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STANDARDIZED CATCH RATES FOR YELLOWFIN TUNA (*Thunnus albacares*) FROM THE US PELAGIC LONGLINE FLEET

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SUMMARY

Two indices of abundance of yellowfin tuna from the United States pelagic longline fishery in the Atlantic are presented for the period 1981-2002. The standardization analysis included data from yellowfin tuna catches reported in (1) the Pelagic Logbooks, and (2) weight-out tickets from houses that record all commercial sales of yellowfin tuna. Indices, in number of fish and biomass per fishing effort (number of hooks), were estimated. The standardization procedure evaluated the following factors: year, area, season, gear characteristics (light sticks, main line length, hook density, etc.) and fishing characteristics (bait type, operations procedure, and target species). Standardized indices were estimated using Generalized Linear Mixed Models under a delta lognormal model approach.

RÉSUMÉ

Le présent document fait état de deux indices d'abondance pour l'albacore de la pêcherie palangrière pélagique des Etats-Unis pour la période 1981-2002. L'analyse de la standardisation a inclus les données de capture d'albacore déclarées (1) dans les carnets de bord pélagiques, et (2) sur les tickets de poids au débarquement délivrés par les entrepôts qui enregistrent toutes les ventes commerciales d'albacore. Les indices, en nombre de poissons et biomasse par effort de pêche (numéro d'hameçons) ont été estimés. La procédure de standardisation a évalué les facteurs suivants : année, zone, saison, caractéristiques des engins (baguettes lumineuses, longueur de la ligne principale, densité de l'hameçon, etc.) et caractéristiques de la pêche (type d'appât, procédures des opérations et espèces-cibles). Les indices standardisés ont été estimés à l'aide de Modèles linéaires généralisés mixtes selon une approche du modèle delta-lognormal.

RESUMEN

Se presentan dos índices de abundancia de rabil de la pesquería de palangre pelágico de Estados Unidos en el Atlántico para el período 1981-2002. El análisis de estandarización incluía los datos de capturas de rabil comunicados en (1) los cuadernos de pesca de los palangreros pelágicos; (2) los tickets de peso de los comercios que registran las ventas de rabil. Se estimaron los índices, en número de peces y en biomasa por esfuerzo de pesca (número de anzuelos). En el proceso de estandarización se evaluaron los siguientes factores: año, zona, estación, características del arte (bastones luminosos, longitud de la línea principal y especies objetivo). Los índices estandarizados se estimaron mediante Modelos Lineales Generalizados con un enfoque de modelo delta lognormal.

KEYWORDS

Catch/effort, abundance, CPUE, longline, logbooks.

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Introduction

Information on the relative abundance of yellowfin tuna is necessary to tune stock assessment models. Data collected from the US Pelagic Longline fleet has been previously used to develop standardized catch per unit effort (CPUE) indices of abundance for yellowfin and other highly migratory species (Cramer and Ortiz 1999, 2001). The present report documents the analytical procedures for standardization of catch rates derived from the Pelagic Longline fleet data through 2002. Catch in numbers and effort information for each longline set were obtained from the Pelagic longline logbooks, while biomass landings were gathered from the Weight-out data, which records carcass weight per vessel trip. Analysis included a preliminary review of recent management regulations that restricted or closed significant areas to longline fishing and their effect on catch rates for yellowfin tuna.

Materials and methods

The US Pelagic Longline fleet has been described by Hoey and Bertolino (1988) while several authors have reviewed the available catch and effort data derived from the Pelagic Logbooks submitted by each vessel in operation (Scott et al. 1993, Cramer and Bertolino 1998, Ortiz et al. 2000). The present report updates catch and effort information through 2002, and includes analysis of variability associated with random factor interactions particularly for interactions that include the Year effect, following the recommendations of the Statistics and Methods Working Group of the SCRS in 1999.

US Pelagic logbooks have been collected since 1986. From 1986 to 1991, submission of logbooks was voluntary, and it became mandatory in 1992. In addition to the logbook reports, the Pelagic Longline fishers are required to submit carcass weight sheets for main target species that are sold. Weight-out sheets are recorded for each vessel trip, and constitute the Weight-Out database which started in 1981. For the US Pelagic Longline Fleet, swordfish, yellowfin and other tunas (bigeye, bluefin) are the main target species.

The Pelagic Longline Logbook data comprises a total of 256,828 record-sets from 1986 through 2002. Each record contains information of catch by set, including: date-time, geographical location, catch in numbers of targeted and bycatch species, and number of hooks per set. In 1992, an Observer Program (PLOP) was initiated for this fishery. At the present time about 4-5% of the Pelagic Longline trips are monitored by observers (Lee and Brown 1999). The observers collect much more detailed information of the fishery operation, including, type and kind of gear deployed, time of set and haul, environmental-related information (sea surface temperature, wind, etc), and fate of the fish hooked (kept or released alive or dead). Observers also measure length and weight information of each individual fish. Restricting the data only to sets made after 1987 and with catch and effort information, resulted in a total of 184,867 sets, of which 115,968 (63%) reported catch of yellowfin tuna.

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**). Eight geographical areas 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. 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 and number of light-sticks 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 1,000 hooks for each observation. The US 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). The 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%. Sets targeting sharks were excluded from the analysis.

By recommendation of the yellowfin working group, relative indices of abundance should be estimated both in biomass and numbers of fish where possible. For the Pelagic logbook dataset, a possible conversion of numbers of fish to biomass of fish per set is to multiply the number by the mean weight of fish sampled from the Observer program (PLOP). The PLOP recorded size measurements for 24,104 yellowfin tuna fish from 1992 to 2002. **Figure 2** shows the mean size by year-area-quarter strata where at least 50 or more fish were measured. Using the current length-weight relationship (http://www.iccat.es/Documents/convers.pdf), average sizes were transformed to weight units, and nominal catch rates were calculated as kilograms of yellowfin tuna per 1000 hooks. In cases where 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). Although the coverage of observer size data is good for most year-area-quarter, 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.

A second alternative for biomass index of yellowfin tuna comes from the Weight-Out database. This data collects carcass weight of each fish sold through commercial markets for each vessel-trip operation. Thus it represents all landed fish, with information of the area fished and date; fishing effort is estimated from the logbooks. The weight-out data started in 1981, however prior to 1987 the percent of trips with fishing effort information was below 30%. Thus, the weight-out data was restricted from 1987 to 2002. The selected data included 23,143 records of pelagic longline trips of which 18,199 (67.4%) reported landings of yellowfin tuna.

Due to management regulations related to swordfish and other species, time-area restrictions were implemented in 2000 that affected significant areas of Pelagic Longline fishing grounds (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).

Because of the time-area restrictions mentioned above, it is important to evaluate their possible effect on catch rates of yellowfin tuna and if necessary account for this source of variability in the standardization process to obtain relative indices of biomass. An approximation is to evaluate historic catch trends within and outside of the management areas prior to the implementation of time-closures, particularly for the two permanent closures. For the Pelagic Logbook data, it is possible to assign most of the longline sets to specific positions and evaluate historic catch trends in and out of the time-area restrictions. However, for the Weight-out data that includes only general geographic zone of the area fished that are larger than the time-area closures, it is not possible to properly allocate the yellowfin catch to a non-closure or closure location. A solution was to assign an average position to the catch-trip record in the weight-out data. Since 1996, records of sets from the logbooks and the Weight-out record are linked by trip for each vessel. A mean position (latitude and longitude) was estimated for each trip based on location of the longline sets for the same trip reported in the logbooks.

Relative indices of abundance of yellowfin were estimated by Generalized Linear Modeling approach assuming a delta lognormal model distribution. The standardization procedure used a delta model with an assumed binomial error distribution for modeling the proportion of positive trips/sets, and an assumed lognormal error distribution for modeling the mean catch rate of successful trips/sets (i.e. trip or set with catch of yellowfin tuna). Parameterization of the model used the GLM structure, the proportion of successful trips or set per stratum is assumed to follow a binomial error distribution where the estimated probability is a linear function of fixed factors and random effect interactions when the *year* term was within the interaction. The logit function was selected as link between the linear factor component and the binomial error. For successful trips or sets, the estimated catch rates are assumed to follow a lognormal error distribution (logCPUE) as a linear function of fixed factors and random effects.

A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability. The deviance difference between two consecutive models follows a Chi-square distribution. 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 each component of the delta model: Proportion of successful trips/sets, and Mean catch rate 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 are included, b) the Chi-square significant test, and c) the type III test significance within the final model. 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. Analyses were done using Glimmix and Mixed procedures from the SAS® statistical computer software (SAS Institute Inc, 1997, Littell et al. 1996).

Relative indices of abundance were estimated from each data set; the weight-out data for landings and the Pelagic Logbooks for total catch (landings + discards). 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 unbalance distribution of the data. Lognormal estimates also included a bias back-transformation correction factor as describe by Lo et al. (1992).

Results and Discussion

The preliminary evaluation of nominal catch rates by time-area closures indicated that historic catch rates for yellowfin tuna were different (Fig. 3). Catch rates were consistently lower in the Grand Banks, Florida east coast and Charleston Bump from 1987 through 2000 compared to the average rate in non-closure areas. The DeSoto Canyon is the only time-area closure that showed comparable catch rates. This was an expected result since most of the fishery for yellowfin tuna operates in the Gulf of Mexico, and the DeSoto Canyon is within the Eastern Gulf region. The Bluefin tuna protection area showed similar catch rates of yellowfin tuna in the early years 1987-1992, but decreased since 1993 compared to the non-closure areas. Overall, the average nominal rates were lower in the closure areas compared to non-closure (**Fig. 4**), and this trend was similar for both the proportion of sets with positive catch of yellowfin tuna and the average mean catch rate for successful sets (**Fig. 5**). **Figure 6** shows the trend of fishing effort measured as number of hooks deployed per year, between the non-closure and closure areas. Apparently, fishing effort started to reduce in the closure areas as early as 1996/97. This trend was also observed in the weight-out data, although time-area closure analysis was possible only from 1996 to 2000.

Figure 7 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 mean hooks deployed and annual mean catch of fish per 1,000 hooks. The plots show the substantial reduction of areas fished in the latest years, and the reduction of nominal catch rates particularly in the Gulf of Mexico region.

The lognormal frequency distributions by data set of the positive catches are shown in **Figure 8**. Deviance analysis (**Table 1**) for the pelagic logbook data indicated that the factors area and proportion of light-stick were the main factors explaining the observed variability for the successful sets (i.e. positive sets observations). Other factors included were management area (Mngarea2) which identifies closure and non-closure areas, season, and the interactions year*area, year*season and area*season. For the probability of successful set or proportion of positives, the factors area and OP were the most important explanatory variables, other factors included in the model were season, light-sticks, and the interactions year*area, area*season and area*light-sticks. **Table 2** shows the evaluation of the mixed model formulations for both components of the delta model: the proportion of positive sets and the mean catch rate of positive sets.

For the yellowfin tuna biomass index derived from the Weight-Out data, deviance analysis indicated that the factors area, target and OP were the main explanatory variables for the proportion of positive trips and the mean catch rate of successful trips. Other factors included were quarter (or season), and the interactions year*area and year*OP (**Table 3**). Basically, similar explanatory factors were obtained from the weight-out data and the Pelagic Logbook data. **Table 4** shows the evaluation of the mixed model formulations for the positive trips and the proportion of successful trips. In **Table 4**, smaller value of AIC and BIC indicated best model fit.

Figures 9 and **10** present some diagnostic plots for the model fit: the cumulative normalized residuals from the positive observations model component (left panels), and the residuals by year distributions also from the positive observations. **Tables 5** and **6** provide the nominal and standardized catch rates from the Pelagic Logbook data and the Weight-out data, with estimated 95% confidence intervals (**Fig. 11** and **12**). Both datasets showed similar trends of standardized catch rates, the overall pattern indicated a decrease in catch rates from 1987/88 through 1996/97, followed by a stable trend from 1998 to 2002 (**Fig. 13**). For the Pelagic Logbook data, a biomass standardized index was estimated by transforming the number of fish caught to weight using the mean size of yellowfin tuna measured in the Pelagic Observer Program (PLOP) by Area-season and year. **Figure 14** shows the comparison of both standard indices from the Pelagic Logbook data. Both indices show similar trends, with only minor differences in the 1993/94 year, and prior to 1992, when the observer program began (the mean size of 1992 strata were used for 1987 to 1991).

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Table 1. Deviance analysis table of yellowfin tuna catch rates from the Pelagic Logbook data from 1987 to 2002. 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 (Numbers of fish)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	117371.4			
Year	15	115862.7	1508.71	5.8%	< 0.001
Year Area	8	103055.1	12807.57	49.4%	< 0.001
Year Area Season	3	102116.6	938.57	3.6%	< 0.001
Year Area Season Lghtc	3	100258.1	1858.43	7.2%	< 0.001
Year Area Season Lghtc Op	6	99899.5	358.62	1.4%	< 0.001
Year Area Season Lghtc Op Mngarea2	1	98920.2	979.26	3.8%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Year*Area	120	96148.7	2771.49	10.7%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Year*Season	45	95386.1	762.66	2.9%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Area*Season	24	94780.8	605.27	2.3%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Year*Lghtc	45	94319.3	461.55	1.8%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Area*Lghtc	24	93808.0	511.28	2.0%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Season*Lghtc	9	93745.4	62.62	0.2%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Year*Op	90	92953.0	792.35	3.1%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Area*Op	40	92787.6	165.40	0.6%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Season*Op	18	92719.5	68.15	0.3%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Lghtc*Op	18	92479.8	239.63	0.9%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Year*Mngarea2	15	92169.7	310.14	1.2%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Area*Mngarea2	4	91589.3	580.42	2.2%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Season*Mngarea2	3	91508.8	80.48	0.3%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Lghtc*Mngarea2	3	91486.6	22.19	0.1%	< 0.001
Year Area Season Lghtc Op Mngarea2 … + Op*Mngarea2	6	91436.3	50.31	0.2%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	100676.1			
Year	15	97691.6	2984.44	4%	< 0.001
Year Area	8	52755.4	44936.22	63%	< 0.001
Year Area Season	3	49721.9	3033.51	4%	< 0.001
Year Area Season Op	6	37552.5	12169.40	17%	< 0.001
Year Area Season Op Lghtc	3	34505.5	3047.04	4%	< 0.001
Year Area Season Op Lghtc Mngarea2	1	32893.1	1612.34	2%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Mngarea2	15	32534.8	358.39	1%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Lghtc	45	31878.8	1014.33	1%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Season	45	31739.6	1153.51	2%	< 0.001
Year Area Season Op Lghtc Mngarea2 Area*Season	24	30817.3	2075.83	3%	< 0.001
Year Area Season Op Lghtc Mngarea2 Area*Lghtc	24	30655.0	2238.15	3%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Op	90	30580.1	2313.02	3%	< 0.001
Year Area Season Op Lghtc Mngarea2 Year*Area	120	29682.5	3210.69	5%	< 0.001

Table 2. Analysis of mixed model formulations for yellowfin tuna catch rates from the Pelagic Logbook data. The Likelihood ratio tests the difference between two nested models. The final model selected for the standardization of catch rates is indicated by an *.

	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 Area*lgthc		26789	26791	26797.8		
	Year Area Season OP lgthc Area*lgthc *Year*Area*		26512.6	26516.6	26522.6	276.4	0.0000
*	Year Area Season OP lgthc Area*lgthc *Year*Area Year*OP*		26324.2	26330.2	26339.1	188.4	0.0000

		Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Positives catch rates						
	Year Area Season OP		312786.1	213788.1	312797.8		
	Year Area Season OP *Year*Area*		310103.4	310107.4	310113.3	2682.7	0.0000
*	Year Area Season OP *Year*Area Year*OP*		309151.8	309157.8	309166.7	951.6	0.0000

Table 3. Deviance analysis table of yellowfin tuna catch rates from the Weight-out data from 1987 to 2002. 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.

Yellow fin 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	37053.4244			
Year	15	36716.8318	336.59	1.6%	< 0.001
Year Area	6	24266.7587	12450.07	59.4%	< 0.001
Year Area Qtr	3	23326.5263	940.23	4.5%	< 0.001
Year Area Qtr Op	6	22376.9721	949.55	4.5%	< 0.001
Year Area Qtr Op Mngarea2	1	22246.3764	130.60	0.6%	< 0.001
Year Area Qtr Op Mngarea2 Targ	3	18842.3551	3404.02	16.3%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area	90	18087.391	754.96	3.6%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Year*Op	89	17676.9147	410.48	2.0%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Area*Op	28	17595.7766	81.14	0.4%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Year*Qtr	45	17380.4751	215.30	1.0%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Area*Qtr	18	17022.1618	358.31	1.7%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Qtr*Op	18	16923.7334	98.43	0.5%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Year*Targ	45	16799.942	123.79	0.6%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Area*Targ	18	16451.2745	348.67	1.7%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Op*Targ	18	16415.795	35.48	0.2%	0.008
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Qtr*Targ	9	16364.284	51.51	0.2%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Year*Mngarea2	6	16329.2379	35.05	0.2%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Area*Mngarea2	5	16178.6773	150.56	0.7%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Op*Mngarea2	6	16149.1036	29.57	0.1%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Qtr*Mngarea2	3	16132.2972	16.81	0.1%	< 0.001
Year Area Qtr Op Mngarea2 Targ Year*Area ...+ Mngarea2*Targ	3	16110.5384	21.76	0.1%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	_	20479.731			
Year	15	19991.937	487.79	3%	< 0.001
Year Area	6	12528.595	7463.34	53%	< 0.001
Year Area Qtr	3	12060.093	468.50	3%	< 0.001
Year Area Qtr Op	6	9833.949	2226.14	16%	< 0.001
Year Area Qtr Op Mngarea2	1	9485.785	348.16	2%	< 0.001
Year Area Qtr Op Mngarea2 Targ	3	7199.454	2286.33	16%	< 0.001
Year Area Qtr Op Mngarea2 Year*Mngarea2	6	7152.445	47.01	0%	< 0.001
Year Area Qtr Op Mngarea2 Year*Targ	45	7034.167	165.29	1%	< 0.001
Year Area Qtr Op Mngarea2 Year*Qtr	45	6898.642	300.81	2%	< 0.001
Year Area Qtr Op Mngarea2 Year*Op	89	6806.498	392.96	3%	< 0.001
Year Area Qtr Op Mngarea2 Year*Area	90	6514.068	685.39	5%	< 0.001

Table 4. Analysis of mixed model formulation for yellowfin tuna catch rates from the Weight-Out data. The Likelihood ratio tests the difference between two nested models. The final model selected for the standardization of catch rates is indicated by an *.

	Yellow fin tuna 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		14595.7	14597.7	14603.7		
*	Year Area Target OP *Year*Area*		14372	14376	14381.4	223.7	0.0000
	Year Area Target OP *Year*Area Year*OP*		14370.4	14376.4	14384.4	1.6	0.2059

		Num obs	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
	Positives catch rates						
	Year Area OP Target Qtr		43341.3	43343.3	43351		
	Year Area OP Target Qtr *Year*Area*		42989.6	42993.6	42999	351.7	0.0000
*	Year Area OP Target Qtr *Year*Area Year*OP*		42809.6	42815.6	42823.6	180	0.0000

Table 5. Nominal and standard catch rates of yellowfin tuna from the Pelagic Logbook data. Catch rates express as number of fish per thousand hooks.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Numb obs	Index	Upp CI 95%	Low CI 95%
1987	9.21	11.28	0.124	1.398	9301	11.28	1.19	0.72
1988	7.91	12.18	0.121	1.477	9370	12.18	1.27	0.79
1989	8.12	11.30	0.124	1.399	11502	11.30	1.19	0.72
1990	7.80	9.73	0.125	1.219	11662	9.73	1.03	0.62
1991	9.44	8.29	0.132	1.098	12031	8.29	0.89	0.52
1992	10.07	10.41	0.123	1.283	12801	10.41	1.09	0.67
1993	6.69	7.47	0.133	0.991	12363	7.47	0.80	0.47
1994	7.22	8.11	0.132	1.074	13114	8.11	0.87	0.51
1995	7.57	8.13	0.126	1.022	14426	8.13	0.86	0.52
1996	5.98	6.10	0.134	0.820	14274	6.10	0.65	0.38
1997	7.56	7.09	0.128	0.910	13672	7.09	0.75	0.45
1998	6.40	5.23	0.137	0.714	10469	5.23	0.56	0.33
1999	9.28	6.69	0.129	0.864	10929	6.69	0.71	0.42
2000	9.35	6.42	0.129	0.829	10281	6.42	0.68	0.41
2001	7.53	5.78	0.139	0.803	9618	5.78	0.63	0.36
2002	8.06	5.79	0.126	0.732	9054	5.79	0.61	0.37

Table 6. Nominal and standard catch rates of yellowfin tuna from the Weight-Out data. Catch rates express as number of pounds per thousand hooks.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Numb obs	Index	Upp CI 95%	Low CI 95%
1987	332.10	697.60	0.161	112.060	740	1.48	2.04	1.08
1988	432.82	766.90	0.153	117.450	944	1.63	2.21	1.20
1989	361.68	764.94	0.155	118.530	745	1.62	2.21	1.19
1990	409.70	641.54	0.153	98.372	805	1.36	1.85	1.00
1991	740.47	578.95	0.154	88.926	1223	1.23	1.67	0.91
1992	606.38	578.63	0.147	84.995	1769	1.23	1.64	0.92
1993	440.89	389.39	0.147	57.379	2015	0.83	1.11	0.62
1994	461.84	367.01	0.149	54.651	2134	0.78	1.05	0.58
1995	491.87	396.09	0.148	58.498	2253	0.84	1.13	0.63
1996	375.20	319.83	0.152	48.670	2435	0.68	0.92	0.50
1997	377.57	358.26	0.152	54.512	2626	0.76	1.03	0.56
1998	382.65	311.14	0.151	46.904	2270	0.66	0.89	0.49
1999	450.55	365.31	0.153	55.822	2125	0.78	1.05	0.57
2000	461.11	353.72	0.150	52.999	2109	0.75	1.01	0.56
2001	433.57	317.19	0.155	49.016	1523	0.67	0.92	0.49
2002	504.41	334.80	0.152	50.913	1273	0.71	0.96	0.52

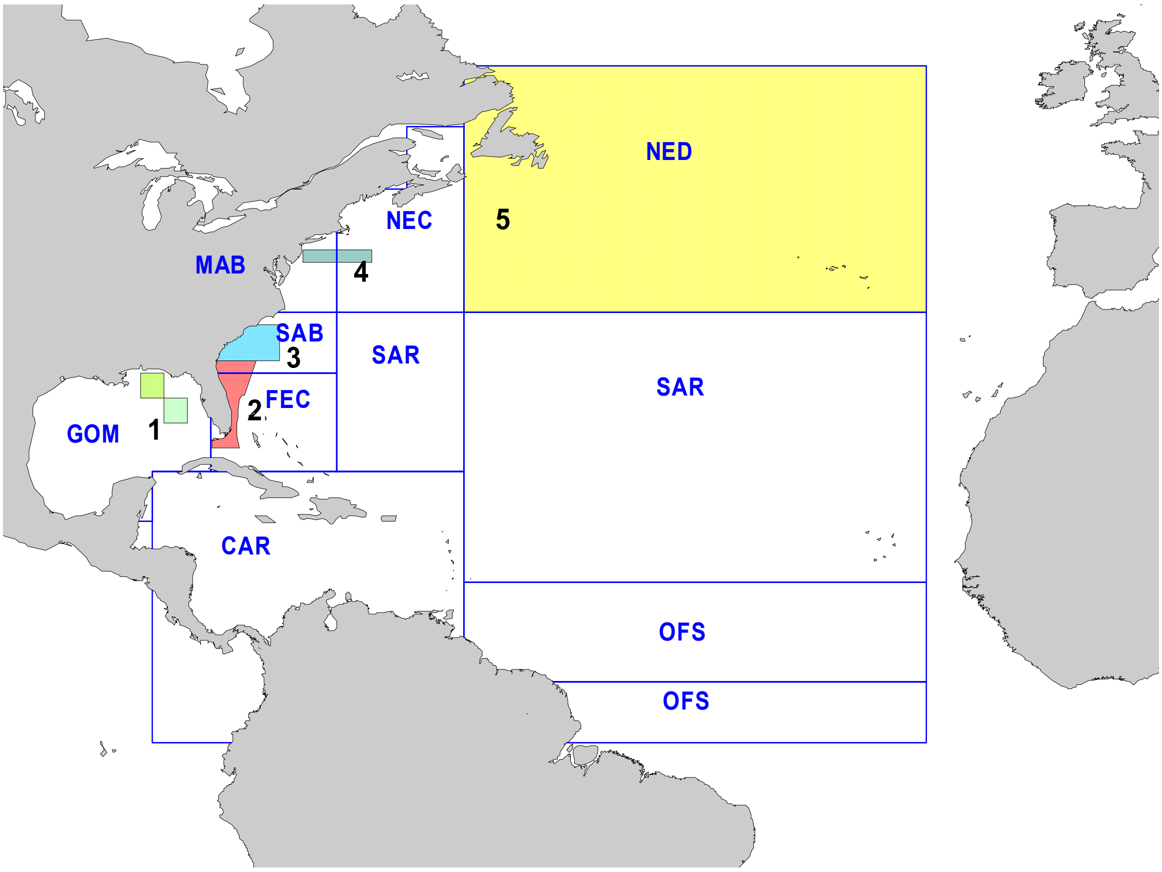


Figure 1. Geographical areas of the US Pelagic Longline fishery: CAR Caribbean, GOM Gulf of Mexico, FEC Florida east coast, SAB South Atlantic bight, MAB mid Atlantic bight, NEC North east coastal Atlantic, NED North east distant waters, SAR Sargasso Sea, and OFS Offshore waters. Shaded areas represent 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. Mean size (fork length cm) of yellowfin tuna from the Pelagic Observer Program by Area, Season and year. Mean values were estimated for 50 or more fish measured per strata.

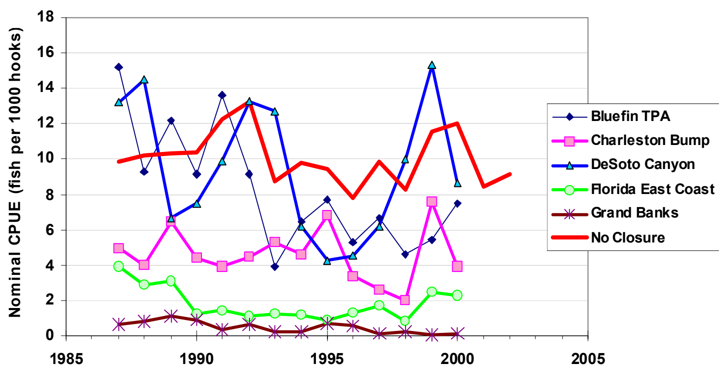


Figure 3. Yellowfin tuna nominal catch rates from the US Pelagic Longline Fleet by time area closure areas

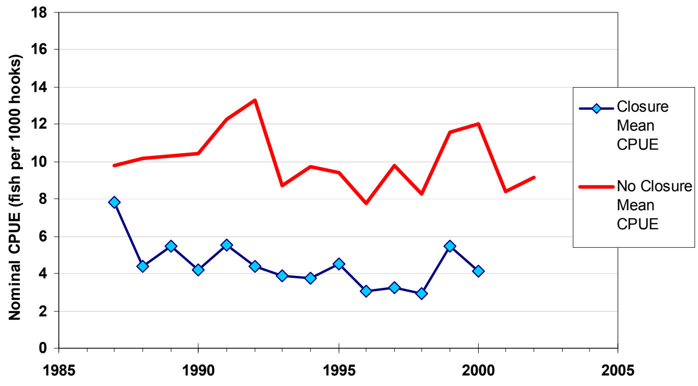


Figure 4. Yellowfin tuna average nominal catch rates from the US Pelagic Longline fleet by time-area closure (all areas) and non-closure areas.

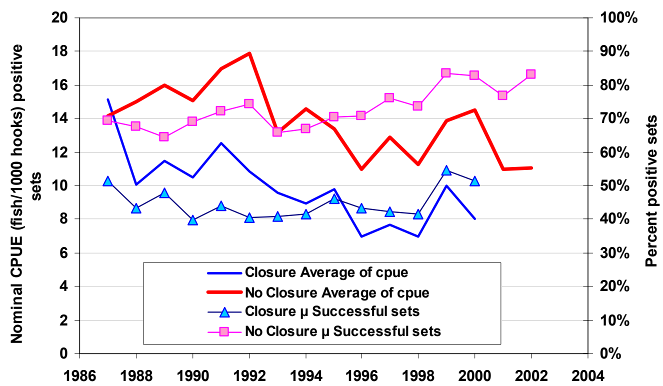


Figure 5. Yellowfin tuna nominal annual CPUE rates (solid lines) and proportion of successful sets (symbol lines) by time-area closure and non-closure areas from the US Pelagic Logbook data.

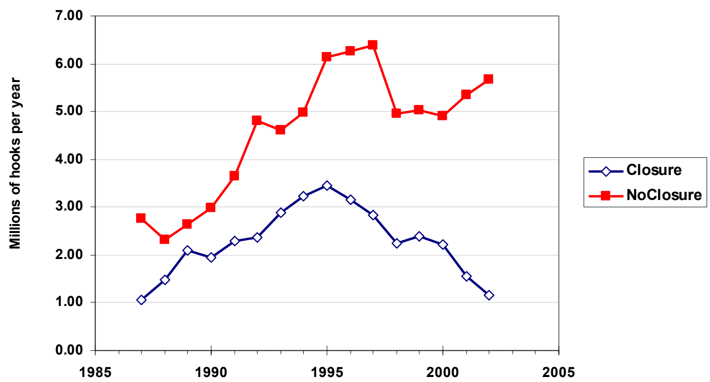
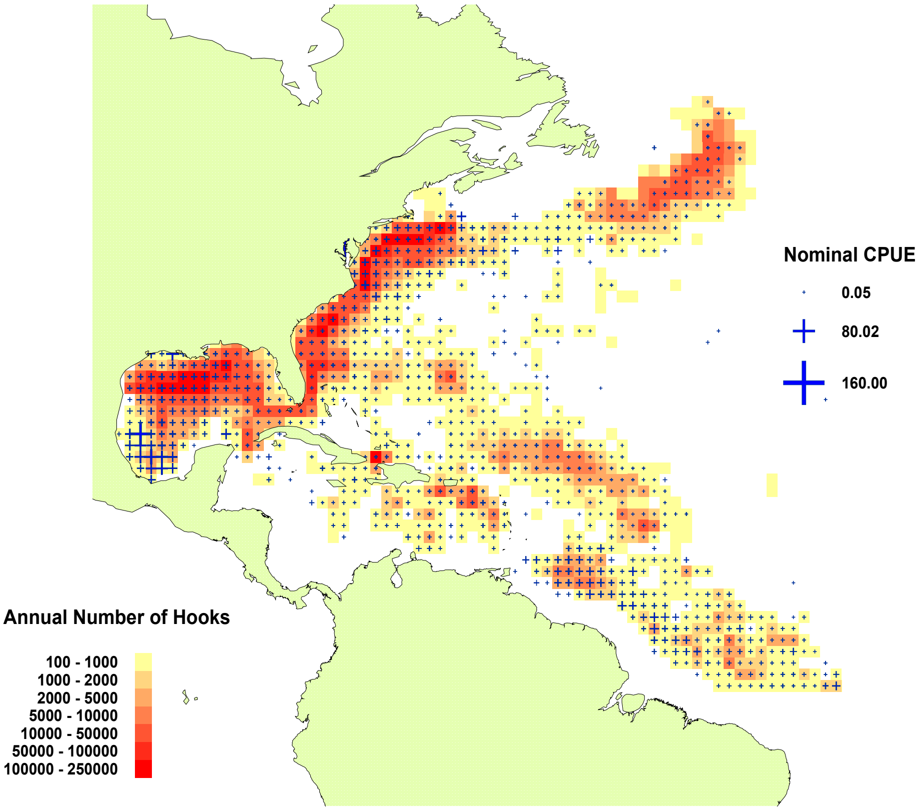


Figure 6. Nominal fishing effort (Number of hooks deployed) by the US Pelagic Longline fleet in time-area closure and non-closure areas. Data compiled from the Pelagic Logbooks.



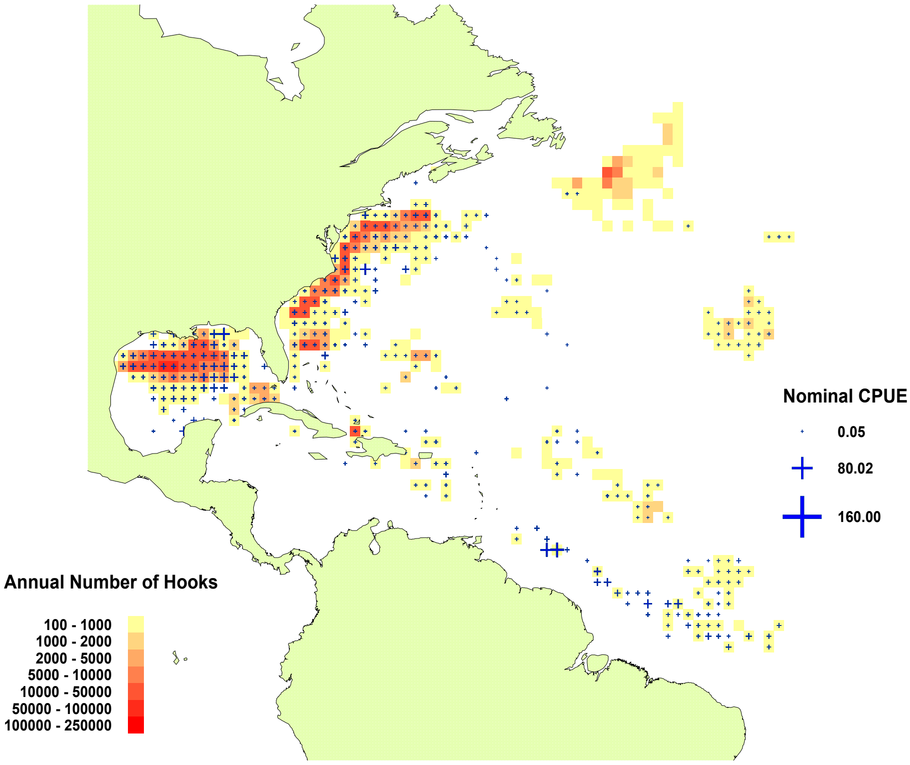


Figure 7. Geographic distribution of fishing effort (Annual mean of hooks deployed, shade areas), and mean annual catch rates (fish per 1000 hooks, symbols) of yellowfin tuna by one degree squares. Data compiled from the Pelagic Logbooks for 1990-2000 (top panel) and 2001-02 (bottom panel).

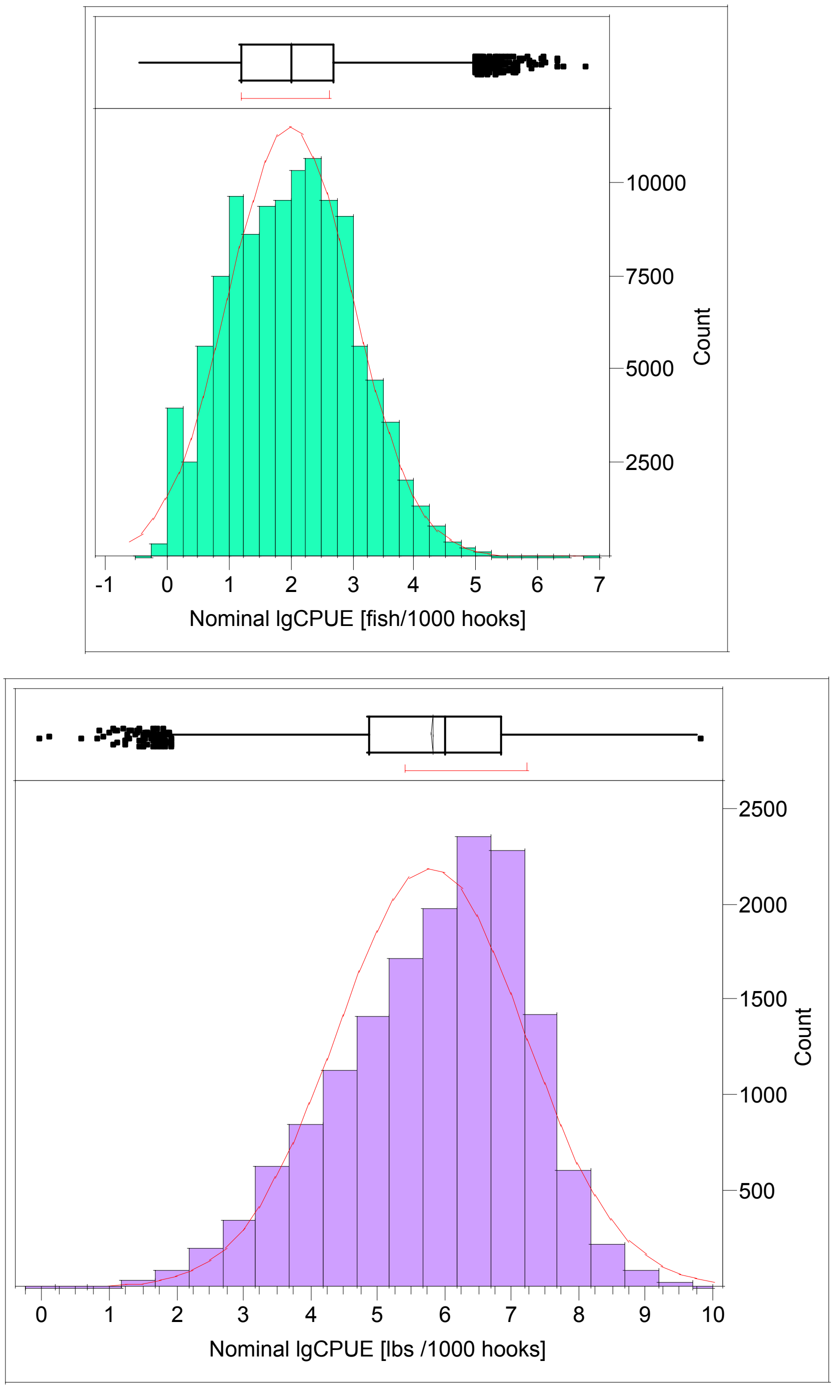


Figure 8. Frequency distribution of nominal catch rates for yellowfin tuna from the US Pelagic longline fishery. Top panel: positive sets from the Pelagic Logbook data (fish per 1,000 hooks). Bottom panel: positive trips from the Weight-Out data (carcass weight per 1,000 hooks).

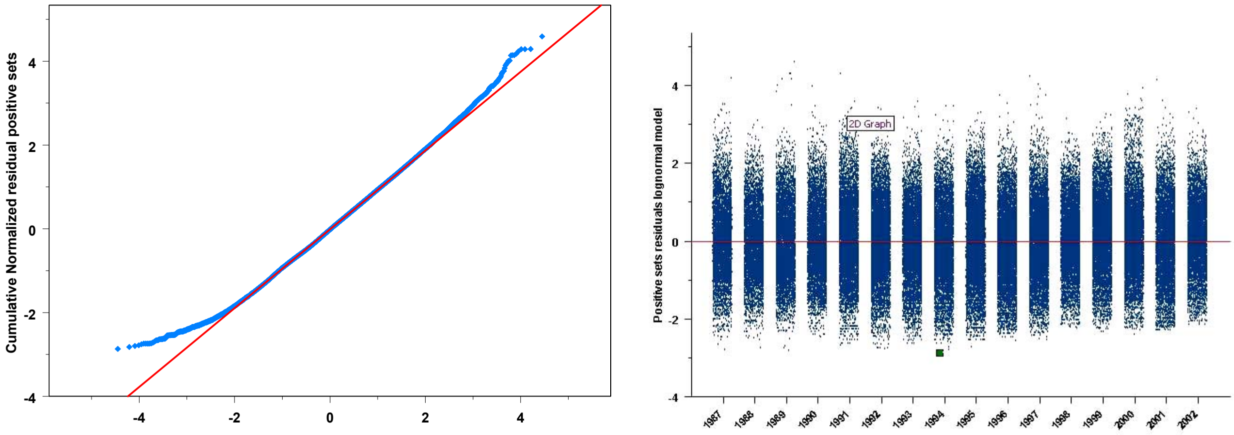


Figure 9. Diagnostic plots for the delta lognormal model fit to the Pelagic Logbook data. Left panel: cumulative normalized residuals (qq-plot) from the lognormal assumed error distribution, right panel: residuals by year for the positive sets of yellowfin tuna.

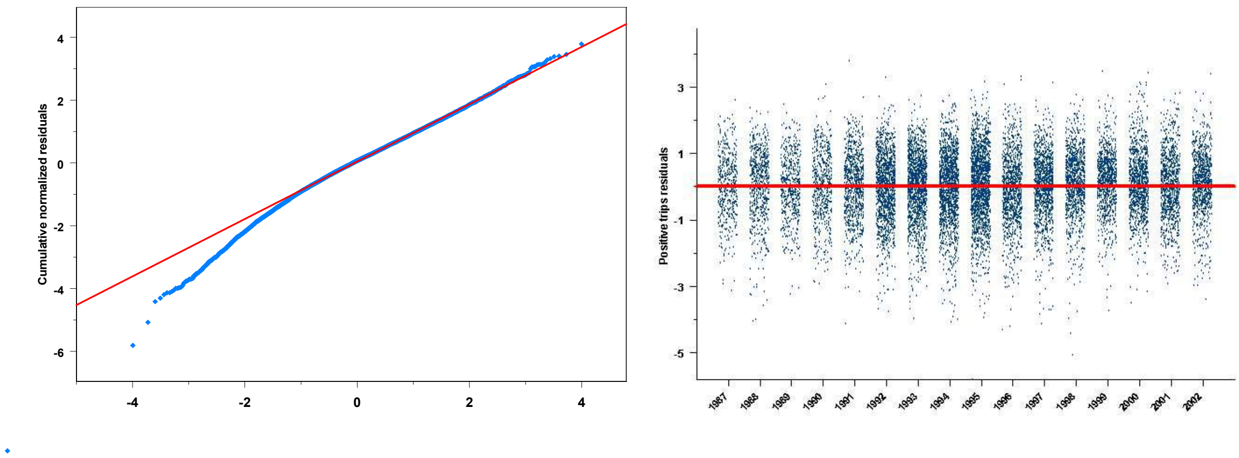


Figure 10. Diagnostic plots for the delta lognormal model fit to the Weight-Out data. Left panel: cumulative normalized residuals (qq-plot) from the lognormal assumed error distribution, right panel: residuals by year for the positive trips of yellowfin tuna.

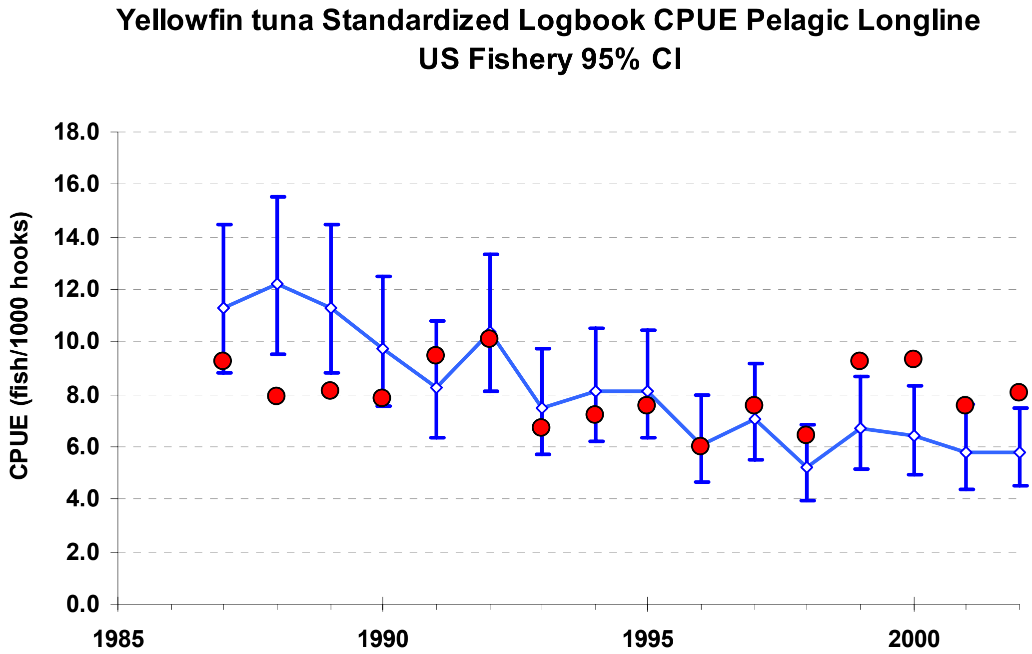


Figure 11. Nominal (solid circles) and standard (open circles) catch rates for yellowfin tuna from the Pelagic Logbook data.

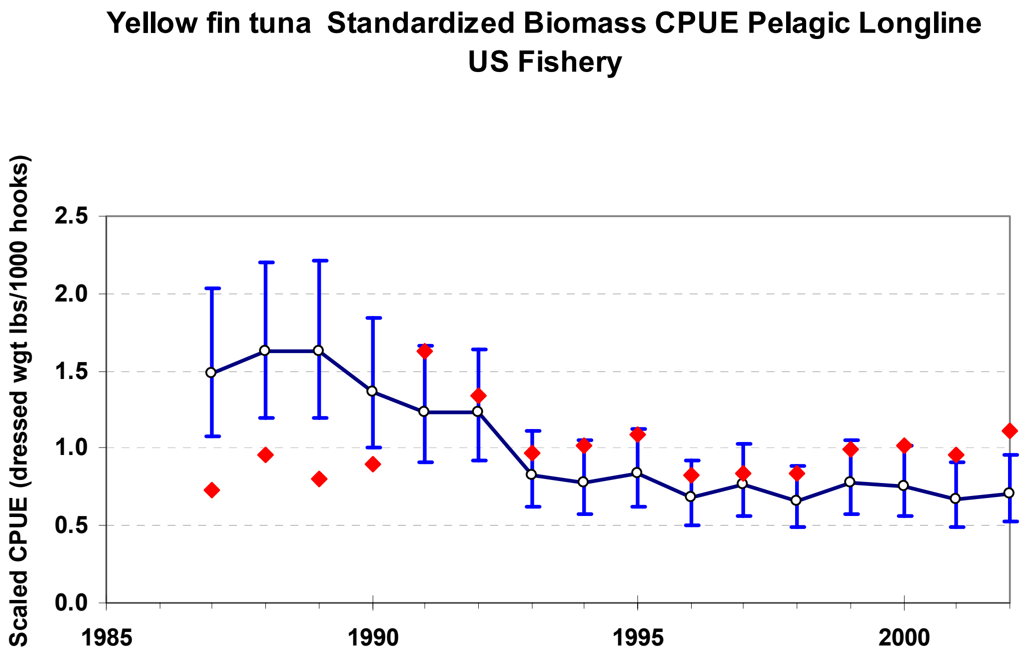


Figure 12. Nominal (solid symbols) and standard (open symbols) catch rates for yellowfin tuna from the Weight-Out data.

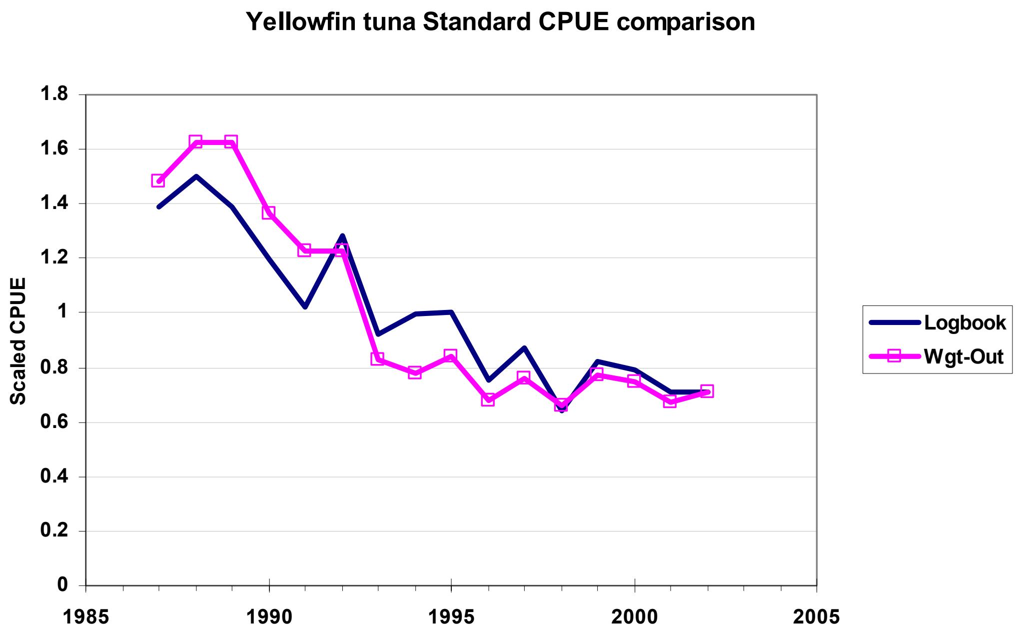


Figure 13. Standard CPUE indices for yellowfin tuna from the Pelagic Logbook data (solid line) and the Weight-Out data (open squares).

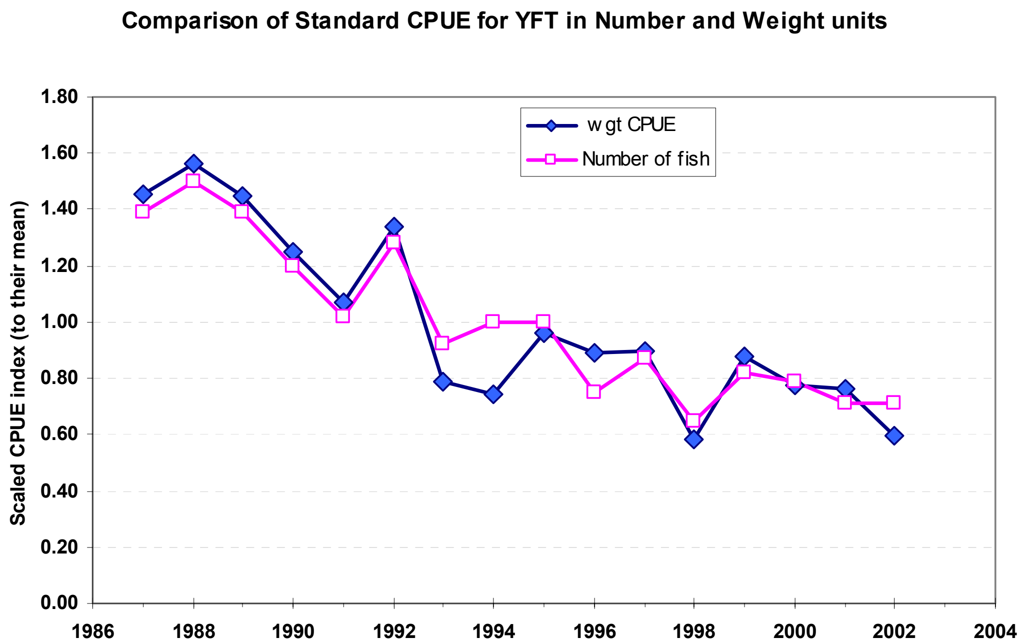


Figure 14. Comparison of the standard CPUE indices from the Pelagic Logbook data using number of fish and weight of fish caught.