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UPDATE OF STANDARDIZED CATCH RATES OF LARGE BLUEFIN TUNA (*THUNNUS THYNNUS*) FROM THE U.S. PELAGIC LONGLINE FISHERY IN THE GULF OF MEXICO 1987-2016

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SUMMARY

An updated 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 1987-2016. The index is an update of the index presented at the 2015 Species Group meeting. The index was constructed using vessel as a repeated measure to account for the variance in catch rates within vessels, and was standardized using two stage Generalized Linear Mixed Models with separate binomial and a lognormal models. Due to management actions that were not possible to model, the index was split into two time periods between 1991 and 1992. In 2011 vessels were required to use a weak hook that would bend due to pressure from a large fish as a means of reducing bycatch of bluefin tuna. Extensive experiments have determined that these hooks result in a 46% (23-62%CI) reduction in the catch rates of bluefin tuna. Indices for 2011- 2016 were adjusted upward to account for this expected reduction in CPUE. Adjusted index values for 2014-2016 have been relatively flat since 2011 with the exception of a spike in 2012. In 2015several management measures may have affected the fishery requiring special treatment of 2015 and 2016 information. It is recommended that the closed areas implemented in 2015 should be modeled as a separate spatial area.It is also recommended that the index be split in 2015 until more years of data can be collected to evaluate the impacts of the regulatory changes.

RÉSUMÉ

Un indice d'abondance actualisé du thon rouge a été créé à partir des registres des carnets de pêche de la pêcherie palangrière pélagique des États-Unis opérant dans le golfe du Mexique des Etats-Unis au cours de la période 1987-2016. Il s'agit d'une actualisation de l'indice présenté à la réunion de 2015 du groupe d'espèces. L'indice a été élaboré en utilisant le navire comme une mesure répétée pour tenir compte de la variance dans les taux de capture entre les navires, et il a été standardisé au moyen de modèles linéaires mixtes généralisés en deux étapes avec des modèles séparés binomiaux et lognormaux. En raison de mesures de gestion qu'il n'a pas été possible de modéliser, l'indice a été séparé en deux périodes temporelles entre 1991 et 1992. En 2011, les navires ont dû utiliser un hameçon faible qui se plierait avec la pression exercée par un gros poisson comme moyen de réduire les prises accessoires de thon rouge. Des expériences à grande échelle ont démontré que ces hameçons entraînent une réduction de 46% (CI de 23-62%) des taux de capture du thon rouge. Les indices de 2011-2016 ont été ajustés à la hausse pour tenir compte de cette réduction escomptée de la CPUE. Les valeurs des indices ajustés pour 2014-2016 sont relativement planes depuis 2011, exception faite d'un point culminant en 2012. En 2015, plusieurs mesures de gestion pourraient avoir affecté la pêcherie en exigeant un traitement spécial des informations de 2015 et de 2016. Il est recommandé que les fermetures de zones mises en œuvre en 2015 soient modélisées comme une zone spatiale distincte. Il est également recommandé que l'indice soit divisé en 2015 jusqu'à ce que davantage d'années de données puissent être collectées pour évaluer les impacts des changements réglementaires.

RESUMEN

Se calculó un índice de abundancia actualizado de atún rojo a partir de los informes de los cuadernos de pesca de la pesquería palangrera pelágica estadounidense en el golfo de México

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estadounidense para el periodo 1987-2016. El índice es una actualización del índice presentado en la reunión del Grupo de especies de 2015. El índice se obtuvo utilizando los buques como una medida repetida para tener en cuenta la variación en las tasas de capturas entre los buques, y se estandarizó mediante modelos lineales mixtos generalizados de dos etapas con modelos separados, binomial y lognormal. Debido a las acciones de ordenación que no fue posible modelar, el índice se separó en dos periodos temporales entre 1991 y 1992. En 2011, se requirió a los buques que utilizasen un anzuelo flojo diseñado para doblarse por la presión de un ejemplar grande, como medio para reducir la captura fortuita de atún rojo. Los amplios experimentos han determinado que estos anzuelos tienen como resultado una reducción del 46% (23-62% CI) en las tasas de captura de atún rojo. Los índices para 2011-2016 fueron ajustados al alza para tener en cuenta esta reducción prevista en la CPUE. Los valores del índice ajustado para 2014-2016 han sido relativamente planos desde 2011 con la excepción de un pico en 2012. En 2015, diversas medidas de ordenación podrían haber afectado a la pesquería, requiriendo un tratamiento especial de la información de 2015 y 2016. Se recomienda que las zonas de veda implementadas en 2015 sean modeladas como una zona espacial separada. Se recomienda también que el índice se separe en 2015 hasta que puedan recopilarse más años de datos para evaluar los impactos de los cambios reglamentarios.

KEYWORDS

Catch/effort, abundance, commercial longline, bluefin tuna

Introduction

This paper is an update of an index constructed from the US pelagic longline fishery in the Gulf of Mexico obtained from vessel logbooks. It is constructed with the same delta-lognormal model as Walter (2014) but with data updated through 2016. In 2014 it was recommended to split the index in 1991 to address issues related to changing fleet dynamics and regulations that could not be modeled within the standardization. This index is a strict update of the index presented in 2014, though management measures implemented in 2015, notably an individual transferable bycatch quota and a large time-area closure in the Gulf of Mexico in April and May likely affect the fishery and the catch rates in ways that are difficult to determine. This paper also presents some analysis of the potential impacts of the 2015 regulations and some proposals for future modeling that might account for these impacts.

1. Materials and methods

Data used in this paper comes from the pelagic longline logbook program which is a voluntary reporting of set by set catches and metadata from the pelagic longline fishery. Data exist from this program since 1986 but since very few sets were reported from then the index starts in 1986. One of the main data treatments was to include vessels in the analysis only if they caught, released or discarded at least one bluefin tuna during two or more years of the time series.

We employ the same modeling structure as in Cass-Calay & Walter (2013) and do not update model factors or data selection criteria. In brief, the model uses a repeated measures approach where the variance in catch rates, by vessel, was modeled using repeated measures within the SAS PROC MIXED procedure (Littell et al.,1998). The two models used are shown, below:

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)

Where italicized year*factor interaction were modeled as random effects. Parameterization of each model was accomplished using the GLIMMIX procedure for the proportion positive and Proc Mixed for the log(CPUE) (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 as:

log(CPUE) = log(Number of Bluefin Tuna kept and discarded / 1000 Hooks)

Following exclusions, the dataset contained 40,910 records from 1987 through 2016. Of these, 10.3% reported catching bluefin tuna (landed, discarded or released).

Correcting for the effects of circle hooks on commercial catch rates

In a previous version of this index (Walter, 2014) index values were adjusted for the expected reduction in catch rates due to the mandatory use of 'weak' hooks in the Gulf of Mexico beginning on May 5, 2011. The weak hook model and make is Mustad 39988. Prior to and after implementation of this rule, NOAA Fisheries conducted extensive experimental trials to determine the effectiveness of the weak hooks at reducing the incidental capture of Bluefin tuna. The results of these trials indicate a 46% (23-62% 95CI) reduction in the catch rates of bluefin tuna (Foster and Bergmann 2012). Hence it was necessary to adjust the commercial longline CPUE to account for this reduction in catch rate. Converting the estimated decrease in catch rate to a factor to be multiplied by each index gives a factor of 1.85= (1/(1-0.46)). For the year 2011 only 20% of the correction was applied which resulted in a factor of 1/(1-0.46*0.2) = 1.101.

To make this correction it was necessary to make the same assumptions as made in 2014:

1. Weak hook effect is knife-edged starting in May 5, 2011.
2. To account for the implementation in May 5, 2011, 20% of the correction was applied in 2011 as the index is calculated for months January-May.
3. The resulted in the index values being increased by a factor of 1.101 in 2011 and 1.85 years 2012-2016.

The variance of the estimate of the weak hook effect was the calculated from the product of two random variables (eq 5, Goodman 1960):

$$v(xy) = v(x) * x^2 + v(y) * y^2 - v(y) * v(x)$$

Where *x* is the index for a given year, *v(x)* is the estimated variance of the index, *y* is the weak hook effect value and *v(y)* is the estimated variance of the correction.

To estimate *v(y)*, the variance of the correction factor we used the delta method approximation given in Zhou (2002) for the function *y*=1/*k*. We let *k* =(1-*c*) and *c* is the estimated percentage reduction in catch rate which had an estimated variance of 0.01 (Foster and Bergmann 2012). The variable *k* has the same variance as c, 0.01, and an estimated value of 0.54. Then the delta approximation for the $\hat{v}(y)$ is given by (Zhou 2002):

$$\hat{v}(y) = v(k)/\bar{k}^4$$

Hence the variance of the correction factor to be applied for increase of 1.85 is 0.12. For the increase of 1.1 the variance is 0.00059.

Effects of the 2015 regulations

The 2015 regulations initiated substantial changes to the longline fishery (Amendment 7 https://federalregister.gov/a/2014-28064). These included: an individual Bluefin quota (IBQ), electronic video monitoring of longline haulback and operations, a large area closure in the Gulf of Mexico in April and May and increased level of trip reporting of bft interactions (Federal register). The IBQ program was initiated where individual vessels were allocated a certain quota of bluefin tuna based upon a combination historical catch rates and observer and logbook program compliance. Along with this all dead bluefin were now required to be retained and to be counted as part of the bycatch quota. Live bluefin could also be retained if vessels had available quota. Vessels also had to have enough IBQ to cover potential BFT interactions in order to begin a trip. IBQ can be traded or leased between vessels. As with other ITQ implemntations these measures may substantially alter how the fishery operates altering the inference on CPUE indices. It is currently unknown what effect these regulations are having upon fishing operations but the number of vessels fishing in the Gulf of Mexico during the Bluefin tuna season (January-May) and the number of trips has reduced to the lowest levels of the 30 year time series, with the exception of the post-Deepwater Horizon-induced reductions in 2011 (**Table 1**). To explore the effects of the 2015 regulations we evaluated time series of catch and effort within the closed area. The other evaluation was to explore whether there was any detectable change in the catch rates before and after the IBQ program for the ~35 vessels that continued to fish after the IBQ program.

Revised index with the BFT closure areas as a separate spatial area

As the most closures associated with Amendment 7 were limited in duration but did occur in the highest catch rate times and areas (**Figure 1, Table 2**) encompassing the majority of the BFT interactions it is undesirable to exclude all of the effort from April and May back in time, as has often been done for closed areas. Simply making this another area in the model- with missing data from years 2015 onwards may be the most plausible strategy for future modeling of this dataset. A preliminary index was constructed by making the two BFT closures as separate spatial area. This might preclude estimating year*zone and month*zone interactions and these were removed from the models, which were estimated as follows:

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

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

Note that the entire model refitting and diagnostic analyses were not conducted for this slight revision.

2. Results and Discussion

Effects of the 2015 regulations

It is difficult to detect an effect of the 2015 regulations other than a substantial reduction in the number of vessels and number of sets from January-May in 2015 and 2016 (**Table 1**). This may be due to the changes related to Amendment 7. The number of sets in the BFT closure areas has declined due to the prohibition on sets in April and May. The nominal catch rates for this area (zone 4, blue line in **Figure 2**) have also declined, largely and likely due to an absence of fishing in the high catch rate months of April and May (**Table 2**). Hence a modeling approach that splits out effort in this area rather than maintaining the previous three zone spatial structure would potentially address this regulation-induced absence of fishing during the high catch rate months in a high catch rate area. This would preserve the high catch rate nature of these areas, use data from Jan-March and then rely upon the month and area effects to account for missing data in April and May. As this closed area (**Figure 1, Table 2**) encompasses the majority of the BFT interactions and a substantial amount of the fishing effort it is undesirable to exclude all of the effort from April and May back in time. Simply making this another area in the model- with missing data from years 2015 onwards may be the most plausible strategy for future modeling of this dataset.

An additional analysis was conducted where vessels that fished through 2016 were split out from vessels that fished in 2009-2015 but did not fish in the Gulf of Mexico from January to May in 2016. This was to determine if the reduction in effort might have altered nominal catch rates due to the loss of many vesssels that did not fish in early 2016. CPUE of the 21 vessels that fished in 2016 (**Figure 3**, black line), was fairly similar to the 28 vessels that did not fish in early 2016 (red lines). The CPUE for the vessels that dropped out was slightly lower than for the vessels that stayed in for 2013 and 2014 but the same for 2015 and hence it is unlikely that the lack of effort from the 28 vessels altered the overall catch rates appreciably. The dropping out of these vessels did not appear to substantially alter the overall CPUE (green line) in a systematic manner. Hence the any changes in CPUE that may have occurred due to changes in the fleet composition do not appear clear in the data.

There was a noticeable shift of fishing effort outside of the closed areas which could be detected in finer-resolution maps, however this is less noticeable in the coarse resolution of **Figure 4**. Due to data confidentiality the finer-resolution data cannot be shown however it does indicate that the closures resulted in a shift of effort outside.

Updated index

Overall the updated index and index diagnostics are almost exactly the same as in previous iterations of this index and are not shown in this update for brevity. With the exception of the 2015 regulations many of the regulatory and other issues (e.g. fishery closures during and after the Deepwater Horizon oil spill) that have affected the index have been previously discussed in Walter (2014). The primary action taken in the most recent 2014 stock assessment was to split the index in 1991, resulting in two time series. We adopt a similar approach and present two separate indices. As the early time period was so short (5 years) it was not used in the 2014 VPA models.

Revised index with the BFT closure areas as a separate spatial area

Modeling the BFT closure areas (**Figure 1**) as an additional fourth spatial zone and removing the year*zone and month*zone interactions resulted in minor changes to the index (**Figure 6**) but almost imperceptible change in the years of the closure (partially 2015 and fully in 2016). It is likely that the impacts of this modeling change may not be detectable for several years, however using the closed areas as a separate spatial zone will likely avoid spurious year*area interactions in the future. An additional model run with the interactions estimated (same model as the original model) had a correlation of 0.98 with the index without interactions indicating that their includion had little practical impact.

Conclusions

Overall, the addition of data from 2016 has resulted in little apparent change in stock condition with the index with index values from 2015 and 2016 very similar to 2013 and 2014 (**Table 3, Figure 5**), even after modeling the closed areas as separate zones, but with missing data for April and May 2016 (**Figure 6**). Nominal, uncorrected CPUEs have decreased fairly substantially and would be among the lowest of the time series (**Figure 5, blue lines**) if not corrected for the reduction in CPUE due to the weak hooks.

There is some anecdotal information that the IBQ program altered fishing behavior such that vessels avoided interactions with BFT, though it is not clear how vessels may have done so. Furthermore it is not clear in the data that there was a detectable change in fishing strategies due to the IBQ program or other changes associated with the 2015 regulations. Consultations with fishery experts indicated that dealers in the Gulf of Mexico region did not want to buy BFT which could result in a reduction in landings but as the index is for both landed and released fish, it is not clear whether this has substantively altered overall catch rates. Nonetheless, as the regulations were specifically designed to disinsentivize dead discards of BFT, this may have caused fishers to alter their fishing strategies to avoid BFT altogether. Other potential impacts of the regulations on BFT catch rates are currently unknown and we cannot say whether the catch rates in 2015 and 2016 are reliable indicators of stock status. It may require additional years of data to fully understand or for the fishing patterns to adjust to the regulatory changes. Future assessment modeling constructions should likely consider a break in the index beginning in 2015 when the regulations began.

References

Cass-Calay, S.L. and Walter, J. 2013. Standardized catch rates of large bluefin tuna (*Thunnus Thynnus*) from the U.S. pelagic longline fishery in the Gulf of Mexico during 1987-2010. Collect. Vol. Sci. Pap. ICCAT, 69(2): 992-1004.

Foster, D. and C. Bergman. 2012 Update of Gulf of Mexico Weak Hook Research (Preliminary results) Presentation to the Fall 2012 HMS advisoroy panel. September 19 - 21, 2012 http://www.nmfs.noaa.gov/sfa/hms/Advisory%20Panels/AP2012/Fall/Agenda.htm.

Goodman, L. A.1960. On the exact variance of products. Journal of the American Statistical Association. 55(292): 708- 713.

Littell, R.C., Henry, P.R. and Ammerman, C.B. 1998, Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci. 76: 1216-1231.

Walter, J. and Cass-Calay, S.L. 2014. Standardized catch rates of large bluefin tuna (*Thunnus Thynnus*) from the U.S. pelagic longline fishery in the Gulf of Mexico during 1987-2010. Collect. Vol. Sci. Pap. ICCAT, 70(2): 646-653.

Walter, J. 2015. Update of standardized catch rates of large bluefin tuna (*Thunnus thynnus*) from the U.S. pelagic longline fishery in the Gulf of mexico 1987-2013 with correction for weak hook effects. Collect. Vol. Sci. Pap. ICCAT, 71(3): 1260-1278.

Zhou, S. 2002. Estimating Parameters of Derived Random Variables: Comparison of the Delta and Parametric Bootstrap Methods, Transactions of the American Fisheries Society, 131:4, 667-675.

Table 1. Number of sets and BFT CPUE by zone with the BFT closure separated for analysis dataset.

	Number of sets				*CPUE*			
	1	*2*	*3*	*BFT closure*	*1*	*2*	*3*	*BFT closure*
1987	92	1243	716	816	0.328	0.507	0.323	0.544
1988	470	1252	566	508	0.131	0.328	0.252	0.569
1989	435	1145	836	420	0.393	0.550	0.208	0.561
1990	335	836	706	385	0.210	0.416	0.071	0.784
1991	159	735	677	547	0.459	0.654	0.104	1.173
1992	196	1108	641	854	0.181	0.369	0.096	0.592
1993	176	740	459	507	0.048	0.103	0.108	0.159
1994	114	789	598	548	0.049	0.103	0.011	0.179
1995	78	769	628	690	0.029	0.045	0.025	0.113
1996	218	860	857	627	0.017	0.052	0.014	0.098
1997	451	795	927	410	0.063	0.073	0.061	0.064
1998	303	583	590	474	0.058	0.071	0.061	0.136
1999	583	937	478	522	0.124	0.168	0.119	0.158
2000	112	1051	432	657	0.055	0.192	0.215	0.395
2001	88	811	443	780	0.052	0.125	0.037	0.229
2002	61	961	215	900	0.042	0.136	0.055	0.202
2003	286	1055	289	900	0.140	0.160	0.089	0.211
2004	117	987	569	1195	0.209	0.246	0.063	0.237
2005	125	1055	447	1021	0.063	0.137	0.084	0.163
2006	32	382	287	745	0.000	0.054	0.097	0.130
2007	34	897	237	532	0.000	0.132	0.000	0.346
2008	35	647	310	601	0.143	0.213	0.036	0.516
2009	14	707	287	734	0.000	0.151	0.164	0.360
2010	61	628	366	349	0.114	0.136	0.148	0.348
2011	NA	161	301	44	NA	0.072	0.079	0.391
2012	12	575	296	978	0.237	0.185	0.125	0.406
2013	11	811	555	447	0.000	0.079	0.054	0.163
2014	2	624	392	390	0.000	0.107	0.069	0.168
2015	8	304	158	424	1.078	0.098	0.092	0.043
2016	2	522	102	315	0.000	0.123	0.071	0.125

Table 2. Table of sets, hooks, number of positive sets and number of BFT (sum of kept and discarded) from logbook data in the Gulf of Mexico from sets that met inclusion criteria. Not that these numbers may differ from official U.S. reports as the inclusion criteria may change the vessels selected for the index in different years. 2016 data is preliminary and fishing effort in 2015 and 2016 may be effected by a combination of the bycatch IFQ and an time area closure in the Gulf of Mexico for April and May.

YEAR	*vessels*	*trips*	*sets*	*totalhooks*	*totalBFT*	*perpos*	*Kept*	*Discards*
1987	58	1499	1499	806552	491	19.5%	184	307
1988	84	1796	1796	942441	298	11.9%	228	70
1989	82	1802	1802	775367	400	12.1%	135	265
1990	72	1455	1455	657088	262	12.9%	174	88
1991	76	1300	1300	606141	471	23.8%	359	112
1992	79	1750	1750	1032910	279	11.8%	165	114
1993	64	1106	1162	864111	113	7.7%	83	30
1994	62	1062	1081	801206	112	7.7%	78	34
1995	61	1177	1214	901175	80	5.2%	71	9
1996	72	320	1472	1077716	72	4.6%	57	15
1997	65	268	1407	1030980	65	3.8%	42	23
1998	62	249	1286	1021732	97	5.2%	40	57
1999	57	315	1825	1430720	227	8.8%	99	128
2000	58	301	1715	1319163	400	9.7%	103	297
2001	57	237	1418	1056371	166	8.7%	73	93
2002	49	248	1557	1211882	198	9.1%	82	116
2003	60	283	1881	1429509	313	11.3%	112	201
2004	55	338	2149	1645196	431	14.1%	203	228
2005	52	299	2127	1672806	267	9.2%	158	109
2006	35	166	1070	816436	100	7.6%	47	53
2007	44	204	1325	999869	191	10.3%	85	106
2008	38	152	1075	831340	325	16.4%	92	233
2009	35	149	1154	893027	246	13.2%	91	155
2010	36	146	1170	887663	179	11.1%	62	117
2011	10	46	300	162945	22	5.3%	11	11
2012	37	166	1343	1005167	217	13.0%	115	102
2013	36	157	1200	835339	85	5.4%	37	48
2014	32	127	970	743203	75	6.5%	38	37
2015	30	99	730	529838	29	3.6%	12	17
2016	21	78	677	532707	69	7.4%	11	58

Table 3. Table of number of nominal and standardized index of Bluefin CPUE from US pelagic longline index in the Gulf of Mexico.Shaded values are the index time period 1987-1991 which was split from the time period 1992-2016 Values in italics received adjustment for circle hook implementation. Normalized index values are scaled to a mean of one for each time period.

Year	*Nsets*	*nominal CPUE*	*% pos*	*std CPUE*	*LCI*	*UCI*	*Corrected for circle hook effect (Normalized index)*	*cv, post circle hook correction*	*std LCI*	*std UCI*	*adjustment factor*
1987	1499	2.80	20%	3.58	2.02	6.35	1.31	0.29	0.740	2.326	1
1988	1796	1.60	12%	1.74	0.94	3.25	0.64	0.32	0.343	1.190	1
1989	1802	2.20	12%	2.69	1.48	4.89	0.99	0.31	0.543	1.792	1
1990	1455	1.87	13%	2.11	1.13	3.94	0.77	0.32	0.415	1.443	1
1991	1300	3.83	24%	3.52	1.97	6.30	1.29	0.30	0.720	2.308	1
1992	1750	1.35	12%	0.87	0.44	1.70	1.14	0.35	0.583	2.230	1
1993	1162	0.58	8%	0.49	0.24	0.98	0.64	0.36	0.317	1.292	1
1994	1081	0.55	8%	0.36	0.17	0.76	0.47	0.39	0.223	0.998	1
1995	1214	0.33	5%	0.33	0.16	0.71	0.44	0.39	0.206	0.933	1
1996	1472	0.26	5%	0.19	0.09	0.42	0.26	0.40	0.118	0.551	1
1997	1407	0.27	4%	0.35	0.17	0.71	0.46	0.36	0.229	0.939	1
1998	1286	0.36	5%	0.38	0.18	0.78	0.50	0.37	0.243	1.019	1
1999	1825	0.63	9%	0.64	0.34	1.21	0.85	0.33	0.449	1.595	1
2000	1715	1.28	10%	0.95	0.50	1.78	1.24	0.33	0.658	2.344	1
2001	1418	0.77	9%	0.54	0.26	1.11	0.71	0.38	0.342	1.463	1
2002	1557	0.83	9%	0.51	0.24	1.07	0.66	0.39	0.316	1.400	1
2003	1881	0.85	11%	0.91	0.49	1.70	1.19	0.32	0.639	2.231	1
2004	2149	0.98	14%	0.82	0.44	1.55	1.08	0.32	0.577	2.031	1
2005	2127	0.62	9%	0.62	0.32	1.20	0.82	0.34	0.424	1.578	1
2006	1070	0.47	8%	0.44	0.21	0.93	0.58	0.39	0.275	1.225	1
2007	1325	0.77	10%	0.59	0.29	1.23	0.78	0.38	0.376	1.612	1
2008	1075	1.61	16%	1.36	0.71	2.59	1.78	0.33	0.938	3.398	1
2009	1154	1.07	13%	1.11	0.56	2.20	1.46	0.35	0.737	2.894	1
2010	1170	0.85	11%	0.93	0.48	1.79	1.22	0.34	0.632	2.352	1
2011	*300*	*0.56*	*5%*	*0.75*	*0.30*	*1.87*	*1.09*	*0.48*	*0.438*	*2.715*	*1.10*
2012	*1343*	*0.96*	*13%*	*1.39*	*0.73*	*2.65*	*3.39*	*0.37*	*1.651*	*6.974*	*1.85*
2013	*1200*	*0.44*	*5%*	*0.51*	*0.24*	*1.07*	*1.23*	*0.42*	*0.547*	*2.779*	*1.85*
2014	*970*	*0.45*	*6%*	*0.42*	*0.19*	*0.90*	*1.02*	*0.44*	*0.441*	*2.340*	*1.85*
2015	*730*	*0.32*	*4%*	*0.42*	*0.18*	*0.97*	*1.02*	*0.47*	*0.417*	*2.479*	*1.85*
2016	*677*	*0.53*	*7%*	*0.47*	*0.20*	*1.09*	*1.14*	*0.47*	*0.466*	*2.800*	*1.85*

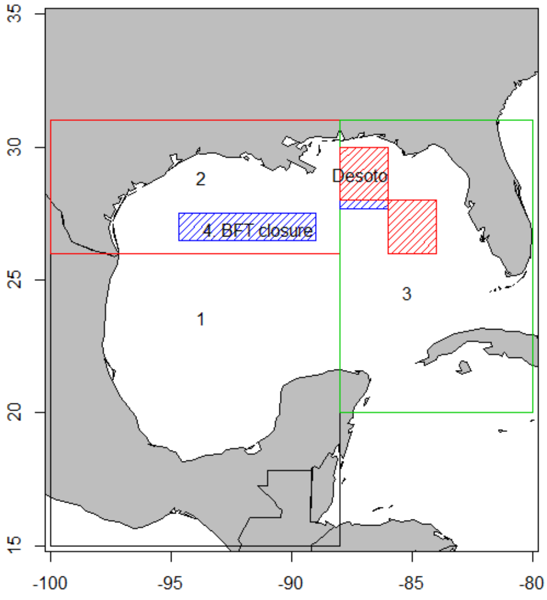

Figure 1. Map of areas used for CPUE standardization in the Gulf of Mexico. Note that the BFT closure went into place in 2015 for the months of April and May. The Desoto closures did not have as much historical effort and so no data correction or elimination of effort prior to and post closure was done for CPUE modeling.

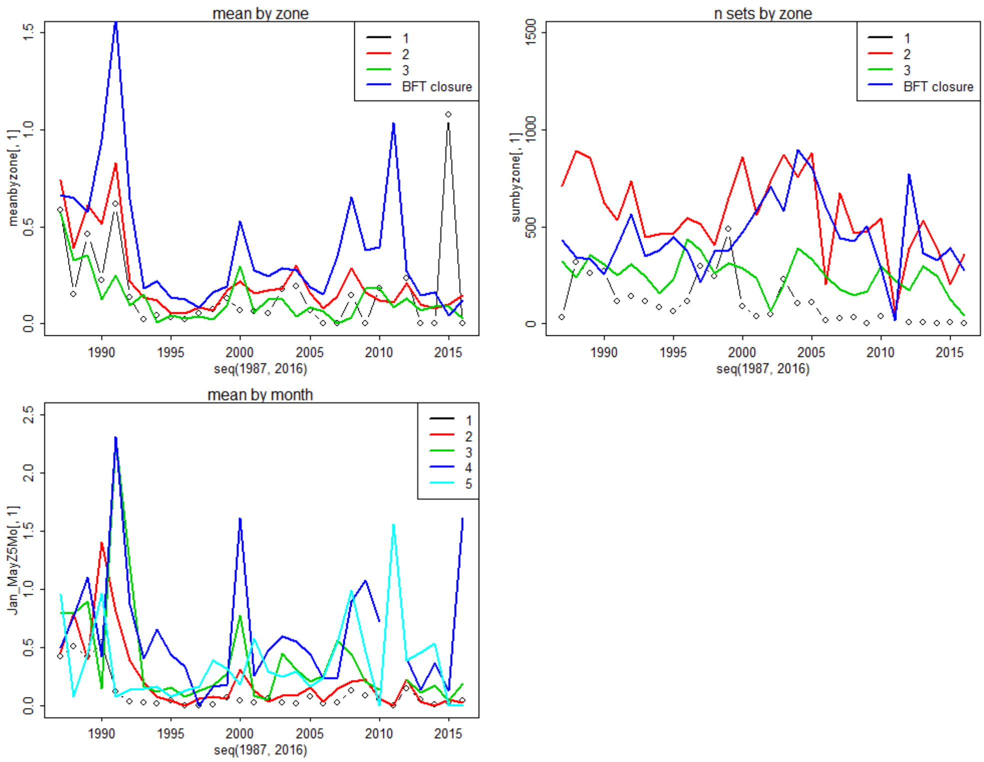

Figure 2. A. nominal mean BFT catch rates by zone, B. number of sets by zone and C. Mean CPUE by month.

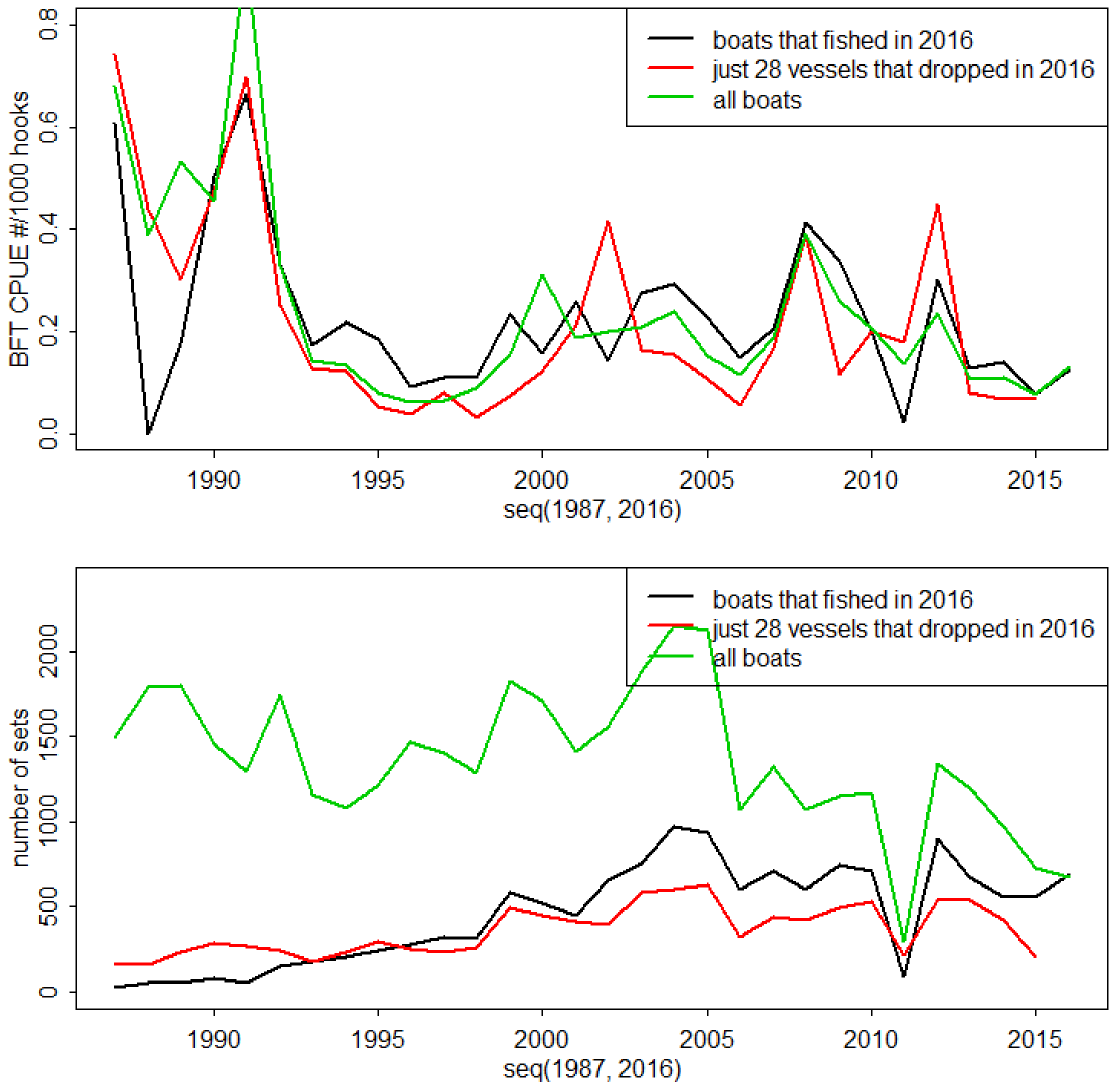

Figure 3. Analysis of the vessels that did not fish in 2016. Top figure shows CPUE of the 21 vessels that fished in 2016 (Jan-May, black line), CPUE of the 28 vessels that fished from 2009-2015 but did not fish in 2016 (red) and all vessels (green). Bottom figure shows the number of sets for each category.

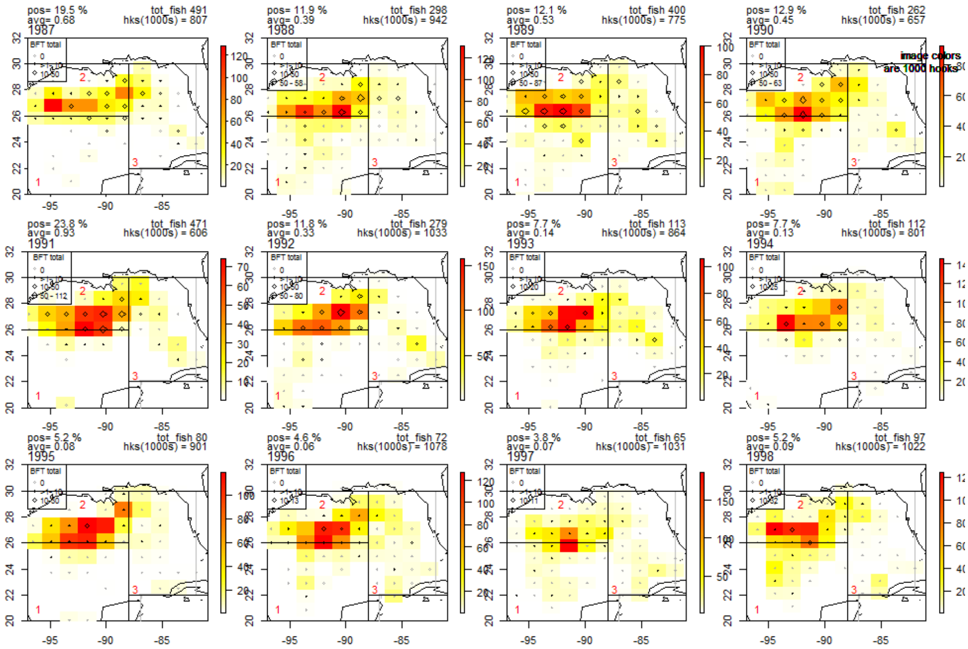

Figure 4. Plots of US pelagic longline catch, CPUE, and effort for the analysis dataset used for the index (Gulf of Mexico records Jan 1-May 31, selected vessels). Summed catch (kept+discards) by cell are shown as diamonds and summed effort is shaded. All catch and effort are aggregatedto grid cells to preserve data confidentiality.The red numbers on the plots refer to each zone. Notes labeled ‘pos’ are the nominal % positive and “avg” is the nominal CPUE in BFT/1000 hooks. The green shaded areas in 2015 are the closed areas for the months of April and May.

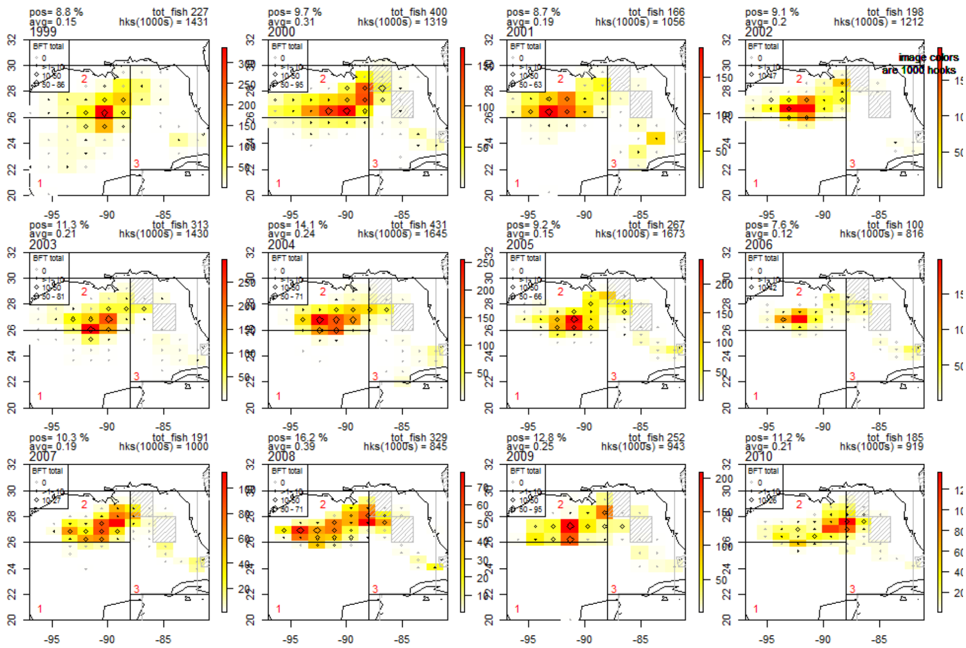

Figure 4. Continued.

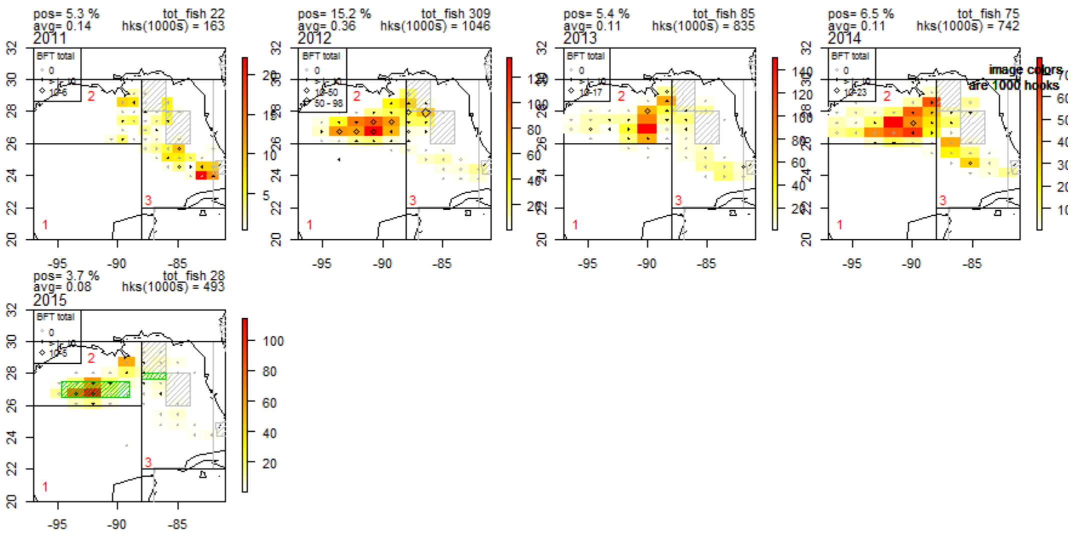

Figure 4. Continued

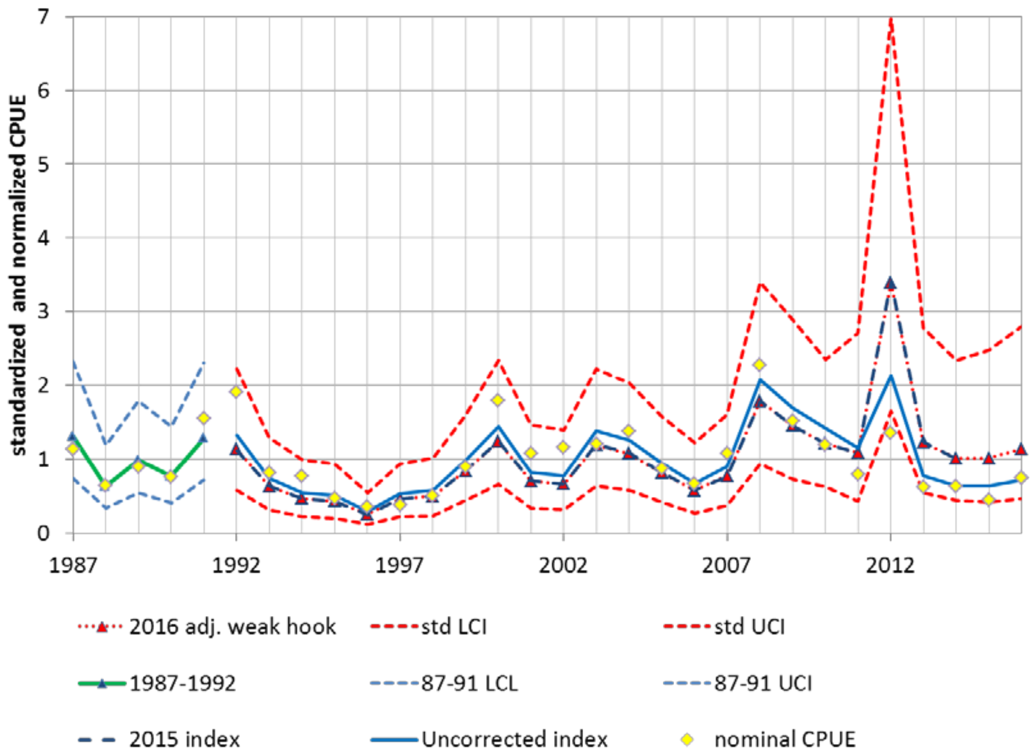

Figure 5. 2016 logbook indices with break in index in 1991. This figure shows the index for the two time periods (1987-1991 and 1992-2014), each normalized to a mean of one. The dashed green lines are the 2015 index.

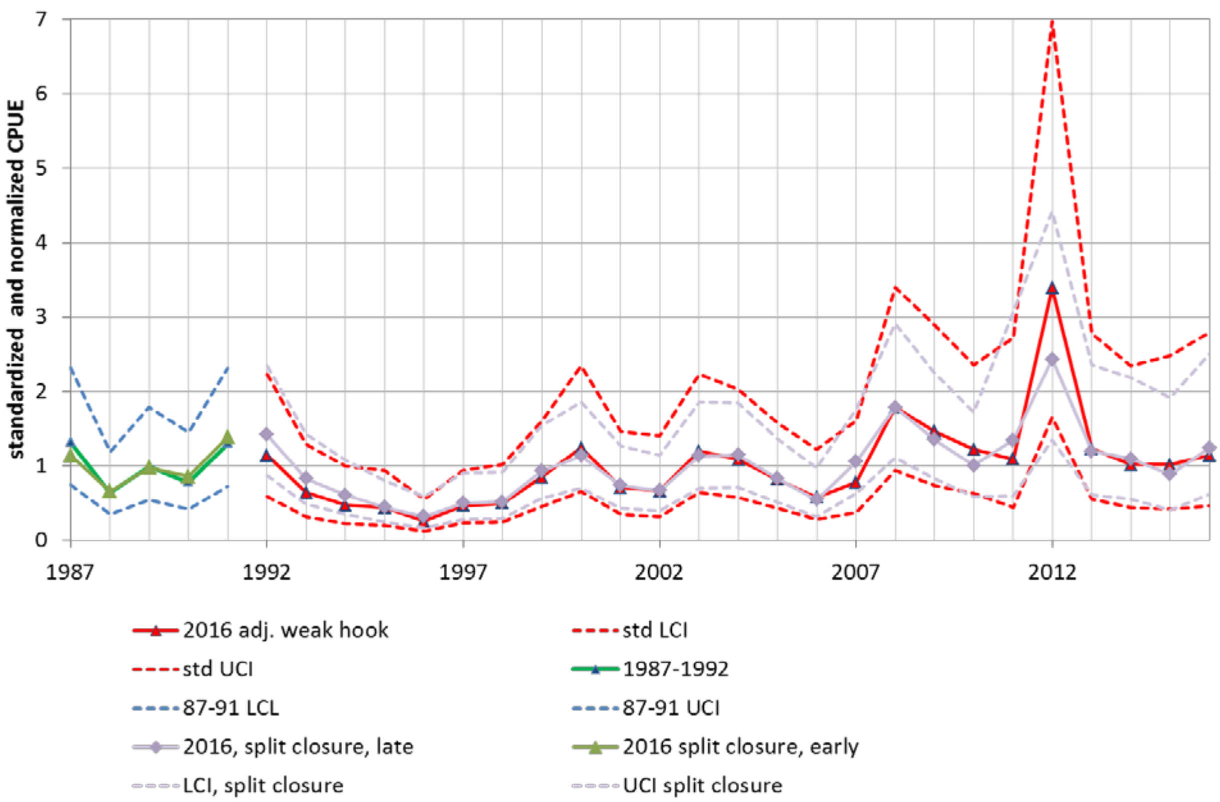

Figure 6. Index with the bluefin tuna closed areas modeled as a separate spatial zone (purple lines) compared with updated index. Note that the same treatments are applied to the split closure area index (split in 1992, weak hook adjustment, etc.) though the year*zone and month*zone interactions are removed.