components of the delta model; the proportion of positive sets and the mean catch rates in numbers and weights of positive sets.

The final model selected for the binomial and lognormal components for the CPUEN in number were:

Proportion Positive = Year Area Season Op Lghtc Targ2 *Year*season Year*Area Year*OP*

log(CPUEN) = Year Area Season Op Lghtc Targ2 *Year*Area Year*OP*

The final model selected for the binomial and lognormal components of the quarterly CPUEW index in biomass were:

Proportion Positive = Year Area Season Op Lghtc Targ2 *Year*season Year*Area Year*OP*

log(CPUEW) = Year Area Season Op Lghtc Targ2 *Year*Area Year*OP*

Standardized catch rates of both yellowfin tuna numbers and biomass per 1000 hooks (Figures 9,10, Tables 6, 7) indicate a decline since 1987, a stable trend from 1992-2002 and a slight increase since 2003. Ortiz and Diaz (2004) noted a similar trend for the periord 1987-2003 with both logbook and weigh-out indices Nominal catch rates show little trend and diverge from standardized indices in the early part of the time series. Both standardized catch in number and weight show very similar patterns (Figure 11) reflective of the absence of a trend in mean size over the time period for the entire fishery (Walter 2007). Comparison of standardized logbook and observer recorded catch rates indicates substantial divergence between the two indices in 1995 and 2000 for unknown reasons (Brown, 2007).

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Table 1. Total numbers of vessels, sets, hooks set and yellowfin tuna reported in pelagic vessel logbooks. Note that CPUE values differ from Table 5 due to removal of incomplete records.

year	Total vessels	Total sets	Total hooks set	Hooks set per boat	total yellowfin	CPUE (# per 1000 hooks)	percent positive trips
1986	98	1,497	531,681	5,425	6,646	11.39	0.52
1987	165	11,370	4,613,266	27,959	38,444	7.85	0.55
1988	192	12,300	4,945,855	25,760	31,367	6.09	0.45
1989	216	14,385	5,773,154	26,728	41,541	6.57	0.46
1990	201	14,076	5,770,372	28,708	42,910	6.48	0.48
1991	198	13,720	6,507,687	32,867	60,047	8.28	0.53
1992	200	13,989	7,599,356	37,997	80,342	9.21	0.57
1993	206	13,532	7,909,598	38,396	54,782	6.12	0.51
1994	214	14,243	8,635,675	40,354	66,156	6.65	0.52
1995	223	15,305	9,932,282	44,539	78,417	7.13	0.58
1996	213	15,513	9,945,130	46,691	62,097	5.53	0.56
1997	208	14,851	9,703,845	46,653	75,237	6.93	0.59
1998	178	11,648	7,715,278	43,344	50,238	5.83	0.57
1999	187	11,867	7,776,397	41,585	73,793	8.56	0.67
2000	154	11,280	7,565,172	49,124	65,355	8.53	0.66
2001	139	10,142	7,167,872	51,567	50,091	7.17	0.68
2002	127	9,274	6,791,389	53,476	54,078	7.88	0.73
2003	110	8,813	6,607,111	60,065	43,973	6.59	0.64
2004	95	8,664	6,626,045	69,748	53,806	8.01	0.69
2005	91	6,886	5,336,069	58,638	36,471	7.02	0.66
2006	81	6,363	4,962,309	61,263	41,988	8.66	0.67
2007	85	6,984	5,246,571	61,724	41,257	7.88	0.69
average	**163**	**11,214**	**6,711,914**	**43,301**	**52,229**	**7.47**	**0.59**

Table 1. Deviance analysis table of yellowfin catch rates in number (CPUEN) from the Pelagic Logbooks. Percent of total deviance refers to the deviance explained by the full model; p value refers to the Chi-square probability test between two consecutive models.

Yellowfin tuna Logbook Catch (weight of fish)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	0	152186.5			
Year	19	149588.0	2598.44	5.4%	< 0.001
Year Area	8	123971.9	25616.17	53.5%	< 0.001
Year Area Season	3	122321.9	1649.94	3.4%	< 0.001
Year Area Season Op	6	121815.6	506.32	1.1%	< 0.001
Year Area Season Op Lghtc	3	119466.4	2349.18	4.9%	< 0.001
Year Area Season Op Lghtc Targ2	3	110575.1	8891.34	18.6%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Mngarea2	1	109510.0	1065.05	2.2%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Season*Targ2	9	109357.6	152.41	0.3%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Op*Mngarea2	6	109188.5	169.13	0.4%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Area*Op	40	109173.3	15.17	0.0%	1.000
Year Area Season Op Lghtc Targ2 ... + Op*Lghtc	18	109138.3	35.04	0.1%	0.009
Year Area Season Op Lghtc Targ2 ... + Area*Lghtc	24	109094.5	43.78	0.1%	0.008
Year Area Season Op Lghtc Targ2 ... + Season*Mngarea2	3	109081.4	13.08	0.0%	0.004
Year Area Season Op Lghtc Targ2 ... + Season*Op	18	108995.3	86.12	0.2%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Lghtc*Mngarea2	3	108959.7	35.59	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Op*Targ2	18	108922.9	36.88	0.1%	0.005
Year Area Season Op Lghtc Targ2 ... + Year*Targ2	57	108884.5	38.36	0.1%	0.973
Year Area Season Op Lghtc Targ2 ... + Season*Lghtc	9	108875.4	9.15	0.0%	0.424
Year Area Season Op Lghtc Targ2 ... + Lghtc*Targ2	9	108867.9	7.45	0.0%	0.590
Year Area Season Op Lghtc Targ2 ... + Year*Mngarea2	19	108826.9	41.00	0.1%	0.002
Year Area Season Op Lghtc Targ2 ... + Targ2*Mngarea2	3	108769.4	57.52	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Area*Season	24	108498.2	271.20	0.6%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Season	57	108320.7	177.46	0.4%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Lghtc	57	108316.2	4.47	0.0%	1.000
Year Area Season Op Lghtc Targ2 ... + Area*Mngarea2	4	108289.6	26.62	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Area*Targ2	24	108229.9	59.76	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Op	114	105840.6	2389.24	5.0%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Area	150	104274.9	1565.68	3.3%	< 0.001

Table 2. Deviance analysis table of yellowfin proportion positive catches from the Pelagic Logbooks. Percent of total deviance refers to the deviance explained by the full model; p value refers to the Chi-square probability test between two consecutive models.

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	0	169986.3			
Year	19	164197.7	5788.64	5%	< 0.001
Year Area	8	102713.2	61484.50	51%	< 0.001
Year Area Season	3	99093.8	3619.43	3%	< 0.001
Year Area Season Op	6	78896.8	20196.94	17%	< 0.001
Year Area Season Op Lghtc	3	73914.1	4982.75	4%	< 0.001
Year Area Season Op Lghtc Targ2	3	57098.3	16815.78	14%	< 0.001
Year Area Season Op Lghtc Targ2 Mngarea2	1	55429.7	1668.57	1%	< 0.001
Year Area Season Op Lghtc Targ2 Season*Mngarea2	3	55227.2	1871.04	2%	< 0.001
Year Area Season Op Lghtc Targ2 Lghtc*Mngarea2	3	55152.1	1946.15	2%	< 0.001
Year Area Season Op Lghtc Targ2 Targ2*Mngarea2	3	55142.6	1955.67	2%	< 0.001
Year Area Season Op Lghtc Targ2 Season*Targ2	9	55077.1	2021.22	2%	< 0.001
Year Area Season Op Lghtc Targ2 Year*Targ2	57	54980.4	2117.85	2%	< 0.001
Year Area Season Op Lghtc Targ2 Op*Mngarea2	6	54890.5	2207.75	2%	< 0.001
Year Area Season Op Lghtc Targ2 Area*Mngarea2	4	54885.1	2213.22	2%	< 0.001
Year Area Season Op Lghtc Targ2 Season*Op	18	54656.8	2441.50	2%	< 0.001
Year Area Season Op Lghtc Targ2 Area*Op	40	54626.9	2471.40	2%	< 0.001
Year Area Season Op Lghtc Targ2 Lghtc*Targ2	9	54547.3	2551.00	2%	< 0.001
Year Area Season Op Lghtc Targ2 Year*Mngarea2	19	54501.8	2596.48	2%	< 0.001
Year Area Season Op Lghtc Targ2 Season*Lghtc	9	54391.8	2706.49	2%	< 0.001
Year Area Season Op Lghtc Targ2 Year*Lghtc	57	54326.9	2771.36	2%	< 0.001
Year Area Season Op Lghtc Targ2 Op*Lghtc	18	54054.2	3044.10	3%	< 0.001
Year Area Season Op Lghtc Targ2 Year*Season	57	53886.5	3211.78	3%	< 0.001
Year Area Season Op Lghtc Targ2 Area*Season	24	53430.1	3668.20	3%	< 0.001
Year Area Season Op Lghtc Targ2 Op*Targ2	18	53158.9	3939.38	3%	< 0.001
Year Area Season Op Lghtc Targ2 Year*Op	114	52395.5	4702.74	4%	< 0.001
Year Area Season Op Lghtc Targ2 Area*Targ2	24	52115.4	4982.92	4%	< 0.001
Year Area Season Op Lghtc Targ2 Year*Area	152	50251.8	6846.46	6%	< 0.001

Table 3. Deviance analysis table of yellowfin catch rates from the Pelagic Logbooks. Percent of total deviance refers to the deviance explained by the full model; p value refers to the Chi-square probability test between two consecutive models.

Yellowfin tuna Logbook Catch (weight of fish)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	0	152186.5			
Year	19	149588.0	2598.44	5.4%	< 0.001
Year Area	8	123971.9	25616.17	53.5%	< 0.001
Year Area Season	3	122321.9	1649.94	3.4%	< 0.001
Year Area Season Op	6	121815.6	506.32	1.1%	< 0.001
Year Area Season Op Lghtc	3	119466.4	2349.18	4.9%	< 0.001
Year Area Season Op Lghtc Targ2	3	110575.1	8891.34	18.6%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Mngarea2	1	109510.0	1065.05	2.2%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Season*Targ2	9	109357.6	152.41	0.3%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Op*Mngarea2	6	109188.5	169.13	0.4%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Area*Op	40	109173.3	15.17	0.0%	1.000
Year Area Season Op Lghtc Targ2 ... + Op*Lghtc	18	109138.3	35.04	0.1%	0.009
Year Area Season Op Lghtc Targ2 ... + Area*Lghtc	24	109094.5	43.78	0.1%	0.008
Year Area Season Op Lghtc Targ2 ... + Season*Mngarea2	3	109081.4	13.08	0.0%	0.004
Year Area Season Op Lghtc Targ2 ... + Season*Op	18	108995.3	86.12	0.2%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Lghtc*Mngarea2	3	108959.7	35.59	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Op*Targ2	18	108922.9	36.88	0.1%	0.005
Year Area Season Op Lghtc Targ2 ... + Year*Targ2	57	108884.5	38.36	0.1%	0.973
Year Area Season Op Lghtc Targ2 ... + Season*Lghtc	9	108875.4	9.15	0.0%	0.424
Year Area Season Op Lghtc Targ2 ... + Lghtc*Targ2	9	108867.9	7.45	0.0%	0.590
Year Area Season Op Lghtc Targ2 ... + Year*Mngarea2	19	108826.9	41.00	0.1%	0.002
Year Area Season Op Lghtc Targ2 ... + Targ2*Mngarea2	3	108769.4	57.52	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Area*Season	24	108498.2	271.20	0.6%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Season	57	108320.7	177.46	0.4%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Lghtc	57	108316.2	4.47	0.0%	1.000
Year Area Season Op Lghtc Targ2 ... + Area*Mngarea2	4	108289.6	26.62	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Area*Targ2	24	108229.9	59.76	0.1%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Op	114	105840.6	2389.24	5.0%	< 0.001
Year Area Season Op Lghtc Targ2 ... + Year*Area	150	104274.9	1565.68	3.3%	< 0.001

Table 4. Analysis of mixed model formulations for yellowfin tuna catch rates from the Pelagic Logbook data of: A. CPUEN #/1000 hooks of positive sets, B. Proportion positive sets and C. CPUEW, kg/1000 hooks of positive sets. The likelihood ratio tests the difference between two nested models. * indicates the final model selected for the standardization of catch rates.

A.

		Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Positives catch rates #/1000 hooks						
	Year Area Season OP lgthc targ2		352896	352898	352908		
	Year Area Season OP lgthc targ2 *Year*Area*		349382	349386	349393	3514	0.0000
*	Year Area Season OP lgthc targ2 *Year*Area Year*OP*		348430	348436	348446	952	0.0000

B.

	Yellowfin tuna GLMixed Model	Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Proportion Positives						
	Year Area Season OP lgthc targ2		82238.8	82240.8	82248.6		
	Year Area Season OP lgthc targ2 *Year*Area*		81475.1	81479.1	81485.4	763.7	0.0000
	Year Area Season OP lgthc targ2 *Year*Area Year*OP*		81178.7	81184.7	81194.3	296.4	0.0000
*	Year Area Season OP lgthc targ2 *Year*Area Year*OP year*season*		80953.3	80961.3	80974	225.4	0.0000

C.

	Yellowfin tuna GLMixed Model	Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Proportion Positives catch in kg/1000 hooks						
	Year Area Season OP lgthc targ2		26789	26791	26797.8		
	Year Area Season OP lgthc targ2 *Year*Area*		26512.6	26516.6	26522.6	276.4	0.0000
*	Year Area Season OP lgthc targ2 *Year*Area Year*OP*		26324.2	26330.2	26339.1	188.4	0.0000

Table 5. Nominal and standardized catch rates of yellowfin tuna in #/1000 hooks (CPUEN) from the pelagic logbook data. Note that the nominal CPUE includes zero catches.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Numb obs	Index	Upp CI 95%	Low CI 95%	Obs. Prop Pos
1987	7.901	12.063	0.123	1.479	10,848	1.702	2.173	1.333	0.55
1988	6.253	12.746	0.120	1.530	11,854	1.799	2.285	1.416	0.46
1989	6.655	11.109	0.131	1.450	14,036	1.568	2.033	1.209	0.47
1990	6.544	9.353	0.130	1.219	13,906	1.320	1.711	1.018	0.48
1991	8.294	6.831	0.152	1.036	13,692	0.964	1.303	0.713	0.53
1992	9.210	8.530	0.132	1.125	13,989	1.204	1.565	0.926	0.57
1993	6.115	5.965	0.147	0.878	13,532	0.842	1.128	0.628	0.51
1994	6.651	6.724	0.143	0.962	14,241	0.949	1.261	0.714	0.52
1995	7.132	6.124	0.138	0.843	15,305	0.864	1.136	0.657	0.58
1996	5.527	4.959	0.152	0.755	15,462	0.700	0.947	0.517	0.56
1997	6.924	6.110	0.138	0.842	14,828	0.862	1.134	0.655	0.59
1998	5.815	4.875	0.149	0.725	11,618	0.688	0.925	0.512	0.57
1999	8.563	6.536	0.136	0.890	11,842	0.922	1.209	0.703	0.67
2000	8.536	6.180	0.135	0.833	11,260	0.872	1.140	0.667	0.66
2001	7.160	4.943	0.156	0.771	10,116	0.698	0.951	0.512	0.68
2002	7.872	5.171	0.140	0.724	9,265	0.730	0.964	0.552	0.73
2003	6.591	4.744	0.166	0.788	8,813	0.669	0.931	0.481	0.64
2004	8.013	6.483	0.146	0.948	8,664	0.915	1.224	0.684	0.69
2005	7.022	6.493	0.139	0.906	6,886	0.916	1.209	0.694	0.66
2006	8.661	6.105	0.149	0.910	6,363	0.862	1.159	0.641	0.67
2007	7.881	6.769	0.140	0.951	6,984	0.955	1.263	0.722	0.69

Table 6. Nominal and standardized catch rates of yellowfin tuna in kg/1000 hooks (CPUEW) from the Pelagic Logbook data. Note that the nominal CPUE includes zero catches.

Year	**Nominal CPUE**	**Standard CPUE**	**Coeff Var**	**Std Error**	**Numb obs**	**Index**	**Upp CI 95%**	**Low CI 95%**
1987	3.15	1.77	0.135	60.009	10848	0.95	2.31	1.35
1988	2.60	1.86	0.133	62.307	11854	0.78	2.43	1.43
1989	2.63	1.63	0.144	58.834	14036	0.80	2.16	1.22
1990	2.70	1.37	0.143	49.386	13906	0.82	1.82	1.03
1991	3.04	1.05	0.166	43.877	13692	0.92	1.46	0.76
1992	3.28	1.26	0.145	45.982	13989	0.99	1.68	0.94
1993	2.72	0.72	0.162	29.170	13532	0.82	0.99	0.52
1994	2.73	0.69	0.157	27.513	14241	0.82	0.95	0.51
1995	3.16	0.84	0.152	31.850	15305	0.96	1.13	0.62
1996	3.03	0.82	0.168	34.800	15462	0.92	1.15	0.59
1997	3.32	0.89	0.151	33.837	14828	1.00	1.20	0.66
1998	3.03	0.65	0.162	26.470	11618	0.91	0.90	0.47
1999	3.80	0.98	0.149	36.824	11842	1.15	1.32	0.73
2000	3.71	0.85	0.147	31.574	11260	1.12	1.14	0.64
2001	3.78	0.77	0.169	32.772	10116	1.14	1.08	0.55
2002	4.05	0.61	0.153	23.335	9265	1.22	0.82	0.45
2003	3.53	0.51	0.181	23.366	8813	1.07	0.73	0.36
2004	3.92	0.87	0.159	34.739	8664	1.18	1.19	0.63
2005	3.63	0.87	0.152	33.280	6886	1.10	1.18	0.64
2006	3.81	0.89	0.163	36.586	6363	1.15	1.23	0.64
2007	3.88	1.10	0.151	41.919	6984	1.17	1.49	0.82

Figure 1. Geographical areas 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 Atlantic, NED North east distant waters, SNA Sargasso Sea, and OFS Offshore waters. Shaded areas represent the current time-area closures affecting the pelagic longline fisheries. Permanent closures: (1) the DeSoto Canyon in the Gulf of Mexico and (2) The Florida east coast areas. Non-permanent closures: (3) the Charleston Bump area closed Feb-Apr, (4) the Bluefin tuna protection area closed in June, and (5) the Grand Banks closed since Oct-2000.

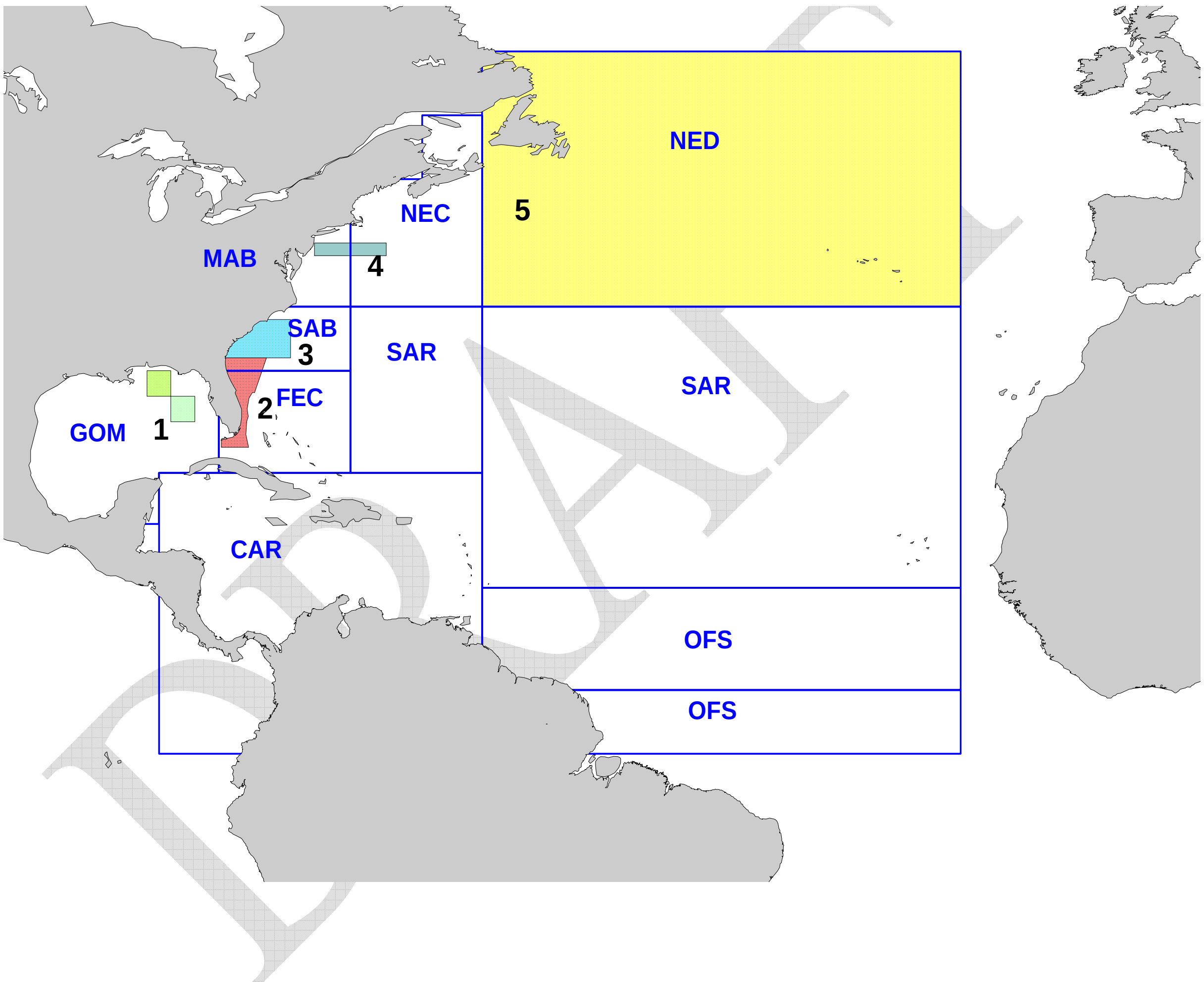

Figure 2. Spatial distribution of catch and effort in the US Pelagic longline fishery for selected years 1987-2006. Scale is log(hooks set) per grid cell. Cell size is approximately 40 x 40 nautical miles.

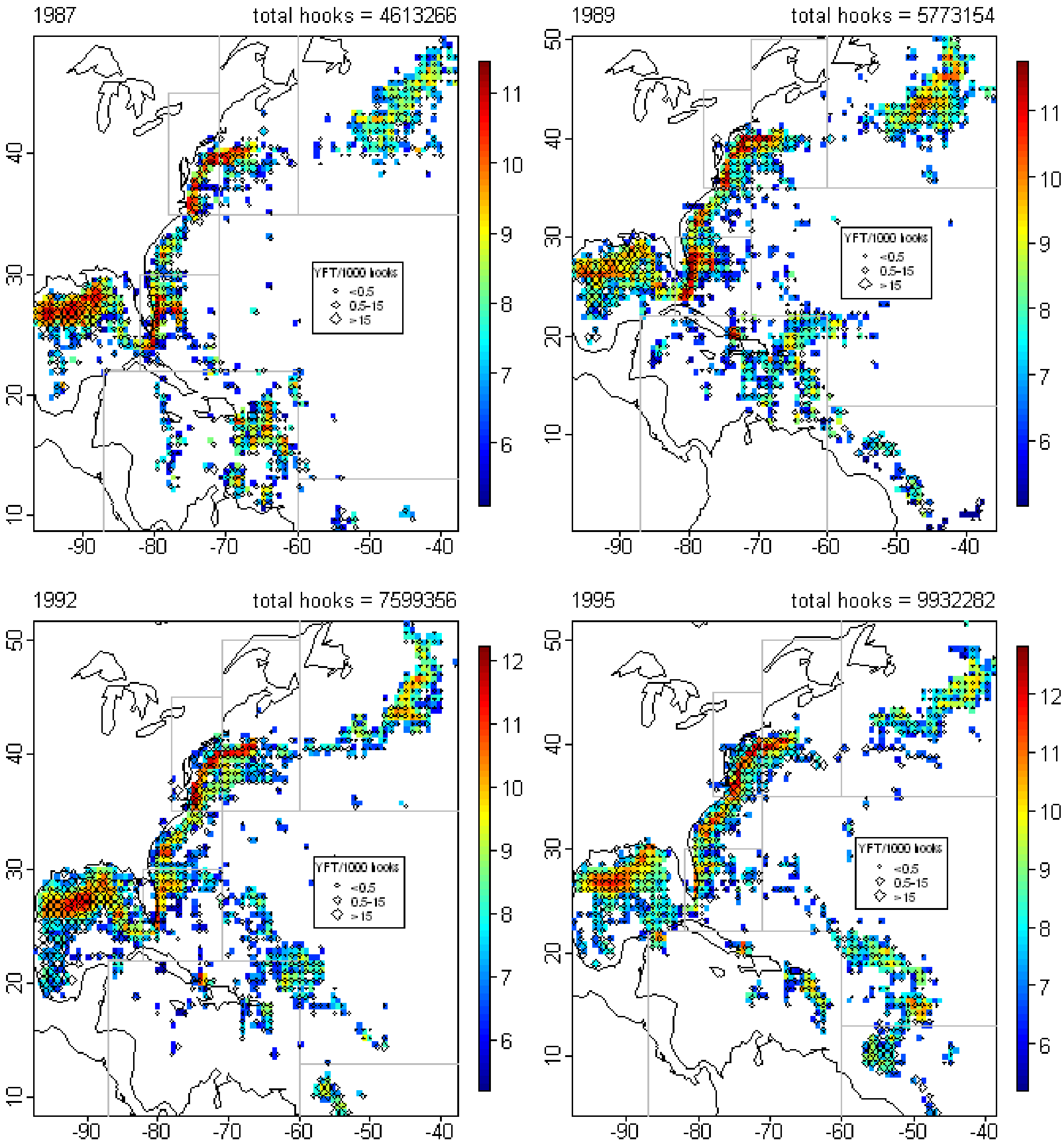

Figure 2, cont.

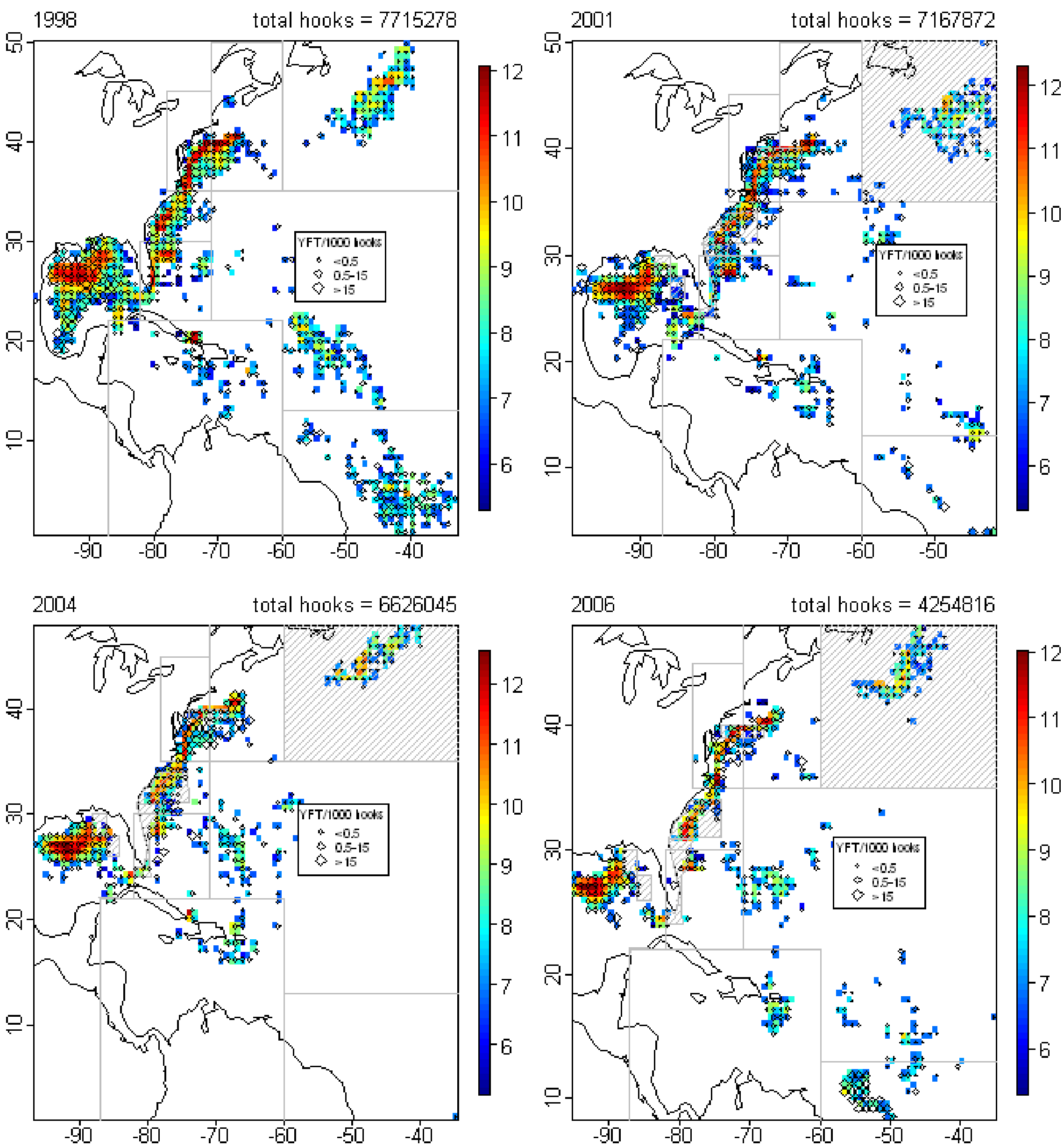

Figure 3. Histograms of yellowfin tuna straight line fork length (cm) by area. Red lines indicate mean fork length.

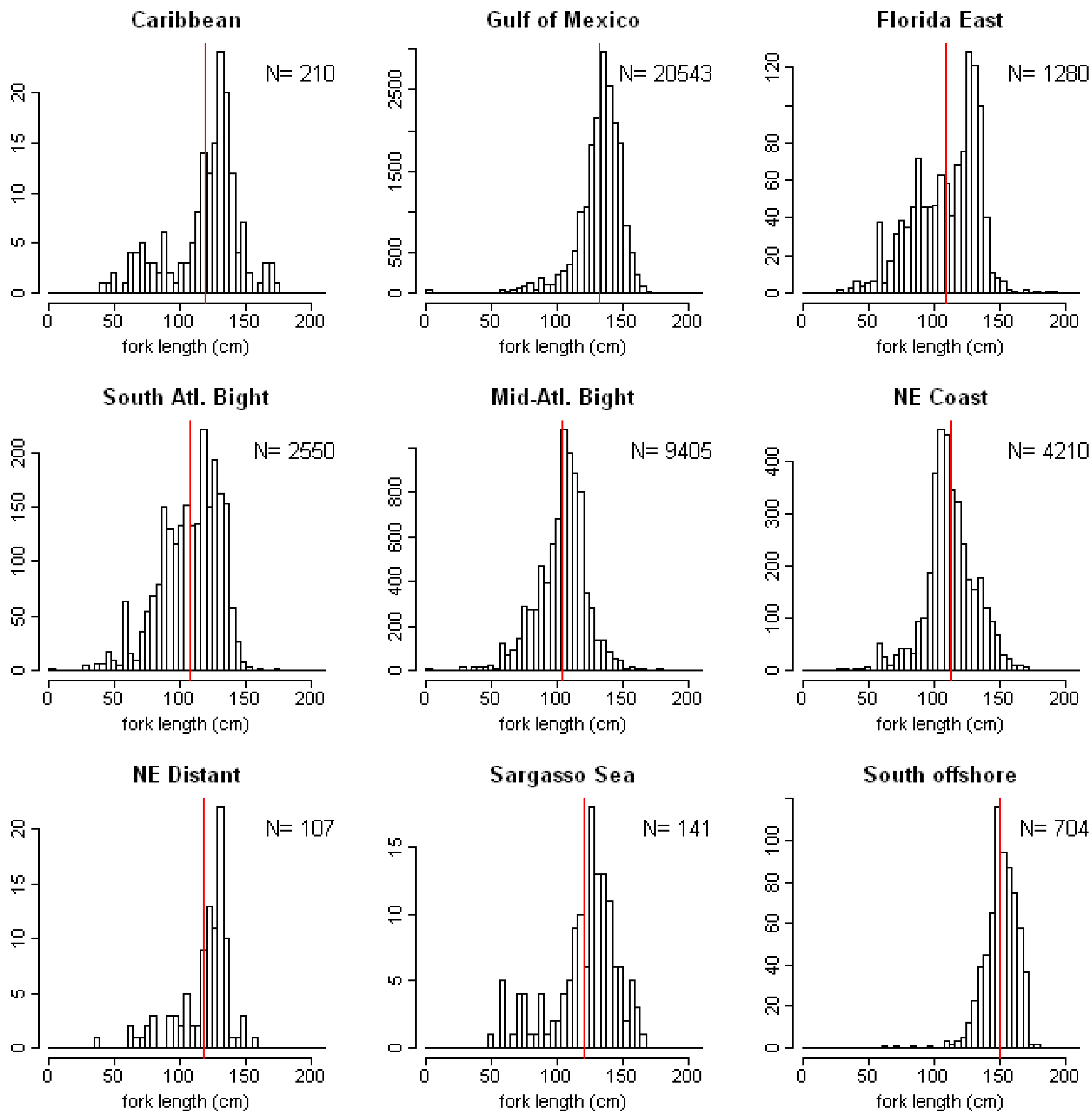

Figure 5. Histograms of yellowfin tuna straight line fork length (cm) by year. Red lines indicate mean fork length.

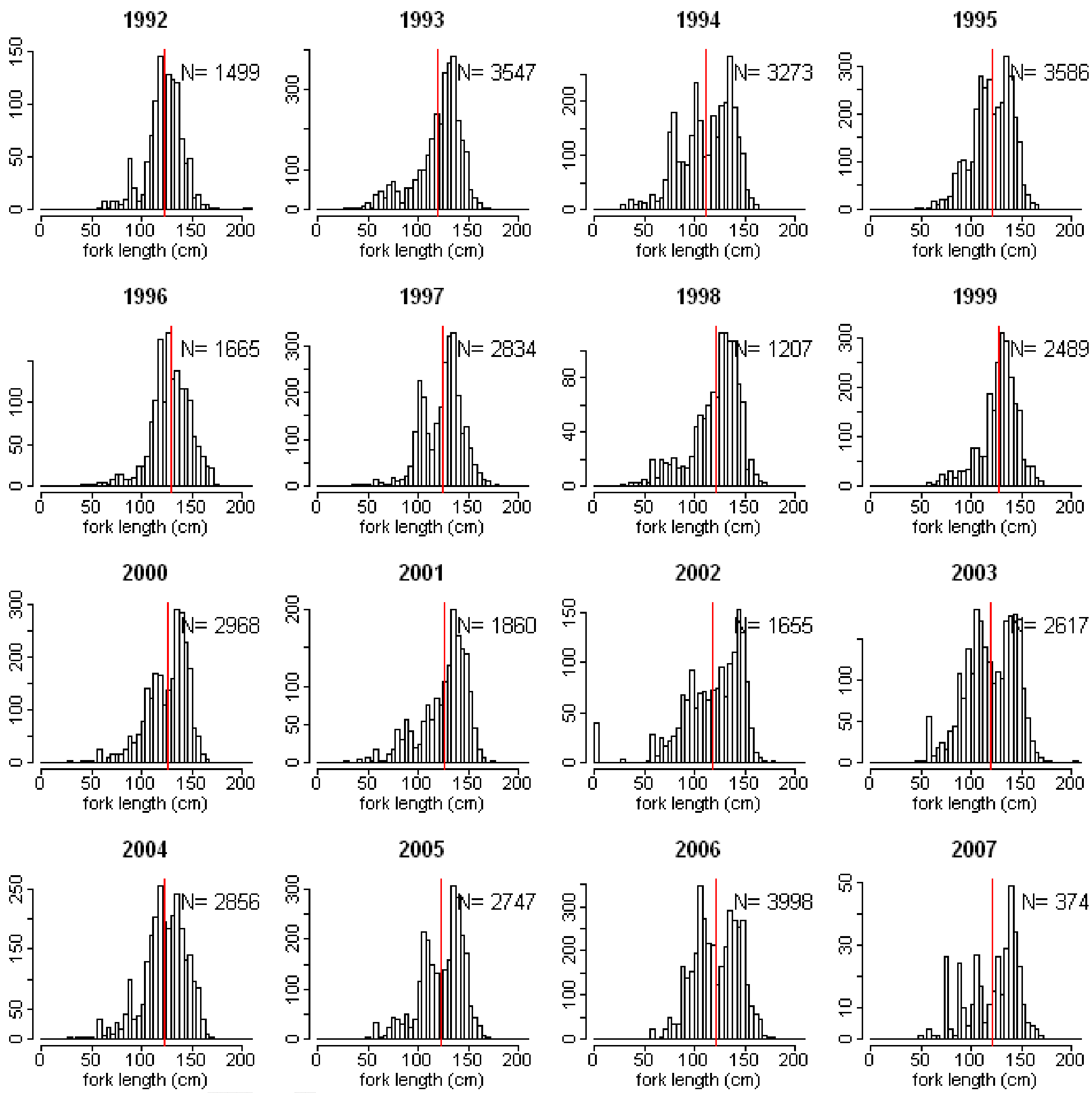

Figure 5. A. Box and whisker plots (median, 1st, 3rd quartile, minimum and maximum) of yellowfin tuna straight line fork length by area (A), year (B) and year just for the Gulf of Mexico (C). Box widths are proportional to sample size and dots represent lengths that are outside the 1.5*interquartile range. Solid dots represent means.

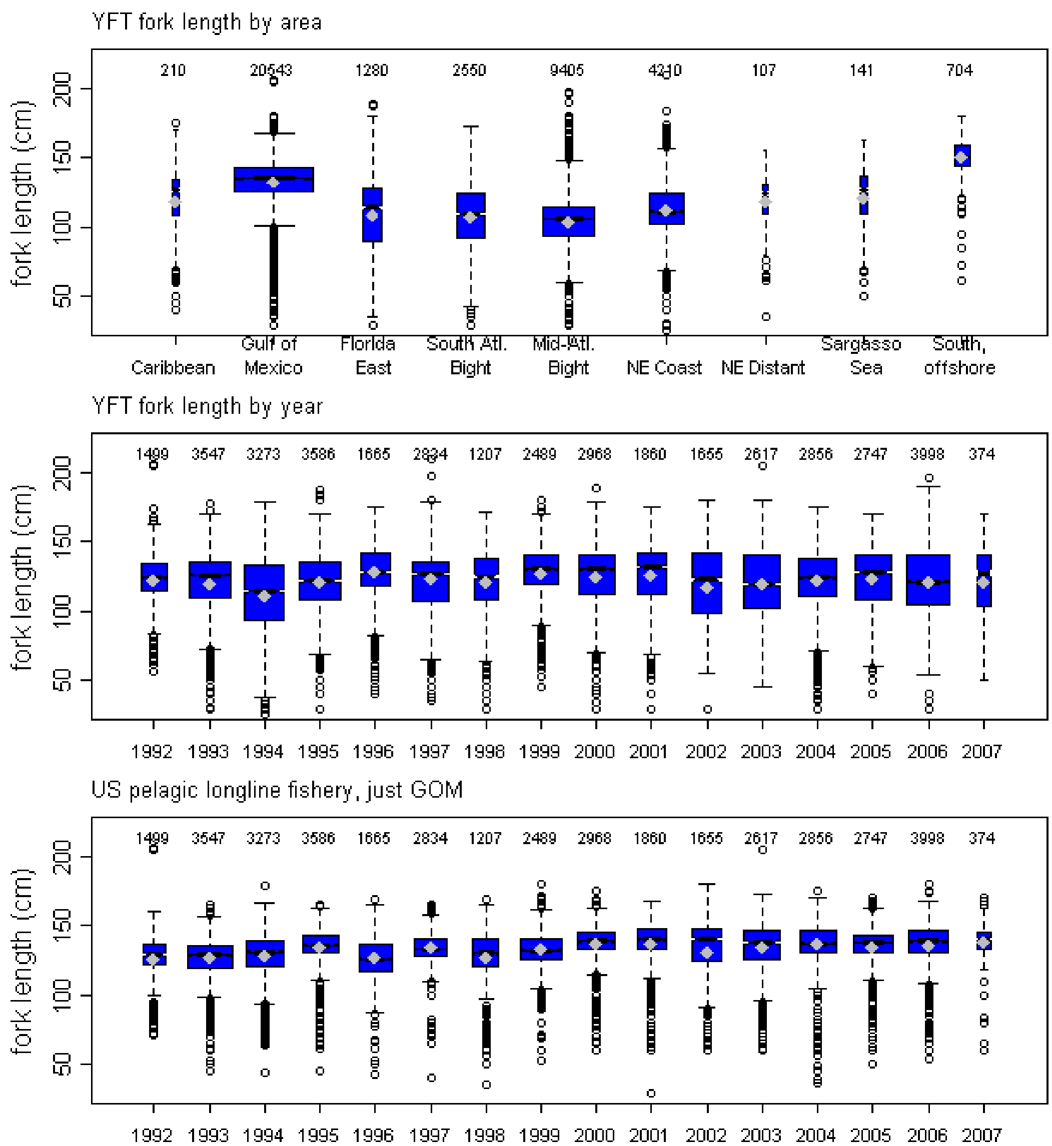

Figure 6. A. Box and whisker plots (median, 1st, 3rd quartile, minimum and maximum) of yellowfin tuna round weight based on measured fork lengths ICCAT length weight conversion, (Caveriviere, 1976) by area (A), year (B) and year just for the Gulf of Mexico (C). Box widths are proportional to sample size and dots represent lengths that are outside the 1.5*interquartile range.

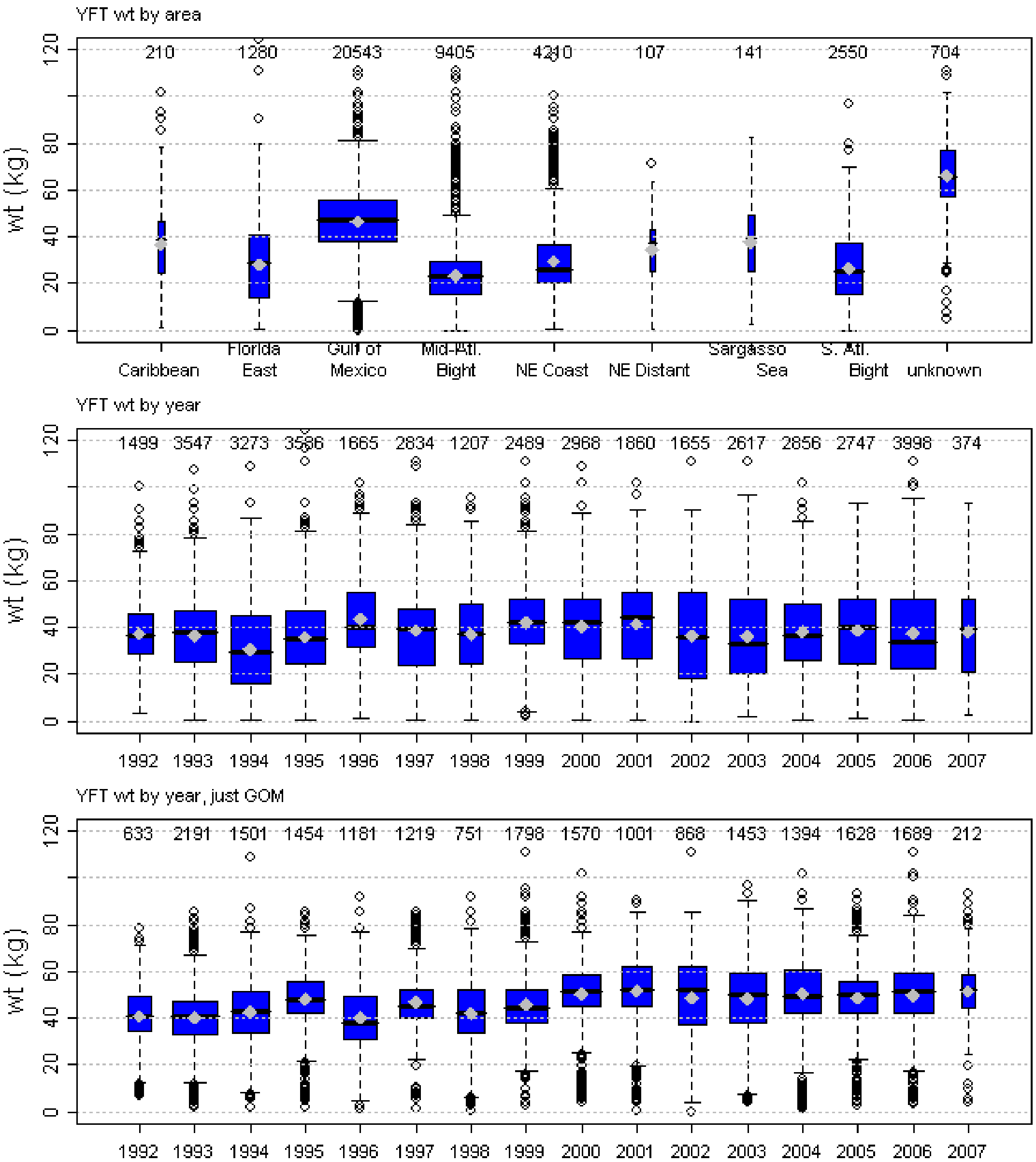

Figure 6. Nominal percentage of positive sets for yellowfin tuna, upper and lower limits are approximate 95% confidence intervals, based on normality. Numbers are the total number of daily logbooks reporting positive skipjack catches.

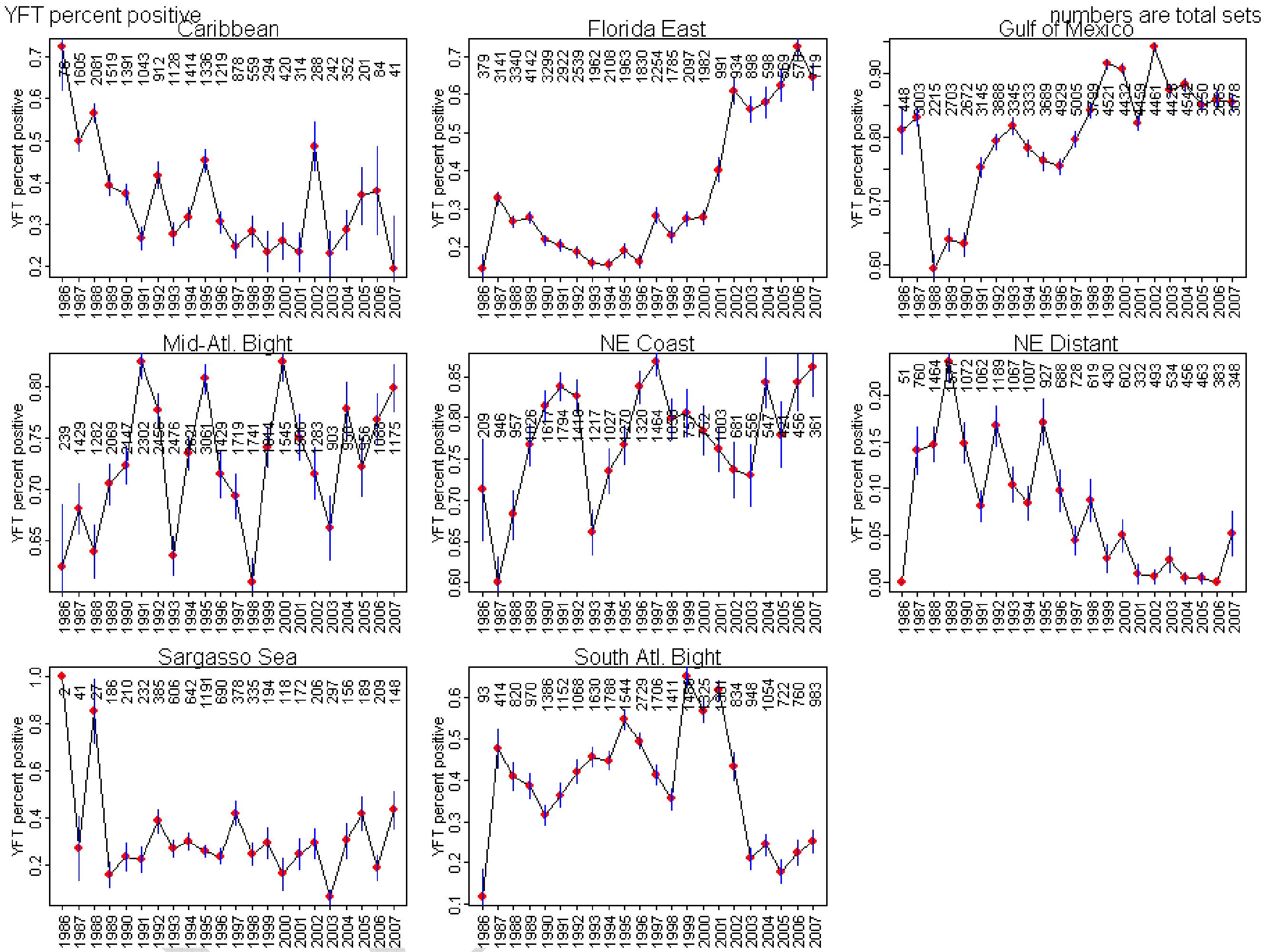

Figure 7. Nominal yellowfin tuna catch per 1000 hooks for each area from logbook data. Upper and lower limits are 95% confidence intervals. Numbers are the total number of daily logbook sets reporting positive skipjack catches.

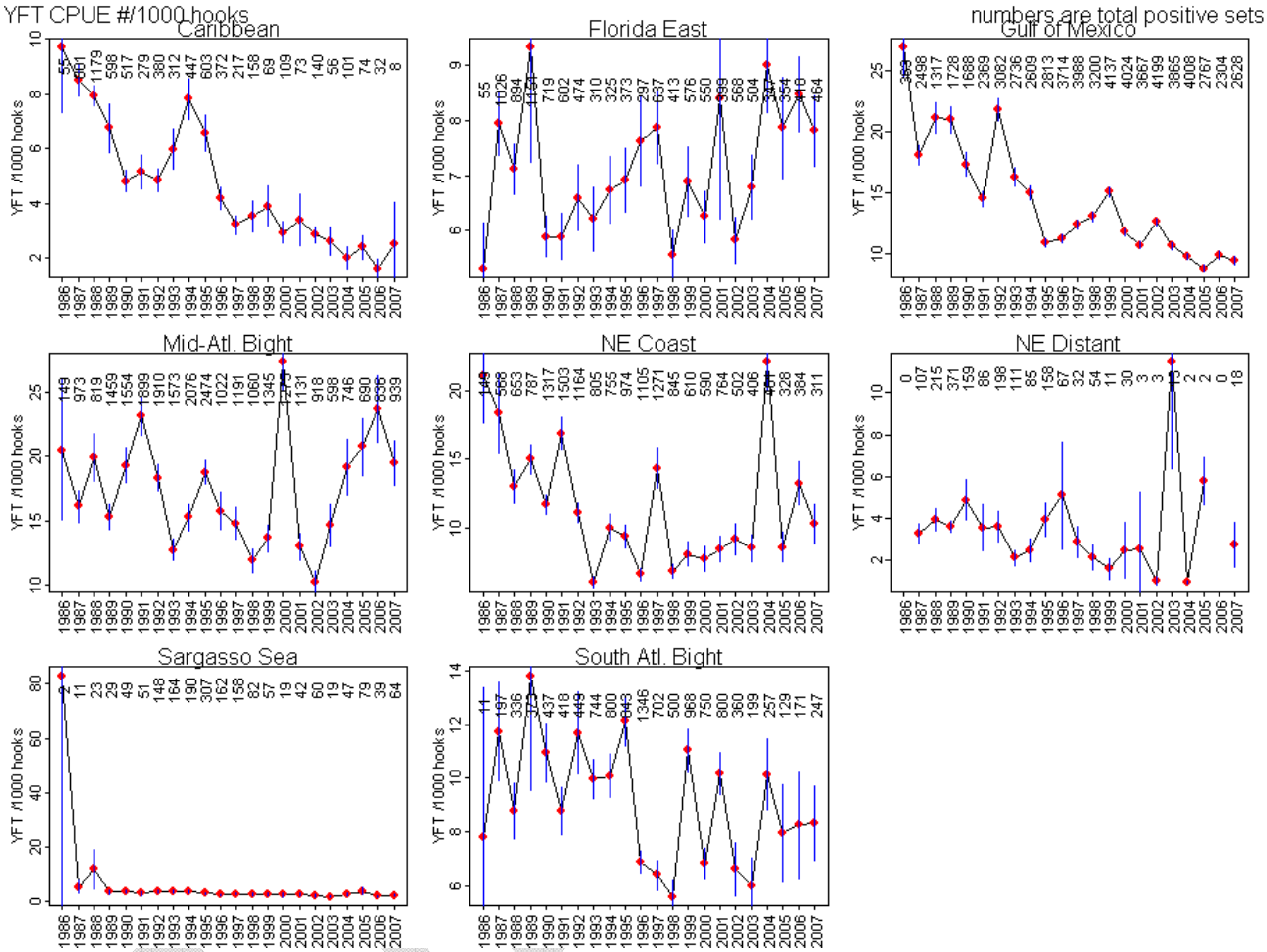

Figure 8. Histograms of log (catch per 1000 hooks, for positive sets, CPUEN) for skipjack tuna form the US Pelagic longline fishery in the Gulf of Mexico from logbook data (A) and catch in weight, CPUEW (C) Histograms of the frequency distribution of the proportion positive over all factors for CPUEN (B). Note that the proportion positive is the same for both CPUEW and CPUEN.

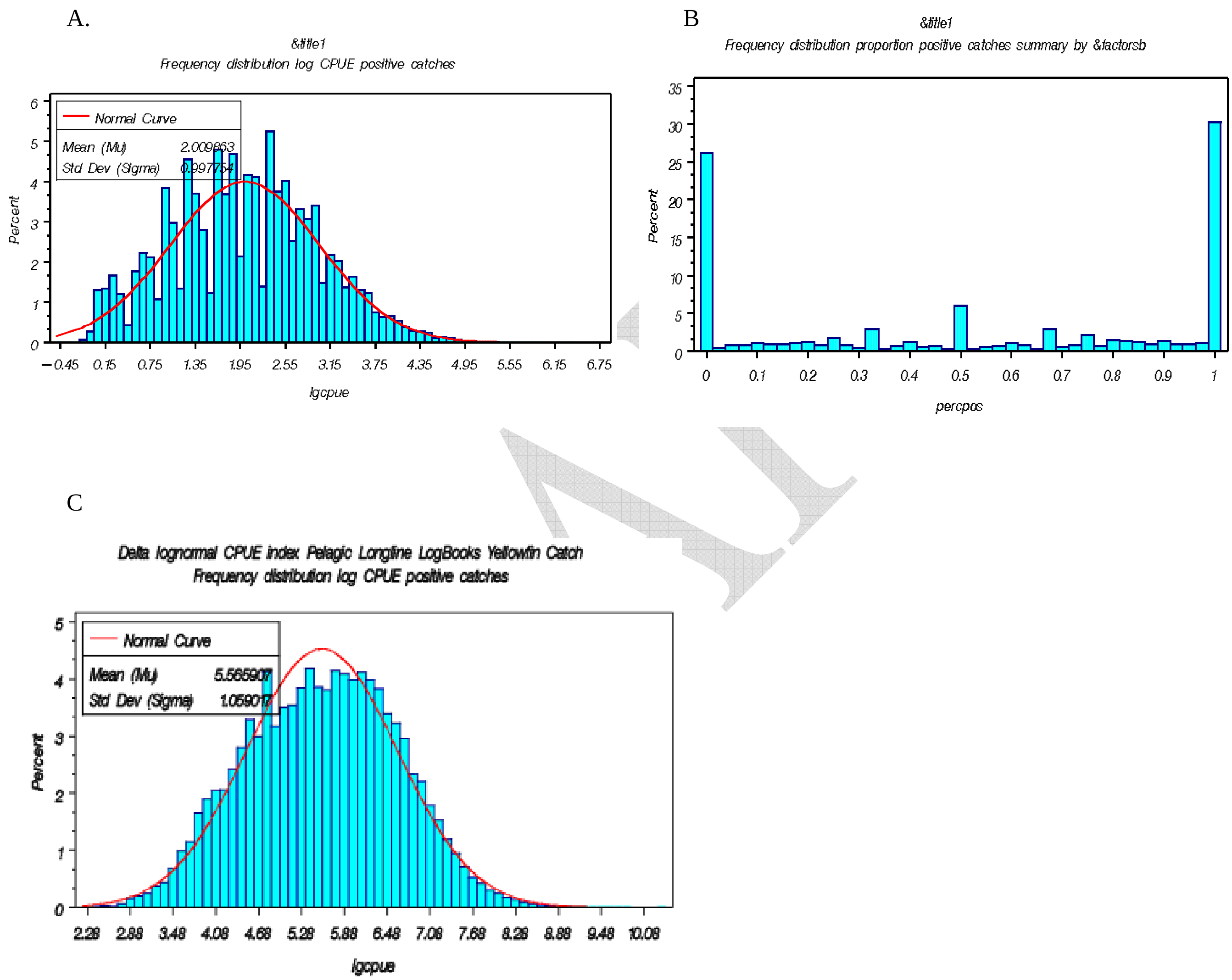

Figure 9. Diagnostic plots for the delta lognormal model fit to the Pelagic Logbook data. Cumulative normalized residuals (qq-plot) from the lognormal assumed error distribution for logbook CPUEN (A) and observer CPUEW (B) and chi-squared residuals for proportion positive (C).

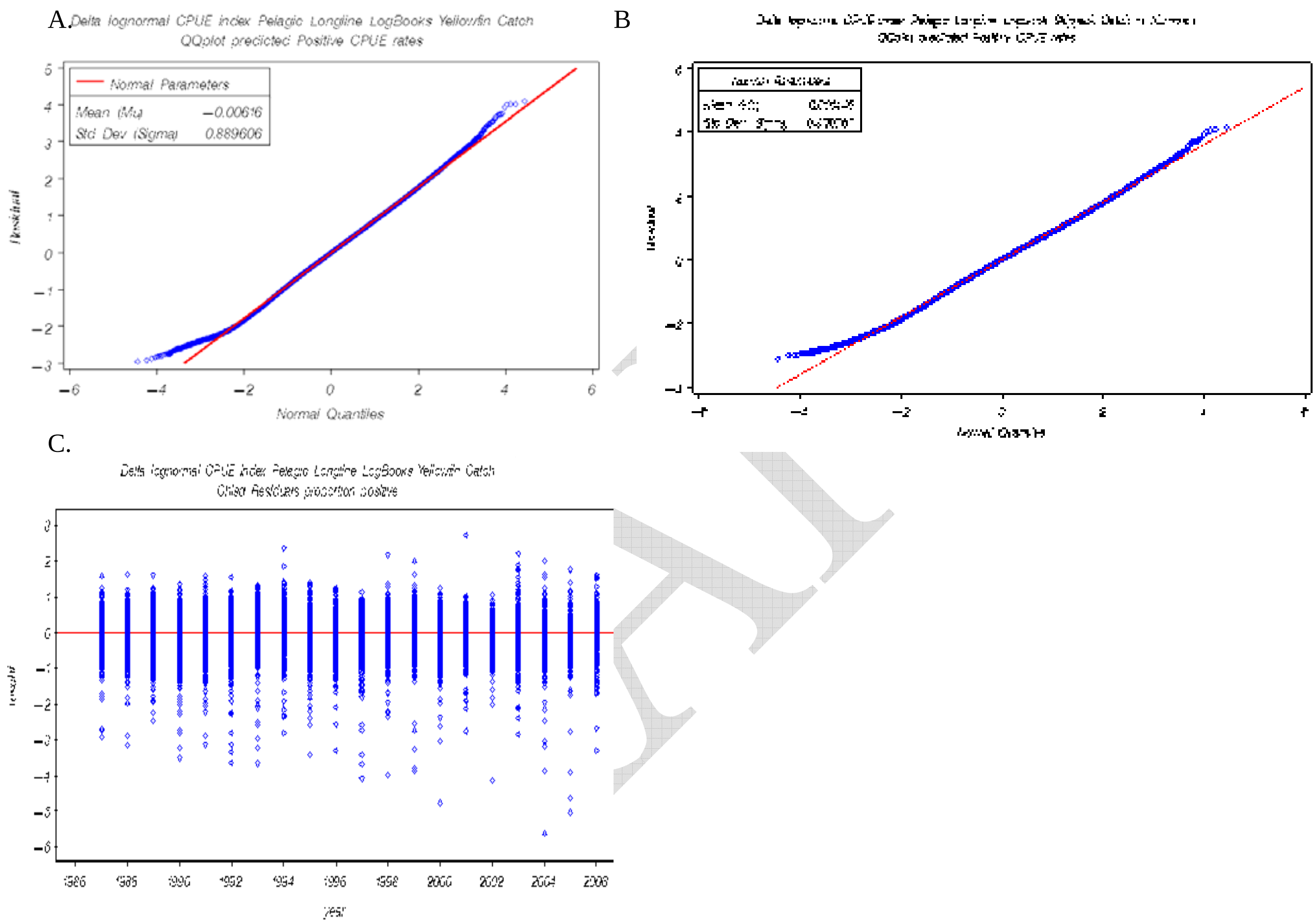

Figure 8. Nominal (solid red circles) and standardized (open blue circles) catch rates for yellowfin tuna from the Pelagic Logbook data (CPUEN).

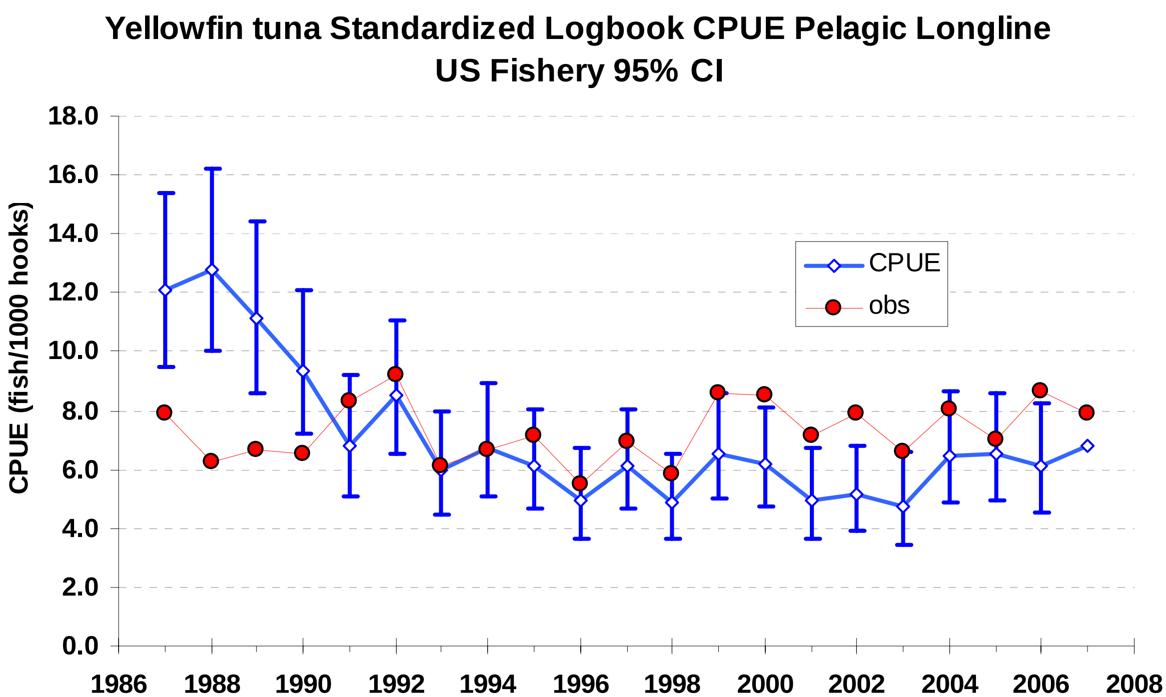

Figure 9. Nominal (solid red circles) and standard (open blue circles) catch rates for yellowfin tuna weight from the Pelagic Logbook data (CPUEW).

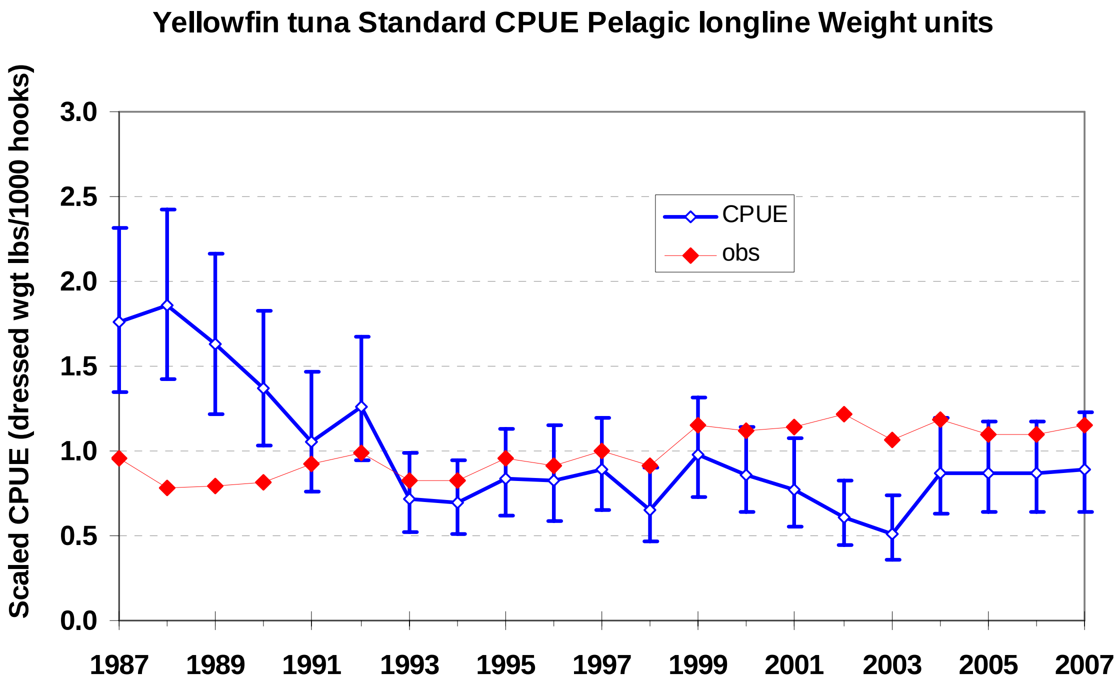

Figure 11. Comparison of standardized CPUE in weight and number. Both measures are scaled to their individual means.