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STANDARDIZED CATCH RATES OF BLUEFIN TUNA (*THUNNUS THYNNUS*), FROM THE ROD AND REEL/HANDLINE FISHERY OFF THE NORTHEAST UNITED STATES DURING 1993-2013

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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 considering factors such as year, month, area fished, boat type, fishing method, fishery open/closed status, bag limits. Data were filtered to exclude samples during fishery closures; filter criteria remained unchanged from the previous update, conducted in 2012. 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 2013. The updated GLMM produced similar least square means as the previous delta-Poisson, assuming the same set of covariates as the binomial component of the previous analysis. The updated GLMM demonstrated better goodness-of-fit to the catch data by modeling overdispersion (small school and large school bluefin) resulting from infrequent high catches, as well as underdispersion of large bluefin resulting from data comprised primarily of zeros and ones.

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 en tenant compte de facteurs, tels que l'année, le mois, la zone de pêche, le type de navire, la méthode de pêche, l'ouverture/la fermeture de la pêche et les limites de capture par personne. Les données ont été filtrées afin d'exclure les échantillons pendant les fermetures de la pêche; les critères de filtrage sont restés les mêmes depuis la dernière mise à jour de 2012. Des modèles linéaires généralisés mixtes (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 2013. Le GLMM mis à jour a produit des moyennes des moindres carrés similaires au modèle antérieur delta-Poisson, en postulant le même jeu de covariables que la composante binomiale de l'analyse précédente. Le GLMM mis à jour démontrait une meilleure qualité de l'ajustement aux données de capture en modélisant la surdispersion (bancs de petits spécimens et bancs de spécimens de grande taille) découlant de captures élevées peu fréquentes, ainsi que la sous-dispersion de grands thons rouges découlant de données comprenant principalement des zéros et des uns.

RESUMEN

Se utilizaron los datos de captura y esfuerzo de atún rojo de mareas individuales de caña y carrete/liña de mano, recopilados mediante varias entrevistas con los pescadores, para estimar índices de captura estandarizados considerando factores como año, mes, zona pescada, tipo de buque, método de pesca, estatus abierto/cerrado de la pesquería y límites por persona. Los datos se filtraron para excluir muestras durante los cierres de la pesquería, los criterios de filtrado no han cambiado desde la actualización previa realizada en 2012. Se desarrollaron modelos lineales mixtos generalizados (GLMM) para tres categorías de talla de atún rojo (talla

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pequeña= 66 a 114 cm, talla 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 2013. El GLMM actualizado produjo medias de cuadrados mínimos, como en el modelo delta-Poisson anterior, asumiendo el mismo conjunto de covariables que el componente binomial del análisis previo. El GLMM actualizado mostraba una mejor bondad de ajuste a los datos de captura mediante la modelación de la sobredispersión (atunes rojos con talla pequeña y atunes rojos con talla grande) resultante de las elevadas capturas infrecuentes, así como la infradispersión del atún rojo grande debido a que los datos incluyen sobre todo ceros y unos.

KEYWORDS

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

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, data from which has typically been used to develop indices of relative abundance for Atlantic bluefin tuna.

As a consequence of ICCAT recommendations which 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. 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 1993-2013 (LGMD-LG). Indices for the period prior to 1993 remain unchanged from the previous assessment (Lauretta and Brown 2012).

2. Materials and Methods

The Large Pelagic Survey collects data on the catch and effort through interviews with fishermen at the dock and over the telephone. 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 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 (BOATTYPE), fishing method (FISHMETH), fishery specific fishing areas (sometimes combined into larger regions), open/closed status of the fishery, angler catch limits, target and interview type (dockside/telephone recall or DOCKRECL). Also considered were any vessel based catch limits in effect for the trip, specific to each size category (*e.g.*, VLIM_SSM refers to the vessel catch limit for SMSM bluefin tuna). 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

- Calendar Year > 1992
- 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

- Calendar 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 bluefin tuna using the SAS GLIMMIX procedure, where the catch of bluefin 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 previous standardization procedure used a Poisson hurdle regression model (delta-Poisson), where the proportion positive and positive observations were modeled separately using the Lo method (Lo *et al*. 1992). The hurdle model assumed separate processes for the zero catches and positive observations (**Figure 1**); however, the Poisson distribution demonstrated poor model fit to the observed distribution of positive catches (**Figure 2**) in comparison to a negative binomial probability model where the zeros are modeled jointly with the positive observations (**Figure 3**). Therefore, it was determined that the negative binomial model was appropriate for index standardization and is consistent with recommendations made during the last model standardization (Lauretta and Brown 2012). The negative binomial regressions were constructed using the same set of fixed and random effects as the previous binomial regression model, since the majority of observations were zero. 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 with year*area interaction modeled as a random effect; 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 3**), and produced similar least square means as the delta-Poisson model used in the previous assessment (**Figures 4, 5, and 6**). The primary difference between the models was the estimated variances, although index variances were not used in the previous bluefin tuna assessment. Regardless, the negative binomial model more accurately estimated the variance of the data by accounting for overdispersion (SMSM and LGSM) and underdispersion (LGMD_LG) of catch data, and resulted in more accurate upper and lower confidence intervals of the indices.

Descriptive statistics and model indices are presented in **Tables 1 to 3** for each size category of bluefin tuna (SMSM, LGSM, and LGMD-LG, respectively). Model comparisons among the nominal catch rate time series, indices from the prior updated assessment, and the current standardization model are presented in **Figures 4, 5, and 6** 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, with agreement as well between current estimates and trends from the previous updated assessment (**Figures 4, 5 and 6**). 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 most likely resulted from a shift in the distribution of survey samples from Virginia to northern fishing areas (**Figure 7**), 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.

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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 2013.

Year	*n*	*Prop. Positive*	*Total Effort*	*Total Catch*	*Obs. Mean CPUE*	*GLMM 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	0.45
1995	195	0.56	1250	243	0.21	0.18	0.06	0.09	0.36	0.35
1996	176	0.66	1153	389	0.36	0.27	0.10	0.13	0.57	0.38
1997	289	0.64	1787	774	0.50	0.39	0.13	0.20	0.75	0.33
1998	244	0.68	1600	380	0.25	0.23	0.08	0.11	0.48	0.37
1999	77	0.69	508	111	0.23	0.22	0.09	0.09	0.52	0.43
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	0.35
2002	120	0.66	813	189	0.26	0.24	0.10	0.11	0.54	0.40
2003	517	0.35	3483	302	0.10	0.07	0.02	0.03	0.13	0.35
2004	327	0.64	2210	731	0.40	0.37	0.12	0.19	0.69	0.32
2005	431	0.57	2718	980	0.40	0.36	0.11	0.19	0.68	0.32
2006	270	0.40	1776	190	0.12	0.09	0.03	0.05	0.19	0.35
2007	636	0.43	4415	375	0.09	0.07	0.02	0.04	0.14	0.31
2008	464	0.21	3024	136	0.05	0.06	0.02	0.03	0.11	0.33
2009	427	0.26	2755	129	0.06	0.06	0.02	0.03	0.11	0.33
2010	379	0.39	2525	270	0.10	0.10	0.03	0.05	0.19	0.33
2011	260	0.36	1548	180	0.11	0.13	0.05	0.06	0.27	0.35
2012	241	0.32	1453	91	0.07	0.07	0.03	0.03	0.15	0.41
2013	234	0.41	1576	129	0.09	0.09	0.03	0.04	0.19	0.36

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 1993-2013.

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	0.062	0.025	0.03	0.141	0.407
1994	82	0.09	557	16	0.030	0.017	0.009	0.01	0.049	0.546
1995	195	0.13	1250	65	0.061	0.040	0.016	0.02	0.091	0.405
1996	192	0.19	1274	85	0.086	0.046	0.022	0.02	0.122	0.481
1997	176	0.06	1108	13	0.018	0.015	0.007	0.01	0.040	0.477
1998	362	0.17	2376	101	0.049	0.057	0.022	0.03	0.124	0.382
1999	85	0.28	563	39	0.079	0.049	0.025	0.02	0.134	0.506
2000	59	0.22	400	21	0.059	0.080	0.045	0.03	0.241	0.556
2001	194	0.21	1346	119	0.139	0.086	0.034	0.04	0.190	0.392
2002	121	0.22	817	62	0.084	0.165	0.075	0.07	0.410	0.454
2003	517	0.15	3483	155	0.047	0.037	0.014	0.02	0.082	0.387
2004	327	0.10	2210	68	0.036	0.043	0.016	0.02	0.091	0.376
2005	431	0.08	2718	72	0.029	0.040	0.015	0.02	0.086	0.377
2006	270	0.21	1776	106	0.064	0.092	0.035	0.04	0.201	0.384
2007	636	0.22	4415	240	0.058	0.094	0.033	0.05	0.190	0.348
2008	464	0.12	3024	160	0.047	0.088	0.031	0.04	0.182	0.358
2009	427	0.08	2755	46	0.017	0.025	0.010	0.01	0.055	0.397
2010	379	0.17	2525	98	0.042	0.079	0.029	0.04	0.167	0.372
2011	260	0.15	1548	53	0.037	0.081	0.033	0.04	0.183	0.408
2012	241	0.13	1453	47	0.047	0.070	0.032	0.03	0.176	0.459
2013	234	0.22	1576	90	0.055	0.066	0.028	0.03	0.156	0.429

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 2013.

Year	*n*	*Prop. Positive*	*Total Effort*	*Total Catch*	*Obs. Mean CPUE*	*GLMM Pred. Mean CPUE*	*SE*	*CV*	*LCL*	*UCL*
1993	334	0.07	2799	38	0.019	0.012	0.0036	0.31	0.006	0.022
1994	261	0.10	2139	37	0.019	0.016	0.0046	0.29	0.009	0.029
1995	486	0.12	4083	79	0.026	0.019	0.0052	0.27	0.011	0.034
1996	172	0.26	1396	91	0.087	0.057	0.0147	0.26	0.034	0.097
1997	68	0.26	554	18	0.038	0.026	0.0097	0.37	0.012	0.054
1998	306	0.19	2517	67	0.038	0.028	0.0072	0.26	0.017	0.047
1999	160	0.21	1223	43	0.044	0.032	0.0094	0.29	0.018	0.058
2000	385	0.08	3311	39	0.018	0.011	0.0030	0.28	0.006	0.019
2001	153	0.12	1279	27	0.031	0.024	0.0071	0.30	0.013	0.043
2002	449	0.26	3724	148	0.047	0.033	0.0080	0.24	0.020	0.055
2003	511	0.07	4303	40	0.011	0.008	0.0022	0.29	0.004	0.014
2004	366	0.10	2857	46	0.017	0.013	0.0036	0.28	0.007	0.023
2005	428	0.06	3522	41	0.013	0.011	0.0031	0.27	0.007	0.020
2006	217	0.05	1722	13	0.009	0.007	0.0028	0.38	0.003	0.015
2007	274	0.03	2164	12	0.006	0.006	0.0021	0.37	0.003	0.012
2008	355	0.03	2820	19	0.008	0.007	0.0025	0.36	0.003	0.014
2009	257	0.02	1887	9	0.007	0.005	0.0020	0.40	0.002	0.011
2010	354	0.06	2667	43	0.018	0.016	0.0044	0.27	0.009	0.028
2011	329	0.05	2605	30	0.013	0.010	0.0030	0.30	0.006	0.018
2012	520	0.06	4040	52	0.014	0.011	0.0030	0.27	0.007	0.019
2013	441	0.05	3592	32	0.010	0.009	0.0025	0.29	0.005	0.016

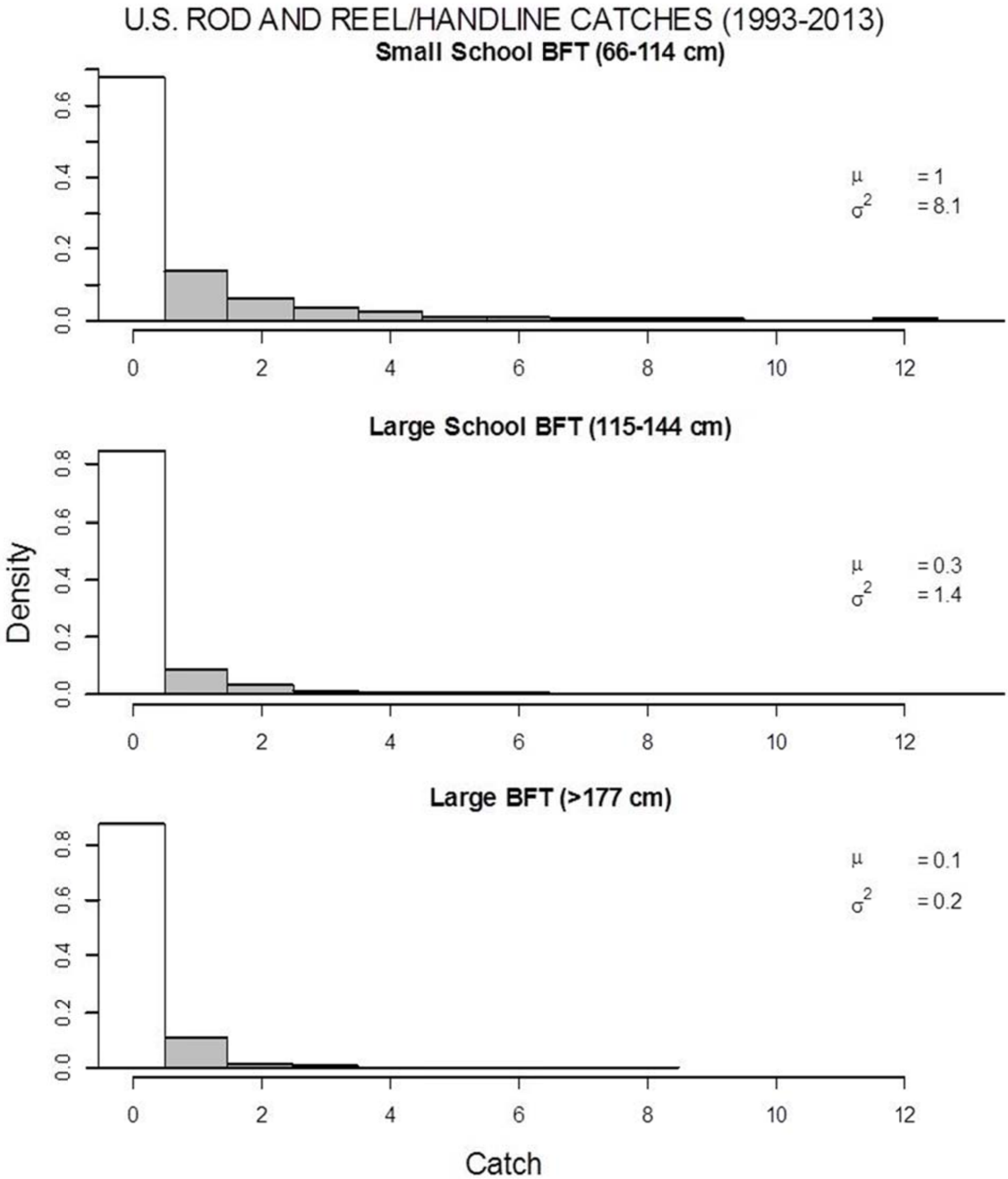

Figure 1. Observed distribution of three size classes of BFT caught in the U.S. rod and reel and handline fisheries. Zero catches are shown in white and positive catches are shaded, demonstrating the hurdle model approach (delta-Poisson) compared to the joint distribution (negative binomial). The observed mean (mu) and variance (sigma-squared) are also shown.

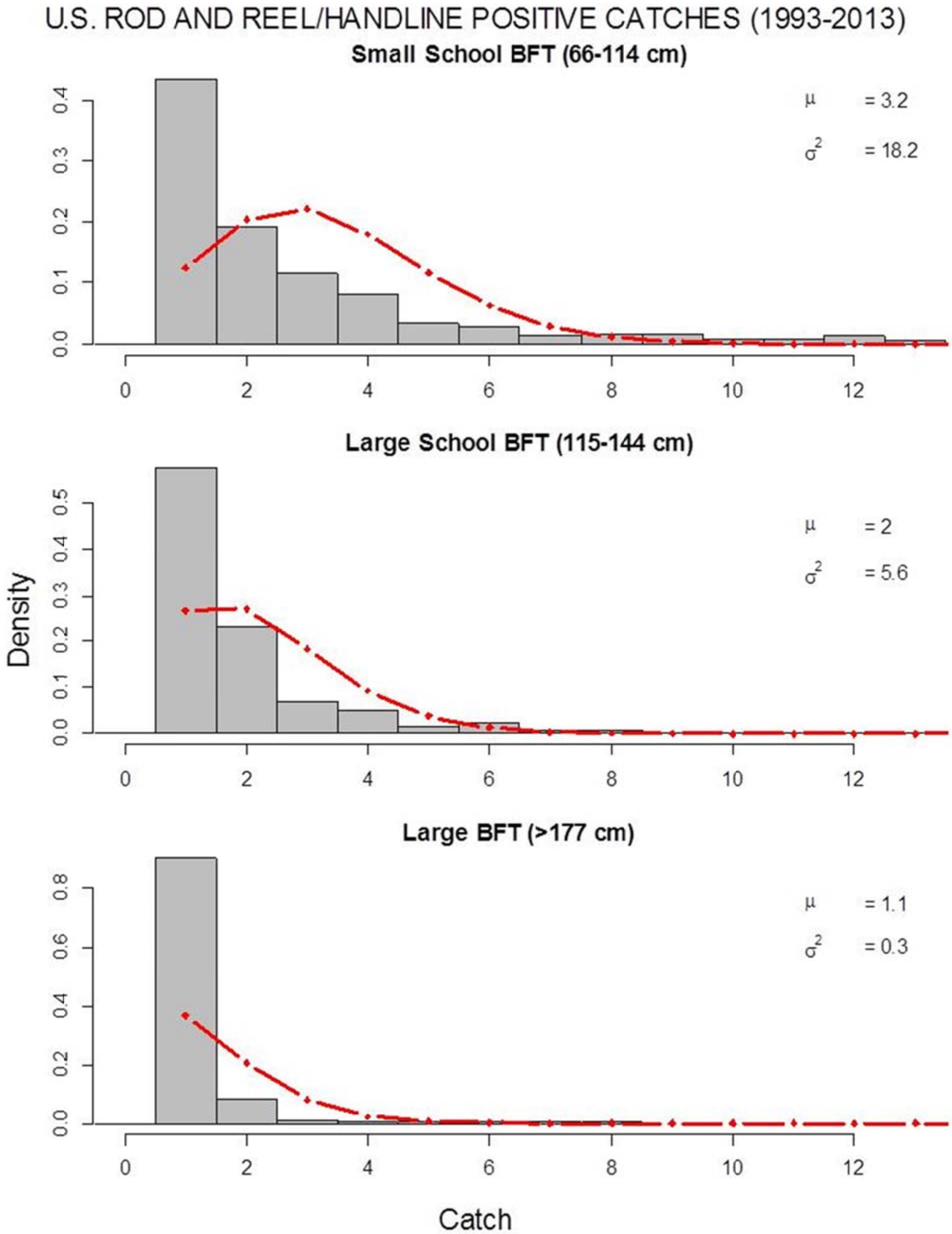

Figure 2. Truncated Poisson model fit (red) to the observed distributions of positive catches (shaded bars) of BFT. The observed mean (mu) and variance (sigma-squared) are also shown.

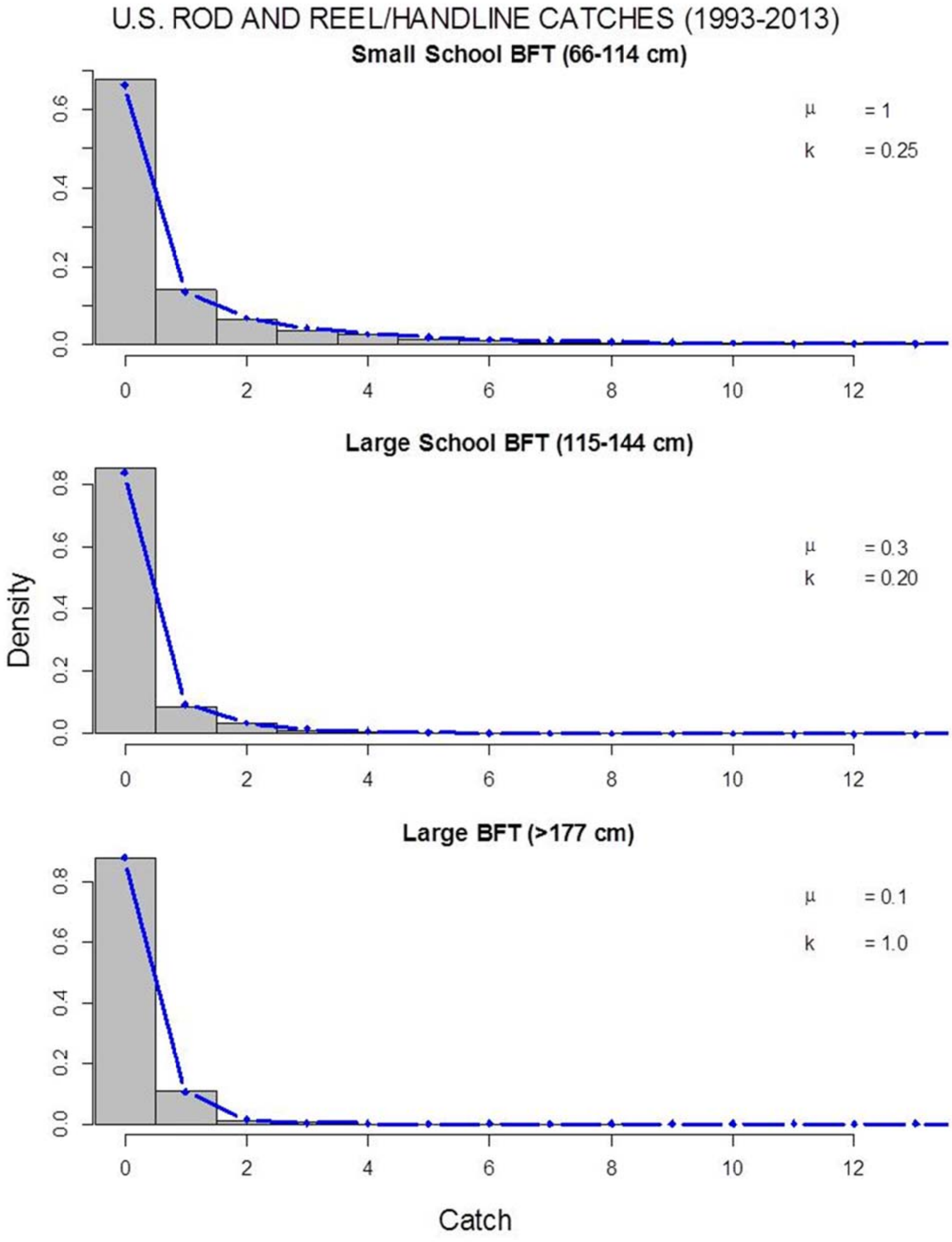

Figure 3. Negative binomial model fit (blue line) to the observed distributions of bluefin tuna catches (shaded bars). The observed mean (mu) and scaling parameter (k) for the fitted negative binomial are also shown.

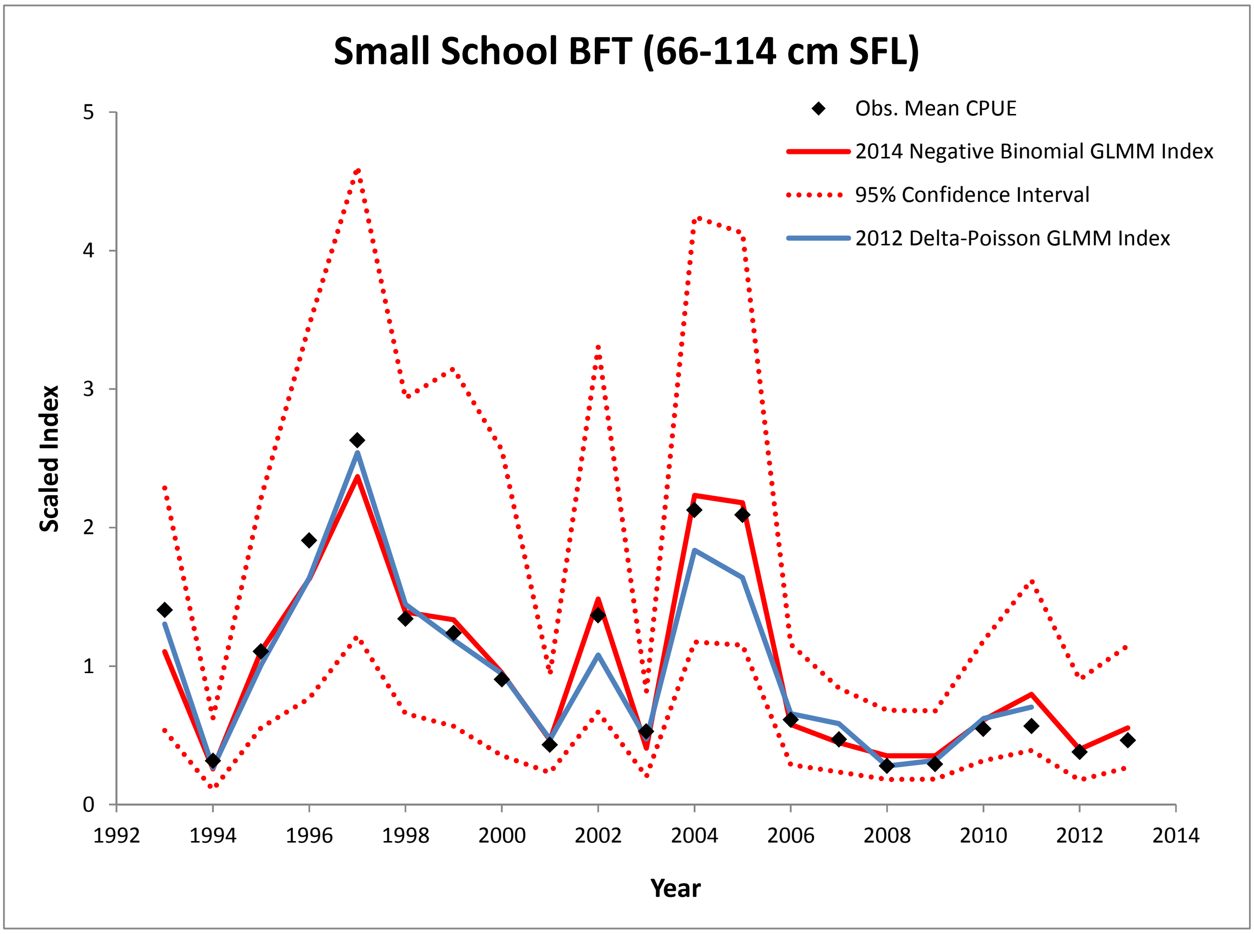

Figure 4. Comparison of small school bluefin tuna (SMSM) standardized time series with nominal catch rate data and previous delta-Poisson model.

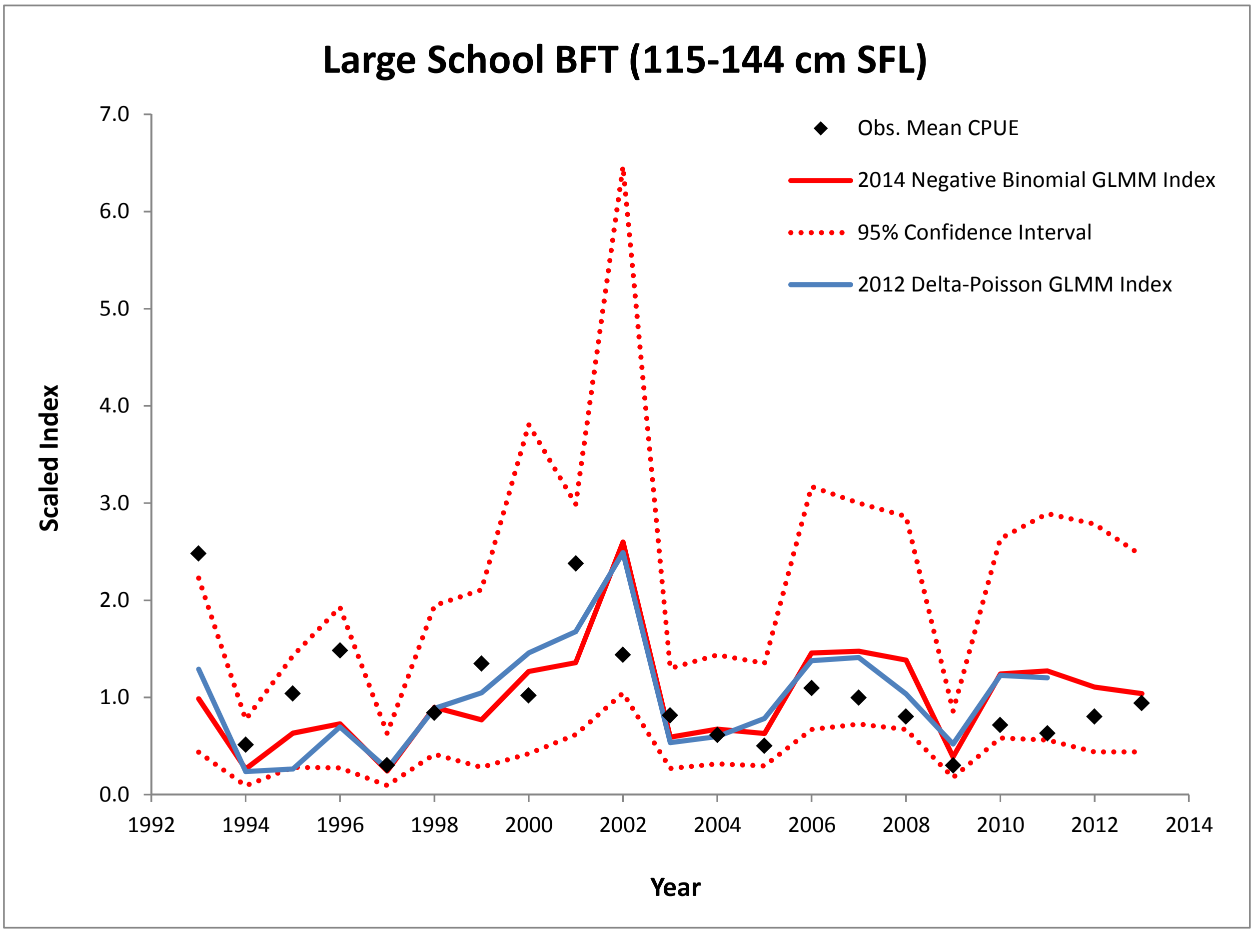

Figure 5. Comparison of large school bluefin tuna (LGSM) standardized time series with observed mean and previous delta-Poisson model.

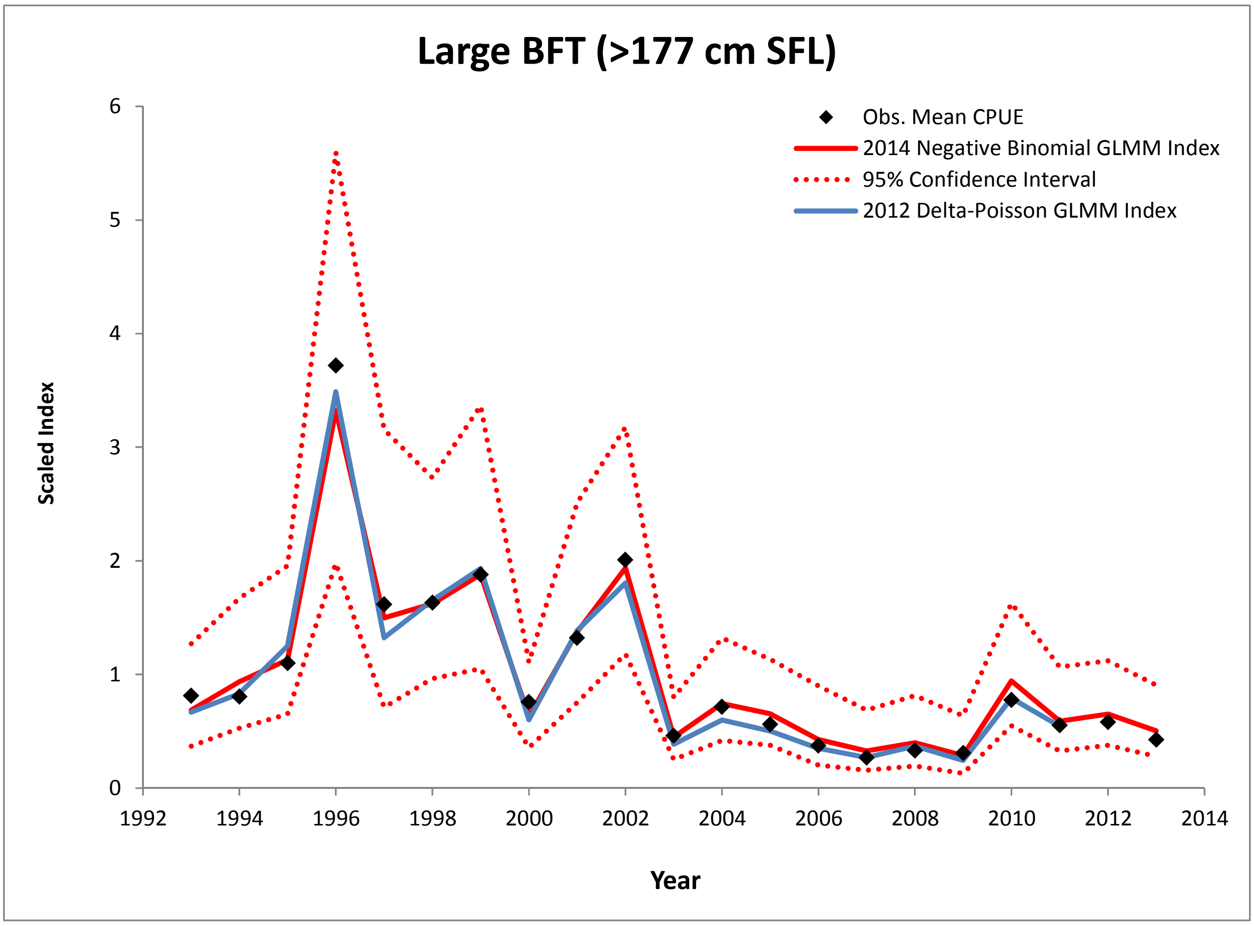

Figure 6. Comparison of large bluefin tuna (LGMD_LG) standardized time series with observed mean and previous delta-Poisson model.

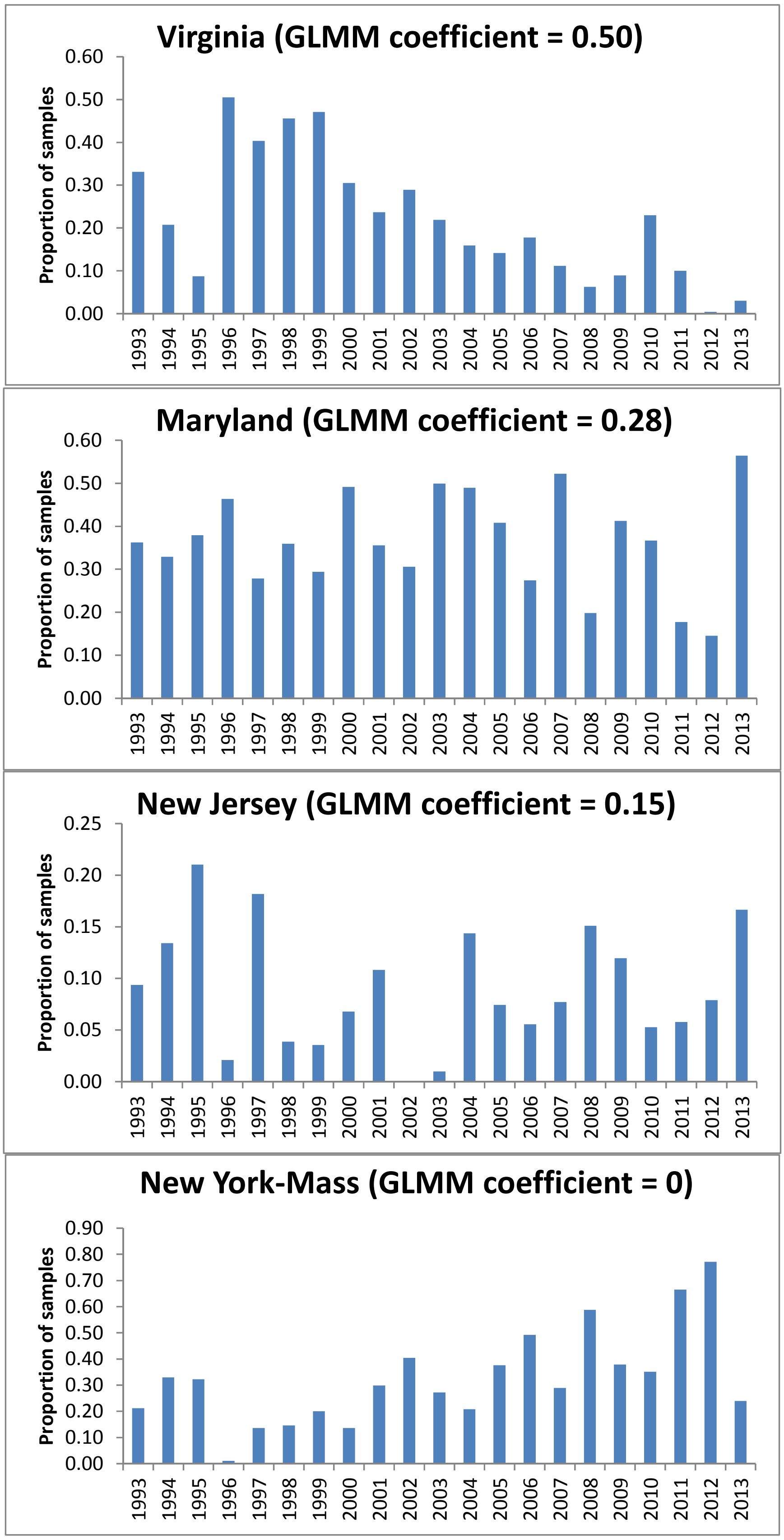

Figure 7. Distribution of Large Pelagic Survey fishing area samples for small school and large school bluefin tuna.