STANDARDIZED CATCH RATES OF BLUEFIN TUNA, *THUNNUS THYNNUS*, FROM THE ROD AND REEL/HANDLINE FISHERY OFF THE NORTHEAST UNITED STATES DURING 1993-2015

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SUMMARY

Individual trip rod and reel/handline bluefin tuna catch and effort data, collected through interviews with fishermen, were used to estimate standardized catch indices. Data filter criteria and model factors remained unchanged from the previous update, conducted in 2014. Generalized linear mixed models (GLMM) were developed for three size categories of bluefin tuna (small school = 66 to 114 cm, large school = 115 to 144 cm, and large > 177 cm), applying a negative binomial regression of the number Bluefin caught using a log link function and fishing effort modeled as an intercept offset. Three current indices of abundance are presented, updated for the period 1993 to 2015.

RÉSUMÉ

Les données de prise et d'effort du thon rouge à la canne et moulinet/ligne à main de sorties individuelles, recueillies lors d'entretiens avec les pêcheurs, ont été utilisées pour estimer les indices de capture standardisés. Les critères de filtrage des données et les facteurs de modèle sont demeurés inchangés par rapport à l'actualisation antérieure menée en 2014. Des modèles linéaires mixtes généralisés (GLMM) ont été élaborés pour trois catégories de taille de thon rouge (petit= 66 à 114 cm, grand= 115 à 144 cm et de taille supérieure à 177 cm), en appliquant une régression binomiale négative du nombre de thons rouges capturés au moyen d'une fonction logarithmique de lien et l'effort de pêche modélisé comme une compensation d'interception. Trois indices d'abondance actuels sont présentés et actualisés pour la période courant de 1993 à 2015.

RESUMEN

Se han utilizado datos de captura y esfuerzo de mareas individuales de caña y carrete/liña de mano dirigidas al atún rojo y recopiladas mediante entrevistas con los pescadores para estimar índices de captura estandarizados. Los criterios de filtrado de los datos y los factores del modelo continúan sin cambios respecto a la actualización previa, llevada a cabo en 2014. Se desarrollaron modelos lineales mixtos generalizados (GLMM) para tres categorías de talla de atún rojo (talla de cardumen pequeña = 66 a 114 cm, talla de cardumen grande= 115 a 144 cm y grande>177 cm), aplicando una regresión binomial negativa del número de atunes rojos capturados utilizando una función de vínculo logarítmica y el esfuerzo pesquero modelado como una compensación de interceptación. Se presentan tres índices actuales de abundancia, actualizados para el periodo 1993 a 2015.

KEYWORDS

Atlantic Bluefin Tuna, Catch/effort, Multivariate analysis, Pelagic fisheries, Catch statistics

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1. Introduction

Rod and reel fishermen have targeted Bluefin tuna off the northeast coast of the United States for several decades. The National Marine Fisheries Service monitors the bluefin tuna fishery through the Large Pelagic Survey, a dockside survey of private and charterboat captains who have just completed fishing trips directed at large pelagic species. This survey is conducted at public fishing access sites that are likely to be used by offshore anglers, and is primarily designed to collect detailed catch data. Data from the survey have typically been used to develop indices of relative abundance for Atlantic bluefin tuna.

As a consequence of ICCAT recommendations that became effective in 1992, various regulatory changes were implemented. Those measures included daily catch limits on anglers and/or vessels and fishery closures for various size categories of bluefin tuna. New size categories were defined:

young small	< 66 cm SFL	also known as young school
small small (SMSM)	66-114 cm SFL	also known as small school
large small (LGSM)	115-144 cm SFL	also known as large school
small medium (SMMD)	145-177 SFL	
large medium (LGMD)	178-195 cm SFL	since 1992 sometimes known as giant
large (LG)	> 195 cm SFL	also known as giant

Large Pelagic Survey procedures to use the new size categories were fully implemented in 1993. These catch limits, closures and size categories were considered in calculations of indices of abundance (Ortiz *et al.* 1999, Turner *et al.* 1999, Brown 2011).

The purpose of this paper is to update relative abundance indices for three sizes of Bluefin tuna: small school (SMSM), large school (LGSM), and large medium plus large (LGMD-LG) groups modeled as a combined index (i.e. large Bluefin > 177 cm). Due to differences in the regulatory and survey methodology amongst size classes, the indices were calculated separately by size category, consistent with previous analyses. Regulatory changes combined the LGMD and LG categories (Turner *et al.* 1999), which were separate categories prior to 1992. There are indications that these changes may have led to an alteration in how the bluefin size classes are perceived by the fishing community; both large medium and large are often jointly referred to as "giants", an apparent change from the years prior to 1992. This suggests that there may be some misclassification in reported size categories (Brown *et al.* 1999) as well as in reported targeting. For these reasons, indices of abundance for large medium and large bluefin (tunas >177 cm SFL) are presented as a combined group for the period 1993-2015 (LGMD-LG). Indices for the period prior to 1993 remain unchanged from the previous assessment.

2. Materials and Methods

The Large Pelagic Intercept Survey collects data on the catch and effort through interviews with fishermen at the dock. Information collected usually includes date, landing area, boat type (charter, private, or party boat), fishing area, number of anglers fishing, number of lines in the water, hours fished, type of fishing (primarily trolling or chumming), fishing target species, and catch by bluefin tuna size category.

The process of calculating the indices of abundance from this data involves the standardization of yearly changes in catches, accounting for the influence of factors which have a significant influence. Factors which were considered as possible influences on catch rates included year, month, boat type , fishing method, fishery specific fishing areas (sometimes combined into larger regions), open/closed status of the fishery, angler catch limits, and target. Also considered were any vessel based catch limits in effect for the trip, specific to each size category. Fishing effort was defined as hours fished as has been done in recent analyses for bluefin tuna (Turner and Brown 1998, Brown 2009, Brown 2011). The applicable fishery closures and catch limits, allocated by regulatory categories Angling (non-commercial) and General (commercial), have been documented by Ortiz *et al.* 1999, Brown *et al.* 1999, and Brown (2003, 2007, 2009). All other restrictions imposed upon the data in recent analyses, such as target category or open/closed fishery status, were retained for the present analyses, and a summary of data restrictions is documented below:

SMSM and LGSM

- Year > 1992
- Bluefin targeted trips used exclusively
- Fishing season = "open"

- Fishing method = “chum” or “troll”
- Boat type = “private” or “charter” vessel
- 1 < vessel bag limit < 20
- Samples with no fishing area recorded were excluded
- If region = “south” and month > 8, then sample was excluded
- If region = “north”, and month < 6 or month > 9, then sample excluded

LGMD_LG

- Year > 1992
- Bluefin targeted trips used exclusively
- If fishing area “Northeast Distant Waters,” then sample was excluded
- Month = 7, 8, 9, or 10
- Fishing season = “open”
- Samples that did not contain data collection method were excluded

The fishing areas were the same as those defined for the large tuna analyses completed over the last several years. For the SMSM and LGSM categories, four fishing areas were classified as off Virginia, Maryland-Delaware, New Jersey, and New York-Massachusetts. For the LGMD_ LG analyses, three fishing areas were classified as off North Carolina-Delaware (NCDE), from New Jersey eastward to south of Cape Cod (STHN), and the Gulf of Maine (GOMA) (Turner and Brown 1998).

A generalized linear mixed model (GLMM) was fit for each of the three size classes of BFT using the SAS GLIMMIX procedure, where the catch of bluefin tuna was modeled as a function of multiple covariates, assuming a negative binomial error structure with a log link function, and modeling effort as a $\log_e$-scale intercept offset. The negative binomial regressions were constructed using the same set of fixed and random effects as the previous analysis. The following factors were modeled: year and area fixed effects for SMSM catches with year*area interaction modeled as a random effect; year, area, and fishing method fixed effects for LGSM catches; and year and month fixed effects for LGMD_LG catches with year*month interaction modeled as a random effect. The GLIMMIX code for LGMD_LG indices standardization is provided here as an example GLMM model.

```
proc glimmix data=analysis;
nloptions maxiter=500;
class year month;
model large_bft = year month / dist=negbin offset=ln_hours ddfm=kr s;
random year*month;
lsmeans year / ilink cl;
output out=GLMM_out pred(ilink) pearson;
id year month area boattype fishmeth dockrecl target hours ln_hours large_bft cpue;
run;
```

3. Results and Discussion

The negative binomial demonstrated good model fit to the observed distribution of bluefin tuna catches (**Figure 1**), and produced similar least square means as the previous standardization (**Figures 2, 3, and 4**). Descriptive statistics and model indices are presented in **Tables 1** through **3** for each size category of bluefin Tuna (SMSM, LGSM, and LGMD-LG, respectively). A summary of the three indices and the associated coefficient of variation is presented in **Table 4**. Model comparisons among the nominal catch rate time series, indices from the prior updated assessment, and the current standardization model are presented in **Figures 2, 3, and 4** along with 95% confidence intervals of the least square means.

Standardized abundance indices demonstrated similar temporal trends to the nominal time series for SMSM and LGMD-LG bluefin tuna, with agreement as well between current estimates and trends from the previous updated assessment (**Figures 2, 3 and 4**). LGSM catch rates showed greater deviation between standardized models and the nominal time series than did those of SMSM and LGMD-LG sized fish. The difference between the observed and GLMM predicted catches of LGSM fish resulted from a shift in the distribution of survey samples from Virginia to northern fishing areas, where these sized fish are believed to be less abundant. This discrepancy between the nominal and standardized time series highlights the importance of standardizing catch rates for this size class of bluefin tuna.

4. Acknowledgements

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Table 1. Descriptive statistics and catch rate indices of SMSM bluefin tuna (66 to 114 cm SFL) captured by the U.S. rod and reel/handline fishery during 1993 to 2015.

Year	*n*	*Prop. Positive*	*Total Effort*	*Total Catch*	*Obs. Mean CPUE*	*Pred. Mean CPUE*	*SE*	*LCL*	*UCL*	*CV*
1993	140	0.48	980	236	0.27	0.18	0.07	0.09	0.37	0.36
1994	82	0.27	557	23	0.06	0.04	0.02	0.02	0.10	0.44
1995	195	0.56	1250	243	0.21	0.18	0.06	0.09	0.36	0.34
1996	176	0.66	1153	389	0.36	0.27	0.10	0.13	0.56	0.37
1997	289	0.64	1787	774	0.50	0.39	0.13	0.21	0.74	0.32
1998	244	0.68	1600	380	0.25	0.23	0.08	0.11	0.47	0.36
1999	77	0.69	508	111	0.23	0.22	0.09	0.09	0.51	0.42
2000	45	0.60	303	42	0.17	0.16	0.08	0.06	0.42	0.50
2001	192	0.41	1319	105	0.08	0.08	0.03	0.04	0.15	0.34
2002	120	0.66	813	189	0.26	0.24	0.09	0.11	0.53	0.39
2003	517	0.35	3483	302	0.10	0.07	0.02	0.03	0.13	0.33
2004	327	0.64	2210	731	0.40	0.37	0.11	0.20	0.68	0.31
2005	431	0.57	2718	980	0.40	0.36	0.11	0.19	0.66	0.30
2006	270	0.40	1776	190	0.12	0.10	0.03	0.05	0.19	0.33
2007	636	0.43	4415	375	0.09	0.07	0.02	0.04	0.14	0.30
2008	464	0.21	3024	136	0.05	0.06	0.02	0.03	0.11	0.32
2009	427	0.26	2755	129	0.06	0.06	0.02	0.03	0.11	0.31
2010	379	0.39	2525	270	0.10	0.10	0.03	0.05	0.19	0.32
2011	260	0.36	1548	180	0.11	0.13	0.04	0.06	0.26	0.34
2012	241	0.32	1453	91	0.07	0.07	0.03	0.03	0.14	0.40
2013	234	0.41	1576	129	0.09	0.09	0.03	0.04	0.18	0.35
2014	172	0.38	1201	119	0.11	0.11	0.04	0.05	0.23	0.37
2015	202	0.24	1405	97	0.07	0.07	0.03	0.03	0.15	0.39

Table 2. Descriptive statistics and catch rate indices of LGSM bluefin tuna (115 to 144 cm SFL) captured by the U.S. rod and reel/handline fishery during 1993-2015.

Year	*n*	*Prop. Positive*	*Total Effort*	*Total Catch*	*Observed Mean CPUE*	*GLMM Pred. Mean CPUE*	*SE*	*LCL*	*UCL*	*CV*
1993	160	0.12	1103	123	0.145	0.082	0.018	0.05	0.124	0.215
1994	82	0.09	557	16	0.030	0.021	0.008	0.01	0.044	0.381
1995	195	0.13	1250	65	0.061	0.045	0.010	0.03	0.070	0.224
1996	192	0.19	1274	85	0.086	0.054	0.012	0.03	0.083	0.220
1997	176	0.06	1108	13	0.018	0.016	0.005	0.01	0.031	0.345
1998	362	0.17	2376	101	0.049	0.057	0.010	0.04	0.080	0.172
1999	85	0.28	563	39	0.079	0.063	0.020	0.03	0.116	0.315
2000	59	0.22	400	21	0.059	0.098	0.038	0.05	0.211	0.388
2001	194	0.21	1346	119	0.139	0.118	0.024	0.08	0.175	0.201
2002	121	0.22	817	62	0.084	0.189	0.048	0.11	0.312	0.255
2003	517	0.15	3483	155	0.047	0.047	0.007	0.03	0.062	0.146
2004	327	0.10	2210	68	0.036	0.045	0.009	0.03	0.066	0.193
2005	431	0.08	2718	72	0.029	0.042	0.008	0.03	0.060	0.179
2006	270	0.21	1776	106	0.064	0.107	0.020	0.07	0.155	0.188
2007	636	0.22	4415	240	0.058	0.122	0.016	0.09	0.158	0.132
2008	464	0.12	3024	160	0.047	0.085	0.013	0.06	0.115	0.155
2009	427	0.08	2755	46	0.017	0.037	0.007	0.02	0.055	0.202
2010	379	0.17	2525	98	0.042	0.089	0.015	0.06	0.125	0.171
2011	260	0.15	1548	53	0.037	0.078	0.017	0.05	0.119	0.215
2012	241	0.13	1453	47	0.047	0.083	0.019	0.05	0.131	0.233
2013	234	0.22	1576	90	0.055	0.131	0.027	0.09	0.196	0.204
2014	172	0.11	1201	32	0.030	0.070	0.018	0.04	0.117	0.261
2015	202	0.06	1405	14	0.011	0.026	0.008	0.01	0.049	0.328

Table 3. Descriptive statistics and catch rate indices of LGMD-LG bluefin tuna (> 177 cm SFL) captured by the U.S. rod and reel/handline fishery during 1993 to 2015.

Year	*n*	*Prop. Positive*	*Total Effort*	*Total Catch*	*Obs. Mean CPUE*	*Pred. Mean CPUE*	*SE*	*CV*	*LCL*	*UCL*
1993	334	0.07	2799	38	0.012	0.012	0.0036	0.30	0.007	0.022
1994	261	0.10	2139	37	0.012	0.016	0.0046	0.28	0.009	0.029
1995	486	0.12	4083	79	0.021	0.020	0.0051	0.26	0.012	0.034
1996	172	0.27	1396	98	0.056	0.065	0.0160	0.25	0.040	0.107
1997	68	0.26	554	18	0.038	0.026	0.0096	0.37	0.012	0.054
1998	306	0.19	2517	67	0.034	0.028	0.0071	0.25	0.017	0.047
1999	160	0.22	1223	48	0.039	0.036	0.0101	0.28	0.021	0.064
2000	385	0.08	3311	39	0.015	0.011	0.0030	0.27	0.006	0.019
2001	153	0.13	1279	30	0.032	0.028	0.0080	0.29	0.016	0.049
2002	449	0.26	3724	148	0.044	0.034	0.0078	0.23	0.021	0.054
2003	511	0.07	4303	46	0.012	0.009	0.0024	0.27	0.005	0.015
2004	366	0.10	2857	49	0.014	0.014	0.0037	0.27	0.008	0.023
2005	428	0.06	3522	41	0.009	0.011	0.0030	0.27	0.007	0.019
2006	217	0.06	1722	16	0.010	0.009	0.0031	0.35	0.004	0.018
2007	274	0.03	2164	12	0.005	0.006	0.0021	0.37	0.003	0.012
2008	355	0.03	2820	19	0.004	0.007	0.0024	0.35	0.003	0.014
2009	257	0.02	1887	9	0.005	0.005	0.0020	0.40	0.002	0.011
2010	354	0.07	2667	52	0.015	0.019	0.0048	0.26	0.011	0.031
2011	329	0.06	2605	36	0.010	0.012	0.0032	0.28	0.007	0.020
2012	520	0.06	4040	58	0.010	0.013	0.0034	0.25	0.008	0.022
2013	441	0.05	3592	32	0.008	0.009	0.0025	0.29	0.005	0.015
2014	361	0.08	2931	38	0.013	0.012	0.0032	0.27	0.007	0.020
2015	565	0.12	4797	95	0.020	0.020	0.0046	0.23	0.012	0.032

Table 4. Summary of standardized indices of bluefin tuna from the U.S. rod and reel fishery.

	US_RR_66_114		*US_RR_115_144*		*US_RR_>177*	
Year	*Index*	*CV*	*Index*	*CV*	*Index*	*CV*
1993	1.16	0.36	1.10	0.21	0.66	0.30
1994	0.27	0.44	0.28	0.38	0.89	0.28
1995	1.15	0.34	0.61	0.22	1.09	0.26
1996	1.71	0.37	0.73	0.22	3.57	0.25
1997	2.47	0.32	0.21	0.35	1.42	0.37
1998	1.44	0.36	0.77	0.17	1.56	0.25
1999	1.39	0.42	0.85	0.31	1.99	0.28
2000	0.99	0.50	1.33	0.39	0.60	0.27
2001	0.48	0.34	1.59	0.20	1.51	0.29
2002	1.54	0.39	2.55	0.26	1.85	0.23
2003	0.42	0.33	0.63	0.15	0.47	0.27
2004	2.31	0.31	0.61	0.19	0.74	0.27
2005	2.26	0.30	0.57	0.18	0.62	0.27
2006	0.61	0.33	1.45	0.19	0.49	0.35
2007	0.46	0.30	1.65	0.13	0.31	0.37
2008	0.36	0.32	1.14	0.16	0.38	0.35
2009	0.36	0.31	0.50	0.20	0.27	0.40
2010	0.63	0.32	1.20	0.17	1.03	0.26
2011	0.82	0.34	1.06	0.21	0.63	0.28
2012	0.41	0.40	1.12	0.23	0.72	0.25
2013	0.57	0.35	1.77	0.20	0.47	0.29
2014	0.70	0.37	0.94	0.26	0.64	0.27
2015	0.45	0.39	0.35	0.33	1.09	0.23

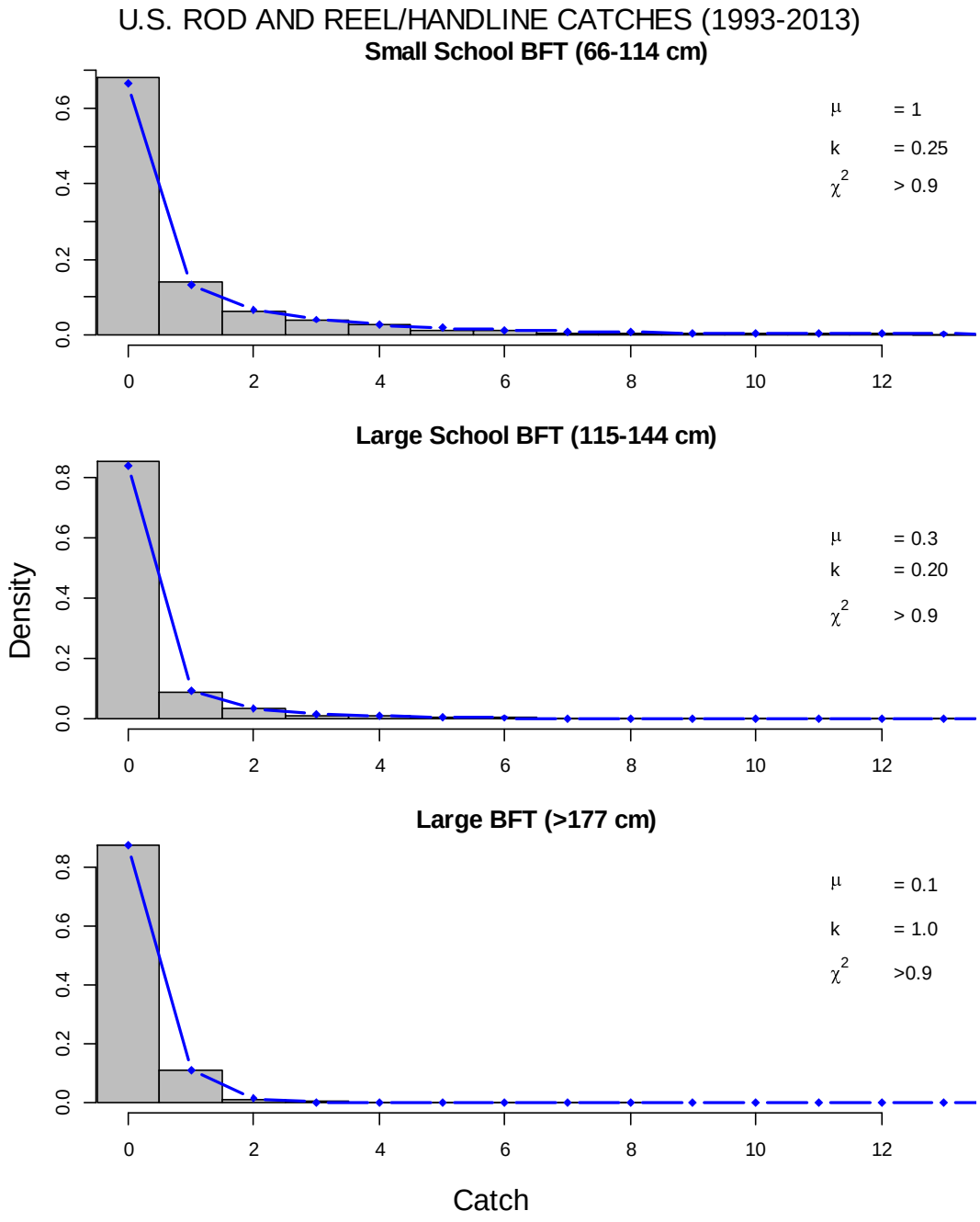

Figure 1. Negative binomial model fit (blue line) to the observed distributions of bluefin tuna catches (shaded bars). The observed mean (mu) and scaling parameter (k) for the fitted negative binomial are also shown.

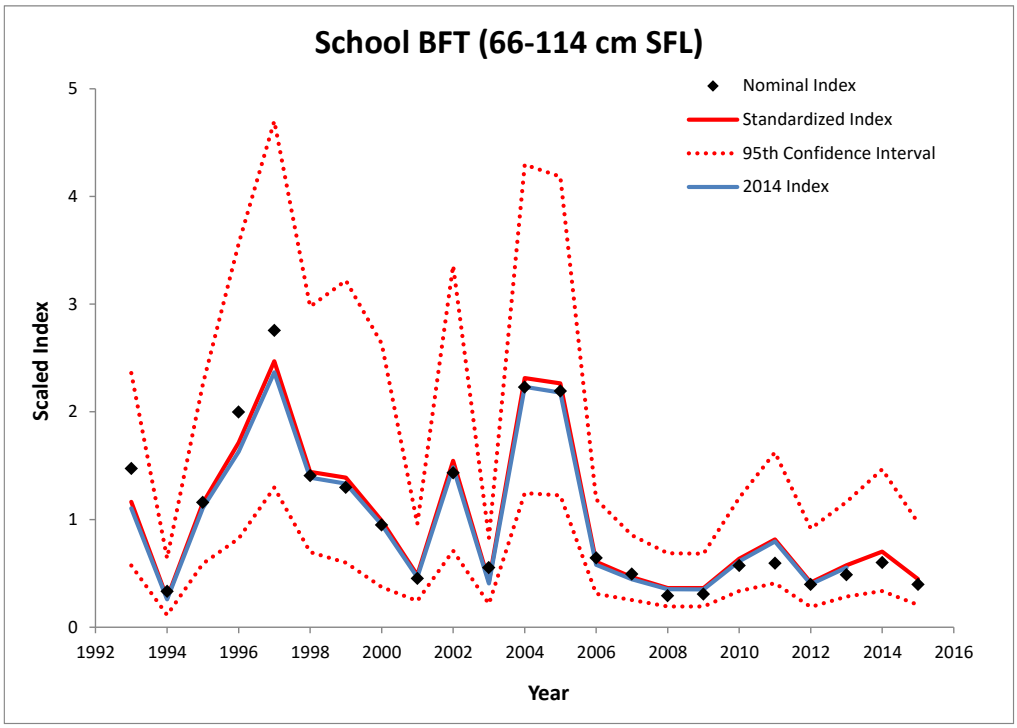

Figure 2. Comparison of small school bluefin tuna (SMSM) standardized time series with nominal catch rate data and previous delta-Poisson model.

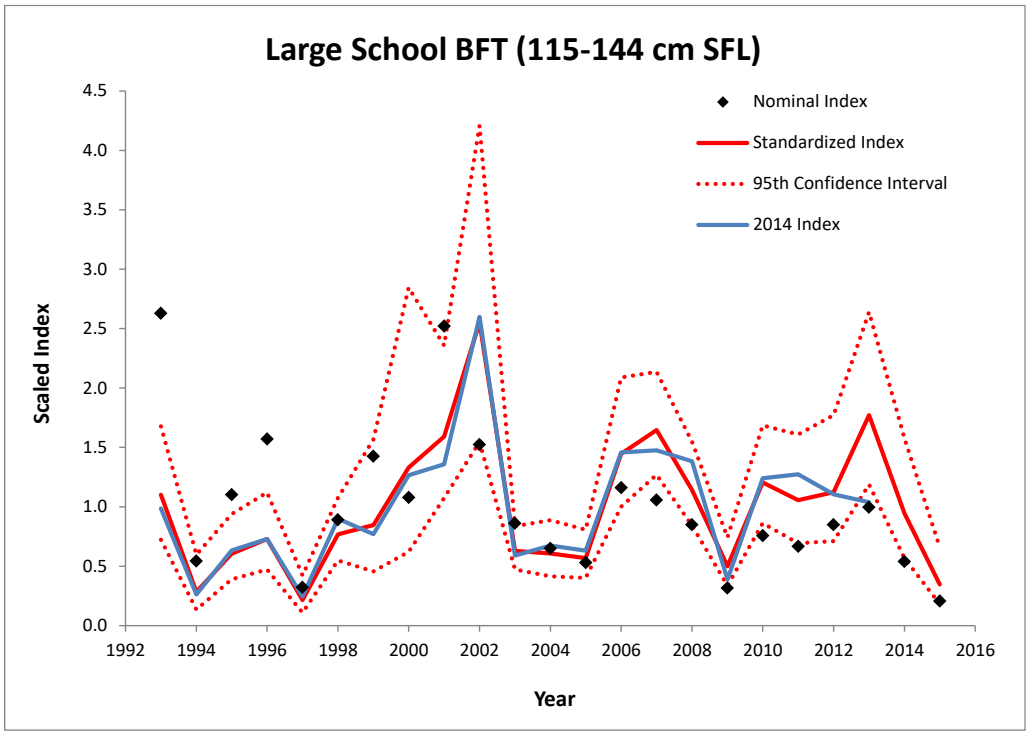

Figure 3. Comparison of large school bluefin tuna (LGSM) standardized time series with observed mean and previous delta-Poisson model.

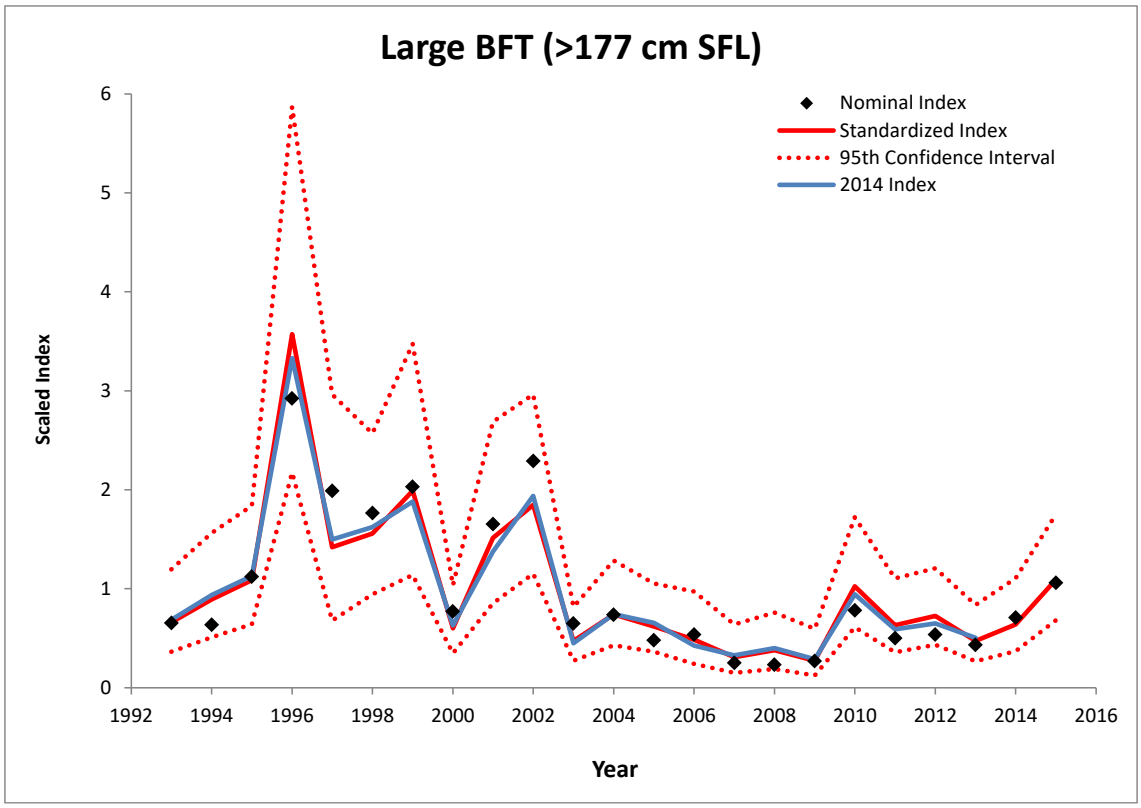

Figure 4. Comparison of large bluefin tuna (LGMD_LG) standardized time series with observed mean and previous delta-Poisson model.