STANDARDIZED CATCH RATES OF LARGE BLUEFIN TUNA (*THUNNUS THYNNUS*) FROM THE U.S. PELAGIC LONGLINE FISHERY IN THE GULF OF MEXICO DURING 1987-2010

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SUMMARY

An index of abundance of bluefin tuna was constructed from logbook reports from the U.S. pelagic longline fishery in the U.S. Gulf of Mexico for the period 1987-2010. The index was constructed using a "repeated measures" procedure to account for the variance in catch rates between vessels, and standardized using Generalized Linear Mixed Models and a delta-lognormal approach. This index was intended to be a strict update of the U.S. Pelagic Longline Index used in the previous assessment of Western Atlantic bluefin tuna. Although pelagic logbook data was available through 2011, changes in the fishery in 2011 resulted in very low fishing effort in the Gulf of Mexico during January-May. Therefore, the bluefin tuna stock assessment working group requested that the U.S. Pelagic Longline Index be reconstructed without the 2011 data. The index presented in this document is consistent with that recommendation.

RÉSUMÉ

Un indice d'abondance du thon rouge a été élaboré à partir des registres des carnets de pêche de la pêcherie palangrière pélagique des États-Unis opérant dans le Golfe du Mexique au titre de la période 1987-2010. L'indice a été élaboré à l'aide d'une procédure de « mesures répétées » pour tenir compte de la variance dans les taux de capture entre les navires, et standardisé au moyen de modèles mixtes linéaires généralisés et d'une approche delta-lognormale. Cet indice était censé être une mise à jour stricte de l'indice palangrier pélagique des États-Unis utilisé dans l'évaluation antérieure sur le thon rouge de l'Atlantique Ouest. Même si les données des carnets de pêche pélagique étaient disponibles jusqu'en 2011 compris, en raison des changements survenus dans la pêcherie en 2011, un très faible effort de pêche a eu lieu dans le golfe du Mexique entre janvier et mai. C'est pourquoi le groupe de travail chargé de l'évaluation du stock de thon rouge a demandé que l'indice palangrier pélagique des États-Unis soit reconstruit sans les données de 2011. L'indice présenté dans ce document est conforme à cette recommandation.

RESUMEN

Se calculó un índice de abundancia de atún rojo a partir de los informes de los cuadernos de pesca de la pesquerías palangrera pelágica estadounidense en el golfo de México estadounidense para el periodo 1987-2010. El índice se obtuvo utilizando un procedimiento de mediciones repetidas para tener en cuenta la variación en las tasas de capturas entre los buques, y se estandarizó mediante modelos lineales mixtos generalizados y un enfoque delta-lognormal. Se pretendía que este índice fuese una actualización estricta del índice de palangre pelágico estadounidense utilizado en la evaluación de stock de atún rojo del Atlántico occidental anterior. Aunque se dispuso de datos de los cuadernos de pesca pelágicos hasta 2011 inclusive, los cambios en la pesquería en 2011 tuvieron como resultado un esfuerzo de pesca muy bajo en el golfo de México durante los meses de enero a mayo. Por tanto, el Grupo de trabajo de evaluación de stock de atún rojo solicitó que se volviera a obtener el índice de palangre pelágico estadounidense sin incluir los datos de 2011. El índice presentado en este documento se elaboró siguiendo esta recomendación.

KEY WORDS

Catch/effort, abundance, commercial longline, multivariate analyses

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1. Introduction

Large bluefin tuna are caught by longline vessels fishing within the Gulf of Mexico. Although bluefin are considered incidental bycatch to this fishery, which primarily targets swordfish, bigeye and yellowfin tunas, previous studies have used logbook data from this fishery to construct catch rate indices for the western stock of Atlantic bluefin (Cramer and Ortiz 2000; Cramer 2002; Cass-Calay 2007; Diaz and Cass-Calay 2009, Cass-Calay 2011). These indices were utilized during previous assessments of Atlantic bluefin tuna. This report updates the catch and effort information through 2010 and describes the construction of a delta-lognormal catch rate index.

Note: A preliminary index was developed that included the 2011 data. During the 2012 bluefin tuna assessment, the working group discussed the validity of the estimated CPUE value for 2011. It was noted that in 2011 the U.S. longline fleet operated very differently from previous years in that only 18 of the sets that met the filtering criteria caught bluefin tuna, and these were limited to vessels targeting swordfish in the southeastern part of the Gulf of Mexico (which historically have low CPUE or BFT). Given these factors, the Group agreed that the CPUE values estimated for 2011 were not consistent with the rest of the time series and did not reflect the relative abundance of bluefin tuna in the Gulf of Mexico. Accordingly, a revised index was created without the 2011 data. The index development, diagnostics and resulting statistics are summarized in this document.

2. Materials and Methods

The main features of the U.S. pelagic longline fleet are described by Hoey and Bertolino (1988). The operational area of the U.S. pelagic longline fleet is large, extending from the Grand Banks in the NW Atlantic to the South American coast, including the Gulf of Mexico and the Caribbean Sea (**Figure 1**). Logbook records have been collected since 1986. Each logbook record contains trip information by fishing day or set, including: vessel ID, date and time, fishing location, catch in numbers and fishing effort (hooks per set). The majority of records describe a unique longline set, other types of records (fishing day) were excluded from the analysis. Because very few sets were reported in 1986, records from 1986 were excluded.

This index is intended to reference the spawning stock biomass of western bluefin tuna. Therefore, to minimize the inclusion of effort targeting species unlikely to co-occur with bluefin tuna and/or effort targeting bluefin tuna that are unlikely to spawn, the analysis dataset was restricted to sets occurring in the Gulf of Mexico (GOM) from January 1 to May 31 of each year. During this time period, vessels were substantially more likely to report bluefin tuna. Vessels were included in the analysis if they that caught, released or discarded at least one bluefin tuna during two or more years of the time series (N = 180).

As of January 1, 2001, the Desoto region of the GOM was permanently closed to the pelagic longline fishery (**Figure 1**). All sets fished that occurred within this area during the closure were excluded from the analysis. Other exclusions were made to remove bottom longline sets as these do not target bluefin, records with missing date, area or effort information, longline sets with fewer than 100 hooks per line, and various sets which were identified as unsuitable for the analysis because they did not reflect the effort of a single set (e.g. trip summary information, tended lines)."Following exclusions the dataset contained 36,610 records from 1987 through 2011. Of these, 3,887 (10.6%) reported catching bluefin tuna (landed, discarded or released).

A delta-lognormal approach (Lo et al. 1992) was used to develop the standardized catch rate index. This method combines separate generalized linear modeling (GLM) analyses of the proportion positive sets (sets that caught bluefin tuna) and the catch rates of successful sets to construct a single standardized index of abundance. Parameterization of each model was accomplished using a GLM procedure (GENMOD; Version 8.02 of the SAS System for Windows © 2000. SAS Institute Inc. Cary, NC, USA). For the lognormal models, the response variable, log(CPUE), was calculated:

$$\log(\text{CPUE}) = \log(\text{Number of Bluefin Tuna} / 1000\ \text{Hooks})]$$

A forward stepwise regression procedure was used to determine the set of fixed factors and interaction terms that explained a significant portion of the observed variability. The factors examined are summarized in **Table 1** (VESSEL_ID was not examined as a fixed factor). For both the binomial and lognormal portions of the delta-lognormal model, deviance tables were constructed to determine the proportion of total variance explained by the addition of each factor or interaction term. In addition, a χ_2 analysis was performed to test the significance of the reduction in deviance between each consecutive set of nested models (McCullagh and Nelder 1989). Factors and interaction terms were selected for final analysis if: 1) the relative percent of deviance explained by adding the factor exceeded one percent , 2) the χ_2 test was significant and 3) the Type-III test was significant for the specified model.

Once a set of fixed factors was identified, the influence of the YEAR*FACTOR interactions were examined. As per the recommendation of the statistics and methods working group of the SCRS (1999), YEAR*FACTOR interaction terms were included in the model as random effects. Selection of the final mixed model was based on the Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion (BIC), and a chi-square test of the difference between the –2 loglikelihood statistics between successive model formulations (Littell et al. 1996). The final delta-lognormal model was fit using the SAS macro GLIMMIX and the SAS procedure PROC MIXED (SAS Institute Inc. 1997) following the procedures described by Lo et al. (1992).

Most vessels did not consistently report catching bluefin tuna during the time series. Instead, vessels tended to catch bluefin during a shorter interval of consecutive years, or sporadically (**Figure 2**). Due to the large number of vessels (N = 180) and the unbalanced nature of the Year*Vessel interaction (**Figure 2**). The variance in catch rates, by vessel, was modeled using "repeated measures" within the SAS PROC MIXED procedure (Littell et al., 1998). The term "repeated measures" refers to multiple measurements taken over time on the same experimental unit (i.e. vessel). Specifying the repeated measure "VESSEL" and the subject "VESSEL(YEAR)" allows PROC MIXED to model the covariance structure of the data. This is particularly important because catch rates of sets fished close in time can be more highly correlated that those fished far apart in time (Littell et al., 1998).

3. Results and Discussion

The 180 selected vessels were responsible for at least 80% of the annual total catch in the Gulf of Mexico and comprised at least 65% of the total vessels that reported catching bluefin each year.

Deviance tables were constructed to identify factors and interaction terms that explained a significant portion of the observed variability, and met all inclusion criteria. The deviance table constructed for the binomial model (**Table 2**) indicates that the significant fixed factors include: YEAR, ZONE, MONTH and the interaction term ZONE*MONTH. The deviance table constructed for the lognormal model (**Table 3**) indicates that the significant fixed factors include: YEAR, ZONE and MONTH.

Once a set of fixed factors was selected, first level random interactions between year and other effects were examined. The results of this procedure are shown in **Table 4**. The final model was selected based on the log-likelihood, Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion (BIC) and the Likelihood Ratio Test of the difference between successive model formulations. All criteria used showed agreement for the best model selection:

PROPORTION POSITIVE SETS = YEAR + ZONE + MONTH + ZONE*MONTH + YEAR*MONTH + YEAR*ZONE

LOG(CPUE) = YEAR + MONTH + ZONE
+ the effect of the repeated measure VESSEL_ID with the covariance structure VESSEL_ID(YEAR)

The annual proportion of positive sets (PPS: sets that caught bluefin) was low, ranging from 4% to 23% (**Figure 3; Table 5**). PPS generally declined from 19% in 1987 to 4% in 1997. Thereafter, PPS generally increased to 8-16% from 2004 to 2010. Nominal CPUE follows a similar pattern (**Figure 4; Table 5**). The highest levels were observed during 1987-1991, and then a substantial decline occurred during 1991-1996. From 1997-2004, nominal CPUE increased, then varied at intermediate values throughout the remainder of the time series.

Diagnostic plots were constructed to examine the fit of the components of the delta-lognormal model. The frequency distribution of nominal catch rates is shown in **Figure 5**. There is evidence that the assumption of a normal fit the distribution of log(CPUE) is violated to a moderate degree. The distribution of residuals from the binomial model on proportion positive sets, by year, and the cumulative normalized residuals from the lognormal model on the catch rates of positive sets are shown in **Figure 6**. Again, some lack of fit is noted. The residuals of the binomial, by year, are more often less than zero, indicating the strong influence of a few large positive residuals (**Figure 6** left) and the QQ-Plot indicates a departure from the assumption of a normal distribution (**Figure 6** right, red line). **Figure 7** illustrates the residuals of the lognormal model on catch rates, by vessel. In general, the residuals are evenly distributed above and below zero, indicating that the model is able to effectively account for variability in catch rates between vessels.

The delta-lognormal catch rate index, with 95% confidence intervals, is shown in **Figure 8** and summarized in **Table 5**. To facilitate comparison, the nominal CPUE and the standardized index were made relative by dividing each annual estimate by the series mean (**Figure 8**). The standardized abundance index is roughly similar to the nominal CPUE series. The index suggests that catch rates were highest in 1991 (3.26), and that CPUE generally declined until 1996 (0.183). Catch rates remained below the series mean (1.0) until 2008 (1.28) when a modest recovery is noted.

During this time series, several regulatory measures occurred which may have confounded the analysis, by changing catchability, selectivity and/or fishing behavior (**Figure 9**):

- 1992: Pelagic longline vessels must land, offload, and sell at least 2500 lbs (1134 kg) of other species as a condition for landing a maximum of ONE BFT.
- 1994: Pelagic longline vessels to land, offload, and sell at least 1500 lbs (680 kg) of other species as a condition for landing a maximum of ONE BFT.
- Jan 1, 2001: Permanent closure of "Desoto" area in Gulf of Mexico (Figure 1).
- May 30, 2002. Three retention tiers implemented: Could retain one BFT with > 2,000 lbs (907 kg) of catch of other species; two BFT with > 6,000 lbs (2722 kg); three BFT with > 30,000 lbs (13608 kg).
- August 4, 2004: Implementation of mandatory circle hooks in Pelagic Longline Fishery.
- May 5, 2011: Implementation of mandatory weak hooks in Pelagic Longline Fishery.

Furthermore, an important oil spill (Deep Water Horizon) began in the Gulf of Mexico on April 20, 2010 and continued until July 2010. To protect food safety, fisheries closures in Gulf of Mexico began on May 2, 2010 and continued for several months. At the peak of the closure, 37%, of all federal waters in the Gulf of Mexico were off-limits to fishing. To date, the effects of these factors have not been adequately accounted for. A thorough examination of these factors is recommended prior to the next assessment of Atlantic bluefin tuna.

4. Acknowledgments

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5. References

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Table 1. Description of the analysis factors.

Factor	***Levels***	***Values***
Year	25	1987-2011
Month	5	Jan, Feb, Mar, Apr, May
Zone	3	Zone 1 = Lat 18°N-25N° and Lon 88°W to 97°W
		Zone 2 = Lat 26°N-29N° and Lon 88°W to 98°W
		Zone 3 = Lat 22°N-30N° and Lon 79°W to 87°W
Vessel ID	180	Not used as a fixed factor

Table 2. The deviance table for the binomial model on the proportion of positive sets. Factors were assumed to be significant if they explained >1% of the total deviance, and were significant according to a Chi-Square test.

GENMOD (FIXED-FACTOR) OUTPUT

Binomial Model Factors - Proportion Positive	DF	DF	Residual Deviance	Reduction in Deviance	% of Total Deviance	Log Like	Chi Square	P
Null	1	36609	24780.5	0.0	0.0	-12390.3		
Year	24	36585	24117.0	663.5	24.2	-12058.5	663.5	<0.001
Year+ Month	4	36581	23514.2	602.9	22.0	-11757.1	602.9	<0.001
Year + Month + Zone	2	36579	23057.8	456.4	16.7	-11528.9	456.4	<0.001
Year + Month + Zone + Zone*Month	8	36571	22960.3	97.6	3.6	-11480.1	97.6	<0.001
Year + Month + Zone + Zone*Month + Year*Month	96	36475	22207.9	752.3	27.5	-11104.0	752.3	<0.001
Year + Month + Zone + Zone*Month + Year*Month + Year*Zone	47	36428	22040.7	167.2	6.1	-11020.4		***

*** Hessian not Positive Definite

Table 3. The deviance table for the lognormal model on catch rates of positive sets. Factors were assumed to be significant if they explained >1% of the total deviance, and were significant according to a Chi-Square test.

Lognormal Model Factors - CPUE

Lognormal Model Factors - CPUE	DF	DF	Residual Deviance	Reduction in Deviance	% of Total Deviance	Log Like	Chi Square	P
Null	1	3886	1570.8	0.0	0.0	-3754.5		
Year	24	3862	1162.7	408.2	77.9	-3169.7	1169.58	<0.001
Year+ Month	4	3858	1140.7	22.0	4.2	-3132.7	74.16	<0.001
Year + Month + Zone	2	3856	1124.5	16.1	3.1	-3105.0	55.37	<0.001
Year + Month + Zone + Zone*Month	8	3848	1120.6	3.9	0.7	-3098.2	13.49	0.0959
Year + Month + Zone + Zone*Month + Year*Month	96	3752	1071.6	49.0	9.4	-3011.3	173.9	<0.001
Year + Month + Zone + Zone*Month + Year*Month + Year*Zone	43	3709	1046.7	24.9	4.8	-2965.6	91.42	<0.001

Table 4. Analysis of the mixed model formulations. The likelihood ratio was used to test the difference of –2 REM logliklehood between two nested models. The final model is indicated with gray shading.

ANALYSIS OF MIXED MODEL FORMULATIONS

Proportion Positive	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	P	Scaled Deviance	Dispersion
Year + Month + Zone + Zone*Month	1096.9	1098.9	1102.7	-	-	323.82	3.68
Year + Month + Zone + Zone*Month + Year*Month	1033.5	1037.5	1043.1	63.4	<0.0001	260.66	1.90
Year + Month + Zone + Zone*Month + Year*Month + Year*Zone	***1022.7***	***1028.7***	***1037.2***	***10.8***	***0.0010***	***241.53***	***1.43***

Catch Rates on Positive Trips	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	P
Year + Month + Zone	6327.7	6329.7	6336.0		
Year + Month + Zone + VesselID(Year)	***5538.8***	***5542.8***	***5552.4***	***788.9***	***<0.0001***
Year + Month + Zone + VesselID(Year) + Year*Month			Did Not Converge		
Year + Month + Zone + VesselID(Year) + Year*Zone	5535.7	5541.7	5548.4	3.1	0.0783

Table 5. Nominal CPUE, proportion positive sets (PPS), number of sets, and abundance index statistics.

YEAR	Nominal CPUE	PPS	Sets	Standardized CPUE	Lower 95% CI	Upper 95% CI	CV
1987	0.654	0.188	1558	3.255	1.703	6.224	0.333
1988	0.368	0.113	1893	1.533	0.762	3.086	0.361
1989	0.518	0.117	1857	2.440	1.247	4.774	0.345
1990	0.435	0.124	1519	1.889	0.936	3.812	0.362
1991	0.917	0.234	1319	3.256	1.693	6.264	0.336
1992	0.328	0.117	1756	0.797	0.379	1.678	0.386
1993	0.140	0.077	1173	0.452	0.205	0.996	0.412
1994	0.133	0.077	1082	0.335	0.145	0.775	0.439
1995	0.080	0.052	1218	0.310	0.132	0.730	0.448
1996	0.062	0.046	1476	0.183	0.077	0.434	0.452
1997	0.065	0.037	1414	0.332	0.148	0.741	0.419
1998	0.087	0.052	1288	0.357	0.158	0.806	0.425
1999	0.154	0.088	1825	0.612	0.300	1.252	0.369
2000	0.308	0.097	1727	0.884	0.433	1.807	0.369
2001	0.185	0.087	1433	0.503	0.223	1.137	0.425
2002	0.199	0.091	1569	0.471	0.205	1.083	0.434
2003	0.207	0.113	1881	0.862	0.427	1.741	0.362
2004	0.238	0.141	2149	0.783	0.386	1.585	0.364
2005	0.152	0.092	2127	0.590	0.282	1.235	0.382
2006	0.115	0.076	1070	0.414	0.177	0.966	0.444
2007	0.206	0.113	1447	0.559	0.249	1.257	0.422
2008	0.389	0.161	1097	1.283	0.619	2.659	0.377
2009	0.254	0.128	1227	1.018	0.470	2.208	0.402
2010	0.207	0.112	1202	0.881	0.417	1.858	0.387

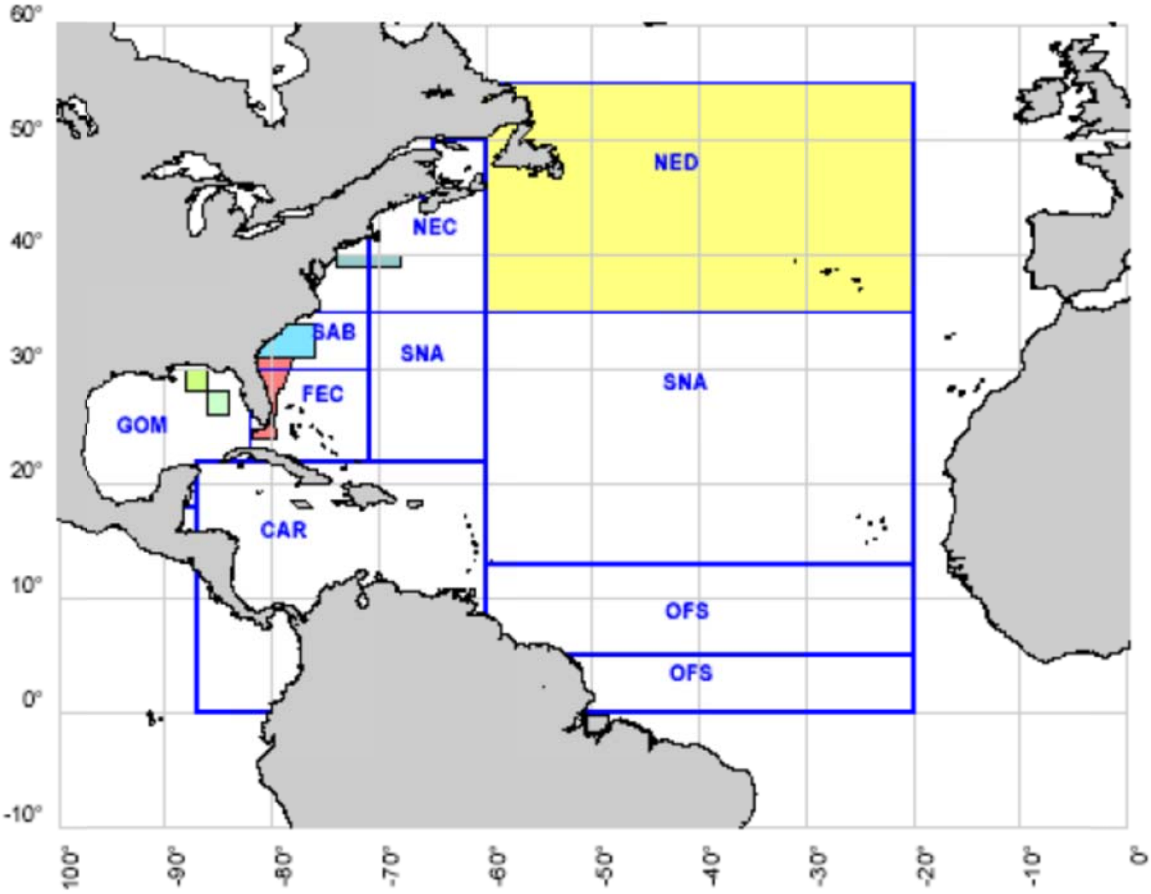

Figure 1. Geographic area classifications for the US Pelagic longline fishery: CAR Caribbean, GOM Gulf of Mexico, FEC Florida east coast, SAB south Atlantic bight, MAB mid Atlantic bight, NEC north east coastal, NED north east distant waters, SNA Sargasso area, and OFS offshore waters. Shaded areas represent the current time-area closures affecting the pelagic longline fisheries. Note: the two boxes within the Gulf of Mexico are the the Desoto area which was permanently closed to the pelagic longline fishery in 2001

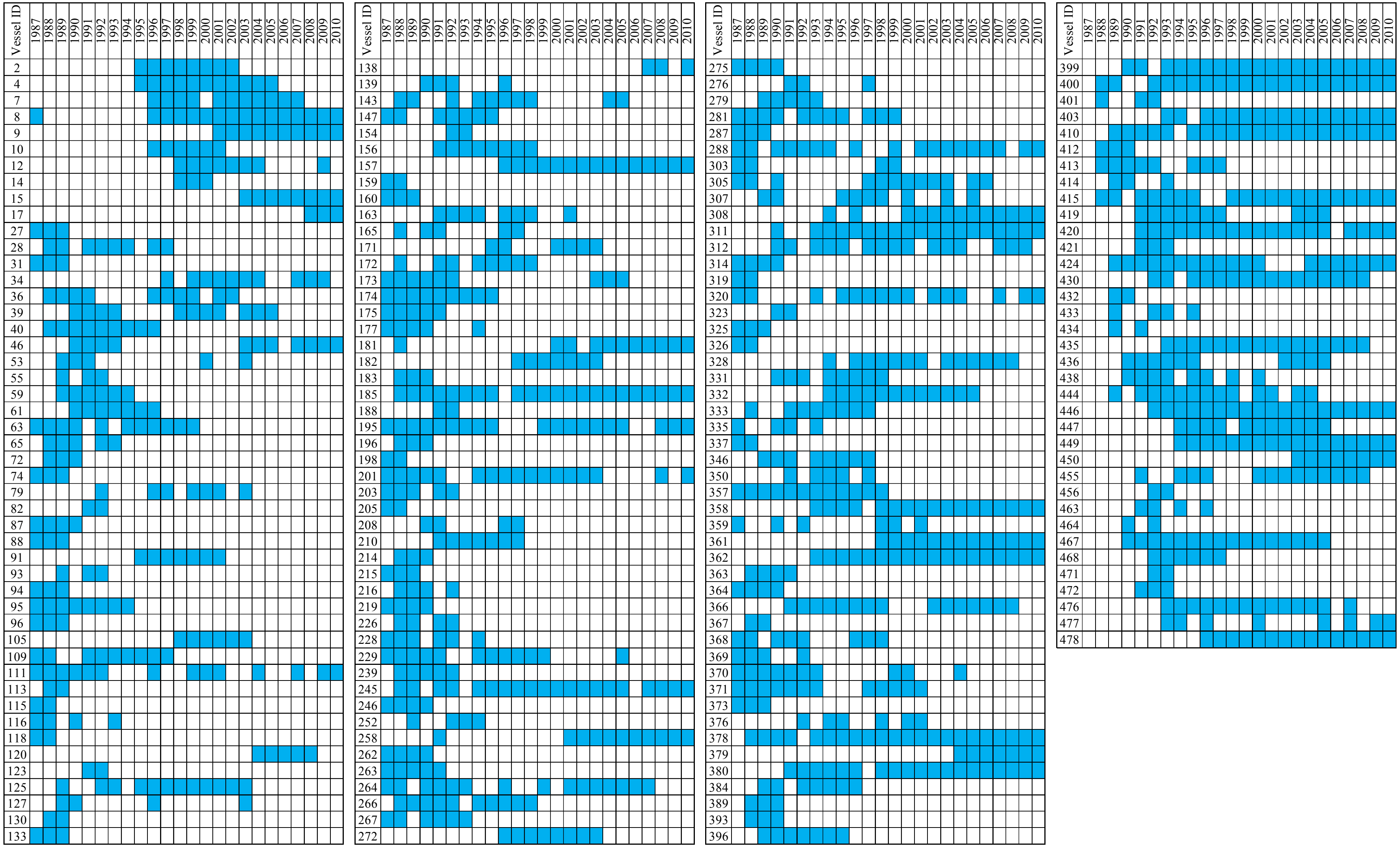

Figure 2. Years that a vessel reported catching (landed, released or discarded) at least one bluefin tuna. (Vessels are coded with a numeric identifier).

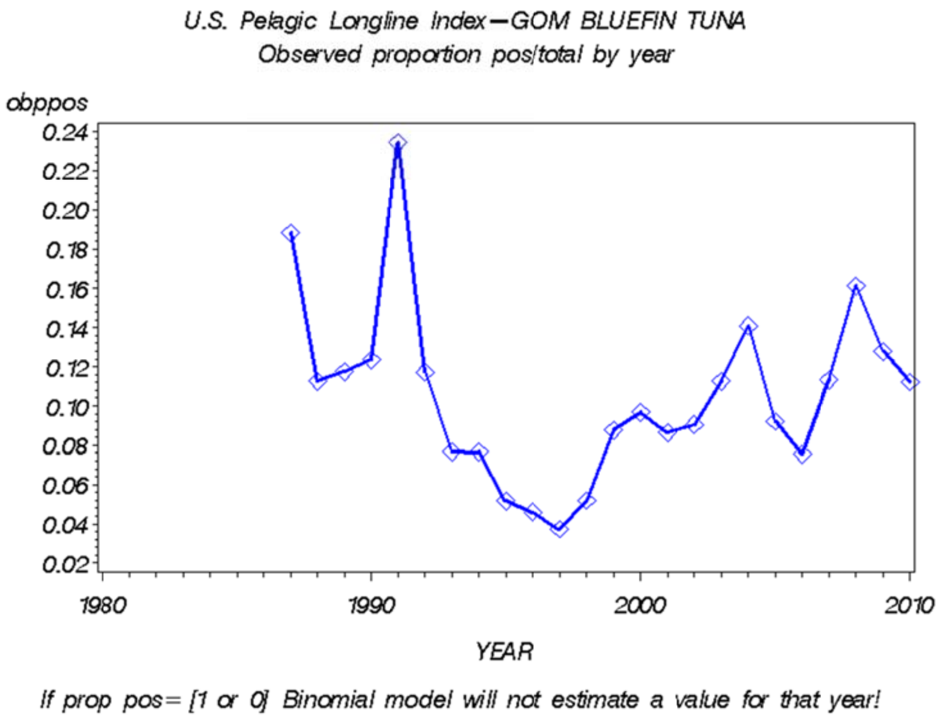

Figure 3. The annual trend in the proportion of positive sets.

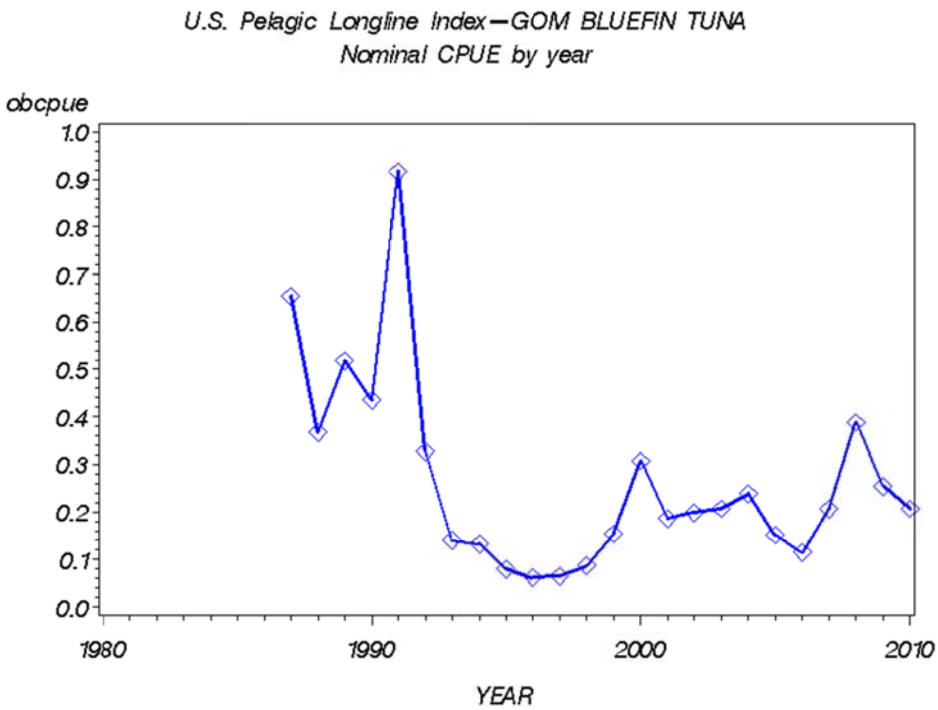

Figure 4. The annual trend in nominal CPUE.

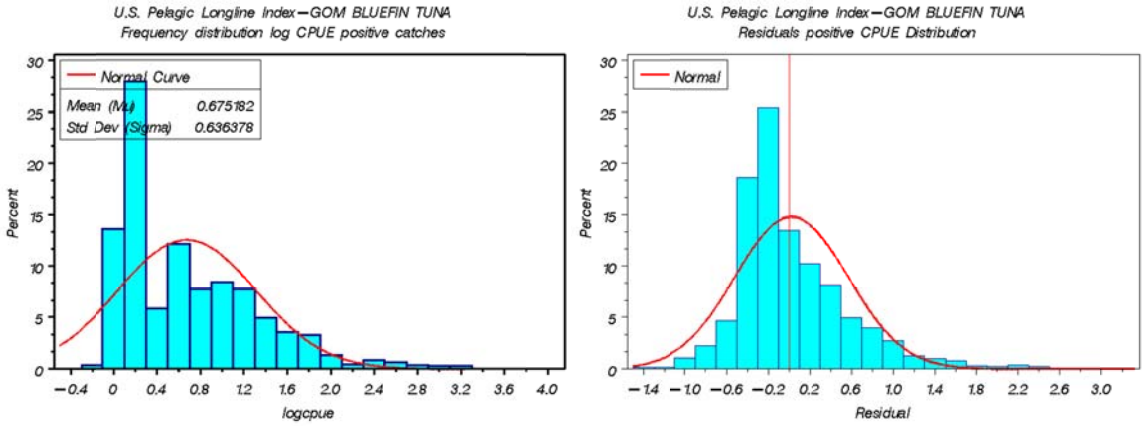

Figure 5. Frequency distribution of nominal catch rates (fish per 1000 hooks) on positive trips.

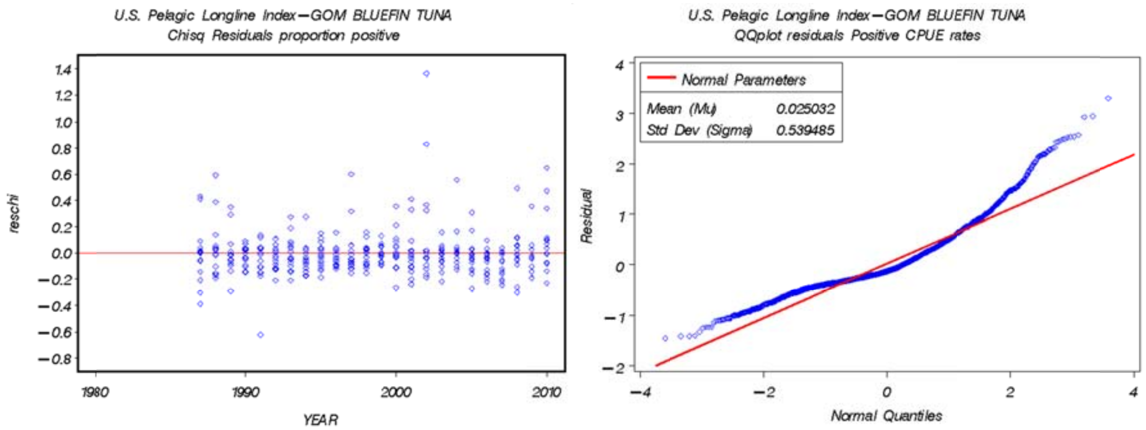

Figure 6. Diagnostic plots for the delta-lognormal model. **Left**) the distribution of residuals from the binomial model on the proportion of positive set, by year. **Right**) the cumulative normalized residuals from the lognormal model on the catch rates of positive sets.

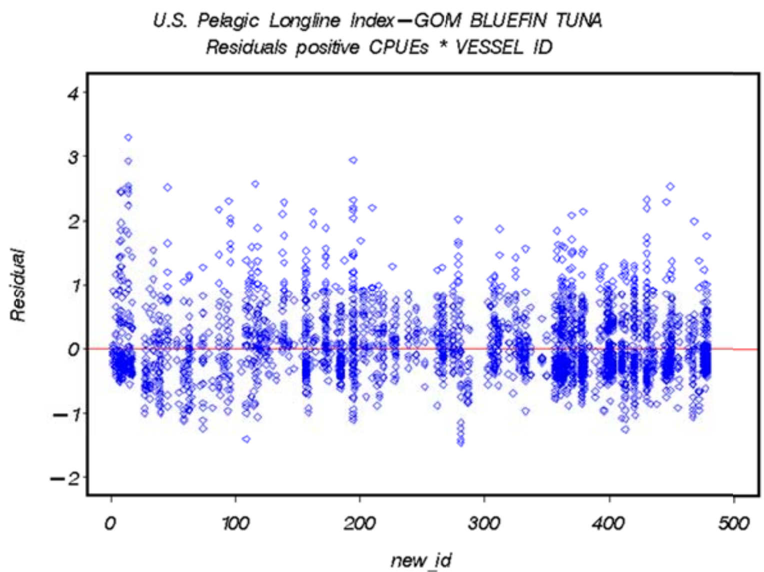

Figure 7. Residuals of the lognormal model on catch rates of bluefin tuna during positive sets, by vessel. Vessels are coded with a numeric identifier.

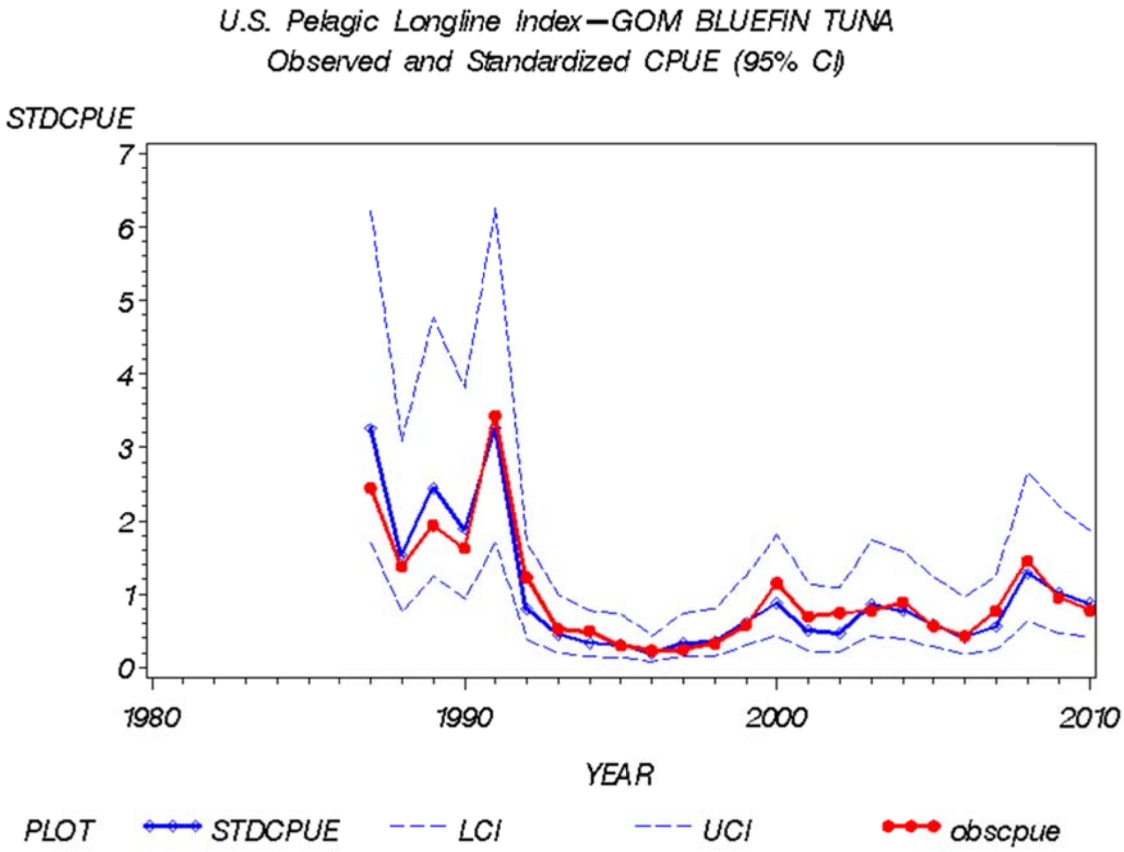

Figure 8. Standardized index (blue with diamonds) with lower and upper 95% confidence intervals (blue dashed) and nominal CPUE (red with filled circles).

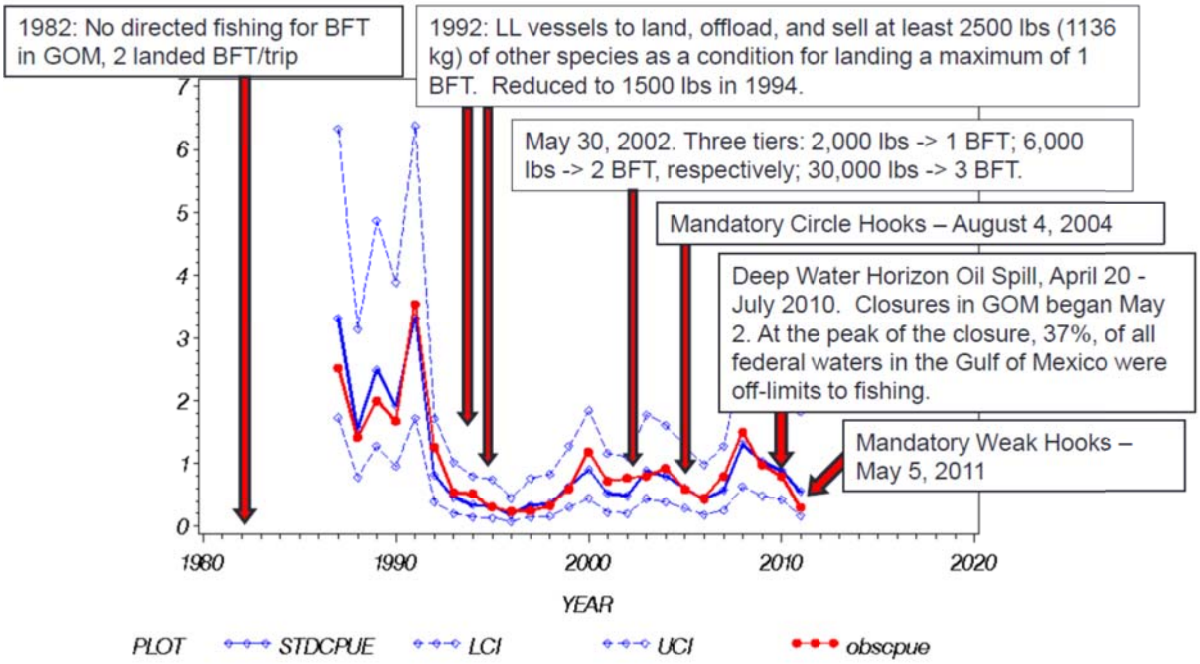

Figure 9. Standardized index and management measures that may influence catch rates.