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THE UNITED STATES ROD AND REEL SMALLER SIZECLASS BLUEFIN TUNA (*THUNNUS THYNNUS*) INDICES OF RELATIVE ABUNDANCE; MAJOR REVISIONS AND RECOMMENDATIONS[1]

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SUMMARY

This report documents the revisions of the U.S. Large Pelagics Survey indices of relative abundance of juvenile and sub-adult bluefin tuna. The review consisted of a series of online workshops which produced several recommendations, including: 1) modeling of a single sizeclass (66 to144 cm straight fork length fish selected), 2) expanded spatial coverage of the samples included, 3) removed state as a fixed factor in the standardization model, 4) integrated sea surface temperature as a covariate to better model dynamic annual spatial distributions of the fish, and added vessel type to account for differences in the fishery related to shifts in angler composition over time. Workshop dialogues pointed to a substantive shift in the spatial distribution of the fish, as well as the fishery away from targeting smaller fish toward larger sizeclasses. The changes require modifications to the partial catch-at-age for the virtual population analysis index. Similarly, for Stock Synthesis, the index can be applied to the rod and reel small fish fleet, with an appropriate minimum size of retention fixed at 66 cm. The revised index showed lower inter-annual variability and greater precision than the separate sizeclass indices, and is recommended to replace the two in the stock assessment.

RÉSUMÉ

Ce rapport documente les révisions des indices d'abondance relative de thons rouges juvéniles et subadultes réalisées dans la cadre de la prospection des États-Unis sur les grands pélagiques. L'examen a consisté en une série d'ateliers en ligne qui ont donné lieu à plusieurs recommandations, notamment : 1) modélisation d'une seule classe de taille (sélection de poissons d'une longueur droite à la fourche de 66 à 144 cm), 2) élargissement de la couverture spatiale des échantillons inclus, 3) suppression de l'état comme facteur fixe dans le modèle de standardisation, 4) intégration de la température de surface de la mer comme covariable pour mieux modéliser les distributions spatiales annuelles dynamiques des poissons, et ajout du type de navire pour tenir compte des différences dans la pêcherie liées aux changements dans la composition des pêcheurs au fil du temps. Les dialogues de l'atelier ont mis en évidence un changement substantiel dans la distribution spatiale du poisson, ainsi que l'abandon de la pêche ciblant les petits poissons au profit des grandes classes de taille. Les changements nécessitent des modifications de la prise par âge partielle pour l'indice d'analyse de la population virtuelle. De même, pour Stock Synthesis, l'indice peut être appliqué à la flottille de petits poissons pêchés à la canne et au moulinet, avec une taille minimale de rétention appropriée fixée à 66 cm. L'indice révisé a montré une plus faible variabilité inter-annuelle et une plus grande précision que les indices séparés de classe de taille, et il est recommandé de remplacer les deux dans l'évaluation du stock.

RESUMEN

Este informe documenta las revisiones de los índices de abundancia relativa de atún rojo juvenil y subadulto en el marco de la prospección estadounidense de grandes pelágicos. La revisión consistió en una serie de talleres en línea que produjeron varias recomendaciones, entre ellas 1) modelación de una sola clase de talla (peces seleccionados de 66 a 144 cm de longitud recta a la horquilla); 2) ampliación de la cobertura espacial de las muestras incluidas; 3) eliminación

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del estado como factor fijo en el modelo de estandarización, 4) integración de la temperatura de la superficie del mar como covariable para modelar mejor las distribuciones espaciales anuales dinámicas de los peces, y adición del tipo de buque para tener en cuenta las diferencias en la pesquería relacionadas con los cambios en la composición de los pescadores a lo largo del tiempo. Los diálogos de los talleres apuntaron a un cambio sustancial en la distribución espacial de los peces, así como a que la pesquería se aleja de los peces más pequeños para dirigirse a los de mayor tamaño. Los cambios requieren modificaciones en la captura parcial por edad para el índice de análisis de la población virtual. Del mismo modo, para stock synthesis, el índice puede aplicarse a la flota de caña y carrete que pesca peces pequeños, con una talla mínima de retención adecuada fijada en 66 cm. El índice revisado ha mostrado una menor variabilidad interanual y una mayor precisión que los índices de clase de talla por separado, por lo que se recomienda sustituir ambos en la evaluación de stock.

KEYWORDS

Atlantic Bluefin Tuna, Catch/effort, Sport Fishing, Fishery Statistics

1. Introduction

The Standing Committee of Research and Statistics, Bluefin Tuna Working Group (Group) prioritized a review of the indices of relative abundance used in the stock assessments and management strategy evaluation of Atlantic bluefin tuna (BFT). A technical workgroup was tasked with reviewing the data, standardization methods, and results of current practices for creating the various indices. As an initial task, the workgroup selected the evaluation of indices in the West Atlantic, beginning with those expected to measure juvenile relative abundance or the Gulf of Mexico spawning stock. Further, any revised indices proposed for update to the assessment models required completion by the end of the first quarter of this calendar year. To accomplish as much as possible, multiple co-leads were appointed with expertise in the following surveys, the U.S. Large Pelagic Survey (recreational and commercial rod and reel fisheries), the U.S. Gulf of Mexico commercial logbook program (commercial longlines), the Mexico Longline Observer Program (commercial longlines), the Gulf of St. Lawrence acoustic herring survey (fishery-independent survey that also detects BFT), the Japan longline data (commercial longlines), and the Gulf of Mexico larval survey (fishery independent ichthyoplankton survey). This report documents the review of the U.S. Large Pelagics Survey (LPS) indices of relative abundance of juvenile and sub-adult BFT (the U.S. rod and reel 66-114 cm, and the U.S. rod and reel 115-144cm indices), proposes several important revisions to the methodologies, and provides a recommended index for use in future assessments and other population modeling applications.

Rod and reel fishers target BFT off the northeast coast of the United States, and productive fisheries have existed for many decades. The U.S. National Marine Fisheries Service monitors the BFT fishery through the LPS, a survey of private anglers, charter boats, and commercial rod and reel fishers who have just completed fishing trips directed at large pelagic species.

The U.S. implemented numerous new fishery regulations beginning in 1992, which included a minimum size limit (66 cm SFL), variable angler and trip bag limits, permit category requirements, and seasonal closures. Regulations were structured by size class (class designations were restructured in 1992) and permit category, separated by commercial and recreational (including charter boat) fisheries. The size classes were defined as:

Young school BFT	< 26 in (66 cm) SFL
School	26-44 in (66-114 cm) SFL
Large school	45-56 in (115-144 cm) SFL
Small medium	57-69 in (145-177 cm) SFL
Large medium	70-76 in (178-195 cm) SFL
Giant	> 76 in (195 cm) SFL

Appendices A and B detail the size-bag limit regulations by permit category. **Figure 1** plots the changes in bag limits over time. The applicable fishery closures and catch limits, allocated by regulatory categories Angling (non-commercial) and General (commercial), are documented by Ortiz *et al.* 1999 and Brown 2011.

To provide a detailed review of the survey, and better integrate the knowledge of fishery participants, a series of public workshops were held. These included dialogues between fishers, scientists, and managers. The first workshop (held online and hosted by the Gulf of Maine Research Institute on February 5, 2021) created a forum for presentation of current survey protocols, discussions of the current states of the fisheries, observations of fishers about BFT distribution and catches, fishing practices over time, and relative abundance by regional fishery. The materials from that workshop; including agenda, presentations, and panelist bios; are accessible online here: https://drive.google.com/drive/folders/1eQ0BvYzplZRb-A6NsKSwtTh2O5TZKCMX.

The second online workshop (February 11, 2021) provided a technical review of the database compilation, filters, and index standardization methodologies. Here, NOAA scientists provided real-time summary statistics and indices of BFT relative abundance generated from the survey database. This data exploration allowed scientists and fishers to ask questions related to the data and its use in the assessment, as well as review fishery information at finer spatial levels that better aligned with the scale of regional fleet observations. A follow-up discussion (online Feb 18, 2021) synthesized the conclusions from the previous workshop and produced a final review of proposed changes to the smaller size class BFT indices of relative abundance.

2. Methods

A major component of the LPS is the dockside intercept survey and biological sampling program. This intercept survey is conducted at public fishing access sites that are frequently used by offshore anglers, covering the U.S. seaboard from Virginia to Maine, inclusive. A comprehensive documentation of the survey protocols, including copies of the survey datasheets and an example questionnaire, are posted online here: https://www.fisheries.noaa.gov/recreational-fishing-data/types-recreational-fishing-surveys#large-pelagics-survey. In addition, the data collected since 2002 are accessible for free download. Data collected includes both kept and discarded fish and both are summed together to provide catch rate data.

The following changes to the index standardization methodologies were implemented, based on the recommendations made at the survey review workshops:

1. Joint modeling of school and large school size class BFT counts combined. Previous indices for school and large school used the same subset of data to produce two indices. As a general best practice, indices of abundance should represent independent samples. A combined index is also expected to be more robust to changes in joint-sizeclass bag limit regulations, since in some years joint bag limits were imposed, while in other years the two size classes were allotted separate bag limits. In general, the effect of regulations on catch rates is not well-understood. However, the subject is explored further in later sections based on analysis of catch distributions over time, proportion retained to discarded, and catch-rates by bag limit. A higher frequency of occurrence resulted in higher information content in the standardization, as well as improved model fit by the negative binomial distribution.

2. The second major change involved the spatial-temporal domain of survey samples used for monitoring relative abundance. Previous efforts (e.g., Turner and Brown 1998, Ortiz 1999, Brown 2011, Lauretta and Brown 2016) modeled samples collected during June 1 to September 30 from Virginia to Massachusetts. Many people indicated that fishing for these size classes occurred well into October and November, with recommendations that all survey months should be included in the fishery index (i.e. June 1 to October 31). Similarly, fishers and expert biologists detailed changes in distributions of the schools, indicating movement away from historical fishery hotspots in the south (e.g., Virginia fisheries) to large schools observed in central-Atlantic states (e.g., New Jersey) and northern areas (e.g., the Gulf of Maine which was traditionally outside the sample domain). The potential for range shifts drew into question the treatment of state as a fixed factor in the standardization generalized linear model. The work group discussed this issue in detail and concluded that a better model would account for sea temperature and prey availability as major factors of tuna relative abundance. Although indices of prey biomass are not available to include in the standardization, measurements of in-situ sea surface temperature (SST) are available for most data in the survey. The proposed spatial treatment changes included expanding the samples to include all states in the survey (Virginia to Maine), removing state as a fixed effect (evaluate as a random effect, if possible), and modeling sea surface temperature as a covariate for the range of samples between 62 and 84 degrees Fahrenheit SST. Spatial (2D)

kernel density estimates of effort and catch were produced to assess ranges of samples and catch observations over time.

3. It was recommended to exclude general category commercial trips, or alternatively model permit category (or equivalent) as a factor of catch rates, since targeting and regulations vary by vessel category. In addition, fishers noted a distinct shift in both permit type and targeting of bluefin in the Gulf of Maine (**Figure 2**). High availability of large fish inshore resulted in a noticeable shift in effort to the larger size classes of bluefin. Further, many noted an increase in effort for large BFT, following the popularity of a fishery-based TV series that demonstrated how to fish for and land giant tuna in the region. To best avoid bias in targeting, the indices were based on only those trips identified as primarily targeting small (66 to 145 cm SFL) size class bluefin. These trips were assumed to be most representative of the fishing effort directed at small BFT. It was noted that other targeted trips may land smaller bluefin in addition to the larger size classes or other species, which are included in the total catch estimates, regardless of the filter used for the indices. Nonetheless, a potential shift in effort away from smaller size classes toward the largest fish (large-medium and giant) warrants further discussion by the SCRS Bluefin Species Group on modeling catch-at-size and catch-at-age in the assessment.

4. The fourth change was to remove the years 1993 and 1994 which contained relatively low sample sizes after the data filter was applied.

A summary of data treatments for generating the U.S. rod and reel index of smaller size class (66 to 144 cm SFL) BFT follows, highlighting those that depart from previous analyses:

- Catch metric = count of school + large school bluefin landed or released (previously by size class)
- Effort metric = vessel fishing hours
- Trips excluded that fished < 1 or > 24 hours
- Year > 1994 (previously 1992, truncated due to sample size)
- School and large-school bluefin primary target (previously included secondary target trips)
- Fishing season = "open"
- Rod and reel gear exclusively
- Vessel type = private or charter vessels, excluded headboats
- Sea surface temperature measured > 62 and < 84 degrees F

A negative binomial generalized linear model (count of bluefin response variable, log-e link function, effort offset) (library "MASS" in R, Vernables and Ripley 2002) (GLM) produced annual estimated marginal mean (library "emmeans" in R, Lenth 2020) catch rates averaged across month, SST (by 2 degree F bin), and vessel type factors. The model formulation follows.

$$\log_e(BFT) = \beta_0 + \beta_1 \cdot Year + \beta_2 \cdot Month + \beta_3 \cdot SST + \beta_4 \cdot Vessel\ type + \log_e(fishing\ hours) + \varepsilon$$

Where
β_0 = linear model intercept
β_i = set of model factor coefficients for levels of factor i
Year is modeled as a calendar year factor
Month is calendar month factor, June to October, inclusive
SST is a discrete factor by 2 degree Fahrenheit bins
Vessel type is the factor for vessel registration type (private or charter vessels only)
Fishing hours is time spent angling
ε is negative binomial distributed residual error

Model residuals, factor coefficients, factor leave-one-out analysis, influence plots (library "influ" in R, Bentley et al. 2012), and predicted relationship between SST and catches are presented.

3. Results and Discussion

The survey recorded thousands of fishing trips targeting large pelagic species per year since 1983 (**Table 1, Figure 3**). Documentation of bluefin catches by the current size class categories began in 1992. **Table 2** provides a list of size class categories, approximated age based on the current growth model (Ailloud et al. 2017), and the sector associated with each fishery. In general, the survey intercepted several hundred up to a thousand bluefin targeted trips per year (**Table 1**). The number of trips targeting larger bluefin (large medium or giant) increased considerably over the last decade, coincident with a decline in trips targeting smaller bluefin size classes (school or large school) (**Table 1, Figure 3**). An opposite trend was observed the decade prior. A thousand or more bluefin were counted during most years (**Table 1, Figure 4**), and school, large-school, and giant size classes comprised the highest proportions by numbers of fish (**Figure 5**).

Spatial distribution of fishing locations showed consistently high density near the Chesapeake and Delaware bay areas over the time series, and an increased density of trips in the Gulf of Maine since 2007 (**Figure 6**). The spatial distribution of school/large-school bluefin trips also expanded similarly (**Figure 7**). The spatial density of school/large-school catches varied across years, with high aggregation of catches in some years versus broadly dispersed in others (**Figure 8**). In general, catches appeared more broadly dispersed during 2009 to 2016 compared to other periods. These observations supported the expansion of the spatial extent of the samples to use the full sampling domain, and remove the state stratification and fixed model factor estimation. An alternative approach could use state as a random effect, but in either case the kernel density analysis showed a shift in catch locations.

We recommend future work evaluate additional spatial temporal modeling approaches (e.g. Campbell 2015, Thorson et al. 2016, Gruss et al. 2019). However, fisher observations primarily attributed fish availability to prey abundance. In general, the fish aggregate on the prey schools, and the fishing effort aggregates on the fish. Given the lack of detailed spatial information on prey distributions and density, it is not feasible to standardize by habitat or biomass proportion per area at this time. Extrapolating catch rates densities to areas delineated by state jurisdiction or sea surface temperature is not recommended, given the scale of the range of the tuna, and the aggregating behavior in optimal foraging areas.

The frequency of occurrence of school or large-school BFT on targeted trips ranged between approximately 30% and 65%, with exception of 2015 when the lowest rate was observed at 21% (**Figure 9**). The spatial distribution of targeted trips in 2015 was noticeably different than the catch densities (**Figures 7 and 8**). No obvious truncation of catch-per-trip (i.e. counts of landed and released fish) was apparent over time that would indicate missing count observations above the annual bag limits (**Figure 10**). Catch rate distributions were relatively similar across bag limits (**Figure 11**), and without obvious trend in proportion kept versus discarded (**Figure 12**).

The negative binomial GLM consistently converged across runs, both when all factors were included and in the leave-one-out sensitivities (**Table 3**). Retained factors included year, month, SST (by 2 degree F bin), and vessel type (**Tables 3 and 4**). Residual patterns were symmetrical with a mode centered near zero, consistent across the data series (**Figure 13**). The estimated coefficients by factor level are listed in **Table 4** and plotted in **Figure 14.** Model predictions included, highest mean catch rates during October followed by June, optimal SST between 72 and 76 degrees (**Figure 15**), and charter vessels more efficient than private ones. Model predicted effects of SST matched the observed distribution of catches, particularly at lower SST (**Figure 15**). The higher mean catch rates at the upper tail could be a result of suitable habitat available at depth, even when the SST is higher than optimal. Influence plots (Bentley et al. 2012) demonstrate the influence and overall effect of adding each model factor on the standardized index values relative to the nominal series (**Figure 16**).

The standardized index for small size class (66 to 144 cm SFL) bluefin tuna in the West Atlantic is listed in **Table 5** and plotted in **Figure 17**. The revised combined sizeclass index is recommended to replace the two individual indices (66-114 cm and 115-144 cm SFL) used prior for the stock assessment. The changes will require modifications to the partial catch-at-age for the virtual population analysis, and it is recommended that the two previous fleet partial catches be combined for the new index. Similarly, for Stock Synthesis, the index can be applied to the rod and reel small fish fleet, with an appropriate minimum size of retention fixed at 66 cm. The revised index showed lower inter-annual variability and greater precision than the previous two separate indices (**Figure 18)**. The overall move in the fishery from angling to general category is fairly substantive in the Gulf of Maine (**Figure 2**), and a shift in targeting to larger bluefin (>177cm SFL) likely resulted in change in fleet selectivity in the recent decade. This subject warrants further discussion by the SCRS Bluefin Species Group on modeling the fleet catch-at-size and catch-at-age in the assessment.

The standardization model was fitted to data from 1995 to 2019. The data series was then updated to 2020, and those results are reflected in the index tables and model summaries.

4. Acknowledgements

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Table 1. U.S. Large Pelagic Survey effort in number of trip intercepts, and counts of bluefin tuna by sizeclass.

Year	Total Intercepts	Large BFT Trips	Small BFT Trips	Young School BFT	School BFT	Large School BFT	Small Med BFT	Large Med BFT	Giant BFT	Unk BFT	School/Large School BFT
1980	1896	0	0	0	0	0	0	0	0	4837	0
1981	777	0	0	0	0	**0**	0	0	0	1250	0
1982	606	0	0	0	0	0	0	0	0	2600	0
1983	2438	0	0	0	0	0	0	0	0	2813	0
1984	3404	2291	718	0	0	0	0	0	0	4543	0
1985	5646	506	549	0	0	0	0	0	0	1854	0
1986	5071	538	646	0	0	0	0	0	0	2440	140
1987	5919	691	503	0	0	0	0	0	85	0	2394
1988	3632	540	446	0	0	0	0	0	130	553	1074
1989	5074	834	658	0	0	0	0	0	123	0	2874
1990	6200	1056	685	0	0	0	0	0	97	0	3816
1991	5774	999	624	0	0	0	0	0	124	0	5365
1992	5373	1184	599	184	2225	65	11	9	97	0	155
1993	4564	475	239	360	1958	832	71	178	72	0	0
1994	4187	372	106	153	456	210	86	35	62	0	0
1995	5109	626	266	661	1810	296	291	49	96	0	0
1996	1493	208	230	64	690	159	58	57	58	0	0
1997	3510	430	368	156	2236	237	75	17	82	0	0
1998	3095	371	408	594	809	201	51	34	80	0	0
1999	1700	241	110	130	427	176	60	20	62	0	0
2000	2779	497	111	76	387	140	87	14	63	8	0
2001	2477	208	368	124	558	650	144	27	33	23	0
2002	2788	437	146	189	756	438	70	13	184	0	0
2003	3810	550	568	14	683	327	96	11	58	0	0
2004	4143	352	459	1901	2224	400	51	49	53	0	0
2005	3613	351	346	307	2555	320	52	16	48	0	0
2006	3139	241	173	118	375	257	66	2	18	2	0
2007	4155	336	702	86	664	401	102	8	15	20	0
2008	3747	386	649	59	589	705	77	21	15	44	0
2009	3972	364	516	53	349	182	298	17	20	3	0
2010	3827	434	535	70	593	346	57	58	54	0	0
2011	3899	433	543	44	525	130	46	30	51	2	0
2012	4238	661	419	23	330	137	66	32	65	8	0
2013	3580	574	278	15	390	282	100	15	39	5	0
2014	3506	463	236	10	231	100	61	7	56	17	0
2015	4184	705	362	29	418	54	84	32	119	2	0
2016	3962	841	231	90	217	199	58	63	130	20	0
2017	3644	768	196	38	497	121	62	60	215	12	0
2018	3851	874	167	12	430	16	51	24	264	9	0
2019	4022	746	243	71	393	147	53	65	238	5	0

Table 2. Summary of U.S. bluefin tuna size categorizations by approximate age classes estimated from the current growth model, and the sector associated with each fishery.

		SFL			RWT			SFL			RWT			Previous	Fishing
Index	~Age	Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	index	Sector
		(cm)	(cm)	(cm)	(kg)	(kg)	(kg)	(in.)	(in.)	(in.)	(lbs)	(lbs)	(lbs)	exists?	
66 to 114 cm	2	50	71	91	3	8	16	20	28	36	7	17	34	Yes	Recreational
	3	68	91	114	7	16	29	27	36	45	16	35	65		
115 to 144 cm	4	87	112	137	14	28	50	34	44	54	31	62	110	Yes	Recreational
	5	105	133	160	24	45	77	41	52	63	52	100	170		
145 to 176 cm	6	122	152	182	36	66	110	48	60	72	79	146	243	No	Recreational
>177 cm	7	138	170	202	50	90	147	54	67	79	111	199	324	Yes	Commercial
	8	151	185	219	66	116	186	60	73	86	145	256	411		
	9	164	199	235	82	142	226	64	78	92	181	314	498		
	10	174	211	248	98	168	264	69	83	98	215	370	583		
	11	183	222	260	113	192	300	72	87	102	248	423	662		
	12	191	230	270	126	214	333	75	91	106	279	472	734		
	13	197	238	278	139	233	362	78	94	109	306	515	798		
	14	203	244	285	150	251	388	80	96	112	330	553	855		
	15	207	249	290	159	266	410	82	98	114	350	585	903		
	16	211	253	295	167	278	428	83	100	116	368	613	945		

Table 3. Model factor leave-one-out analysis results, showing the change in model parameter degrees of freedom (Df), model residual deviance, and Akaike Information Criterion when each factor is removed.

Trip type	Df	Deviance	AIC	deltaAIC
Full		4165	14104	0
drop Year	17	4350	14256	**152**
drop Month	4	4340	14272	**168**
drop SST	10	4214	14134	**30**
drop Boat type	1	4193	14130	**26**
drop Trip type	1	4169	14107	3
drop Tournament	1	4169	14106	2

Table 4. Generalized linear model estimated coefficients and z-test.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.88	0.20	-4.37	0.0000
fYear1996	0.09	0.17	0.55	0.5820
fYear1997	0.47	0.15	3.11	0.0019
fYear1998	-0.26	0.15	-1.69	0.0920
fYear1999	-0.31	0.21	-1.51	0.1312
fYear2000	-0.09	0.21	-0.42	0.6734
fYear2001	-0.49	0.16	-3.03	0.0024
fYear2002	-0.13	0.19	-0.72	0.4713
fYear2003	-0.64	0.14	-4.46	0.0000
fYear2004	0.27	0.15	1.81	0.0703
fYear2005	0.25	0.15	1.61	0.1076
fYear2006	-0.54	0.20	-2.74	0.0062
fYear2007	-0.57	0.14	-4.00	0.0001
fYear2008	-0.59	0.15	-3.98	0.0001
fYear2009	-0.80	0.17	-4.83	0.0000
fYear2010	-0.35	0.15	-2.27	0.0231
fYear2011	-0.47	0.16	-2.93	0.0034
fYear2012	-0.38	0.17	-2.21	0.0271
fYear2013	0.07	0.17	0.43	0.6639
fYear2014	-0.42	0.19	-2.25	0.0244
fYear2015	-1.15	0.18	-6.39	0.0000
fYear2016	-0.75	0.18	-4.07	0.0000
fYear2017	-0.27	0.18	-1.48	0.1400
fYear2018	-0.59	0.20	-3.00	0.0027
fYear2019	0.02	0.17	0.12	0.9062
fMonth7	-0.69	0.07	-9.48	< 2e-16
fMonth8	-0.92	0.08	-11.49	< 2e-16
fMonth9	-0.53	0.09	-5.98	0.0000
fMonth10	0.54	0.14	3.79	0.0002
fSST64	0.28	0.17	1.63	0.1043
fSST66	0.31	0.17	1.81	0.0696
fSST68	0.37	0.17	2.24	0.0254
fSST70	0.51	0.17	3.00	0.0027
fSST72	0.75	0.17	4.50	0.0000
fSST74	0.85	0.16	5.18	0.0000
fSST76	0.81	0.17	4.83	0.0000
fSST78	0.65	0.17	3.74	0.0002
fSST80	0.31	0.20	1.53	0.1270
fSST82	0.28	0.33	0.86	0.3907
fBoatPR	-0.81	0.05	-17.56	< 2e-16

Table 5. Summary statistics and standardized index of relative abundance of bluefin tuna (66-144 cm SFL) in the West Atlantic.

Year	n	# of BFT	Success	Obs_CPUE	Index	Index_CV	Lower_95%CL	Upper_95%CL
1995	214	452	0.41	1.27	1.24	0.12	0.97	1.58
1996	213	517	0.67	1.61	1.33	0.12	1.04	1.69
1997	314	883	0.61	1.94	1.97	0.10	1.62	2.41
1998	348	497	0.53	0.97	0.95	0.10	0.78	1.16
1999	102	203	0.64	1.26	0.89	0.17	0.63	1.25
2000	93	196	0.48	1.81	1.14	0.18	0.80	1.62
2001	280	324	0.37	0.88	0.76	0.11	0.61	0.95
2002	139	264	0.57	1.22	1.07	0.15	0.80	1.44
2003	532	542	0.33	0.75	0.66	0.09	0.55	0.78
2004	383	1169	0.65	2.05	1.61	0.09	1.34	1.93
2005	277	742	0.61	1.84	1.57	0.11	1.27	1.93
2006	137	160	0.39	0.72	0.72	0.16	0.52	0.99
2007	562	515	0.40	0.55	0.70	0.09	0.59	0.83
2008	458	448	0.42	0.61	0.68	0.10	0.56	0.82
2009	319	205	0.31	0.42	0.55	0.12	0.44	0.70
2010	341	399	0.41	0.72	0.87	0.10	0.71	1.07
2011	297	323	0.34	0.81	0.77	0.12	0.61	0.97
2012	224	211	0.35	0.70	0.85	0.13	0.66	1.10
2013	214	332	0.44	0.93	1.31	0.13	1.02	1.68
2014	162	153	0.42	0.60	0.80	0.15	0.60	1.08
2015	254	143	0.21	0.32	0.39	0.14	0.30	0.52
2016	191	152	0.41	0.49	0.58	0.15	0.43	0.77
2017	160	301	0.41	0.99	0.95	0.14	0.71	1.26
2018	147	140	0.43	0.53	0.69	0.16	0.50	0.94
2019	192	314	0.54	1.02	1.26	0.13	0.97	1.62
2020	142	275	0.42	1.19	1.70	0.15	1.27	2.28

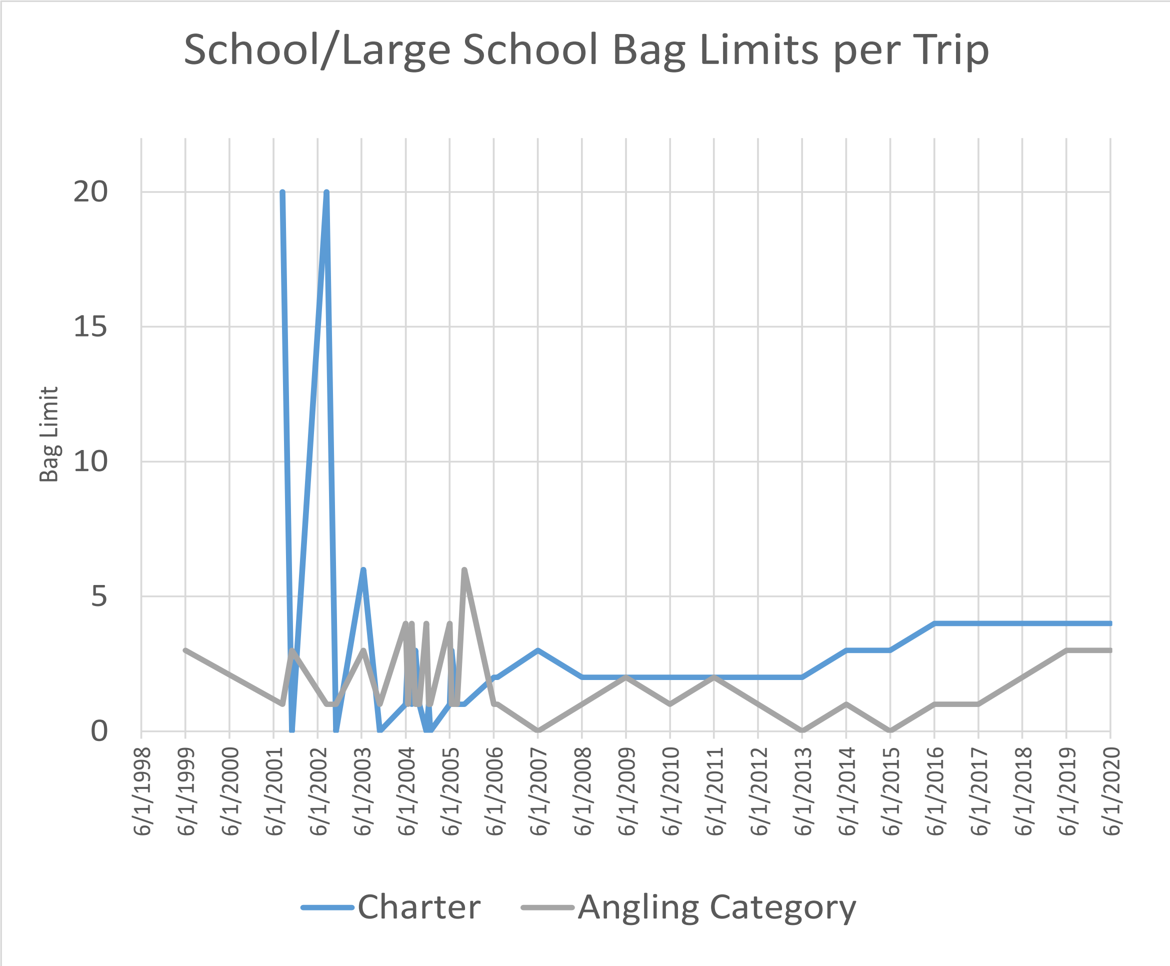

Figure 1. Bag limits of school and large-school bluefin tuna landed by U.S. angling permitted fishers.

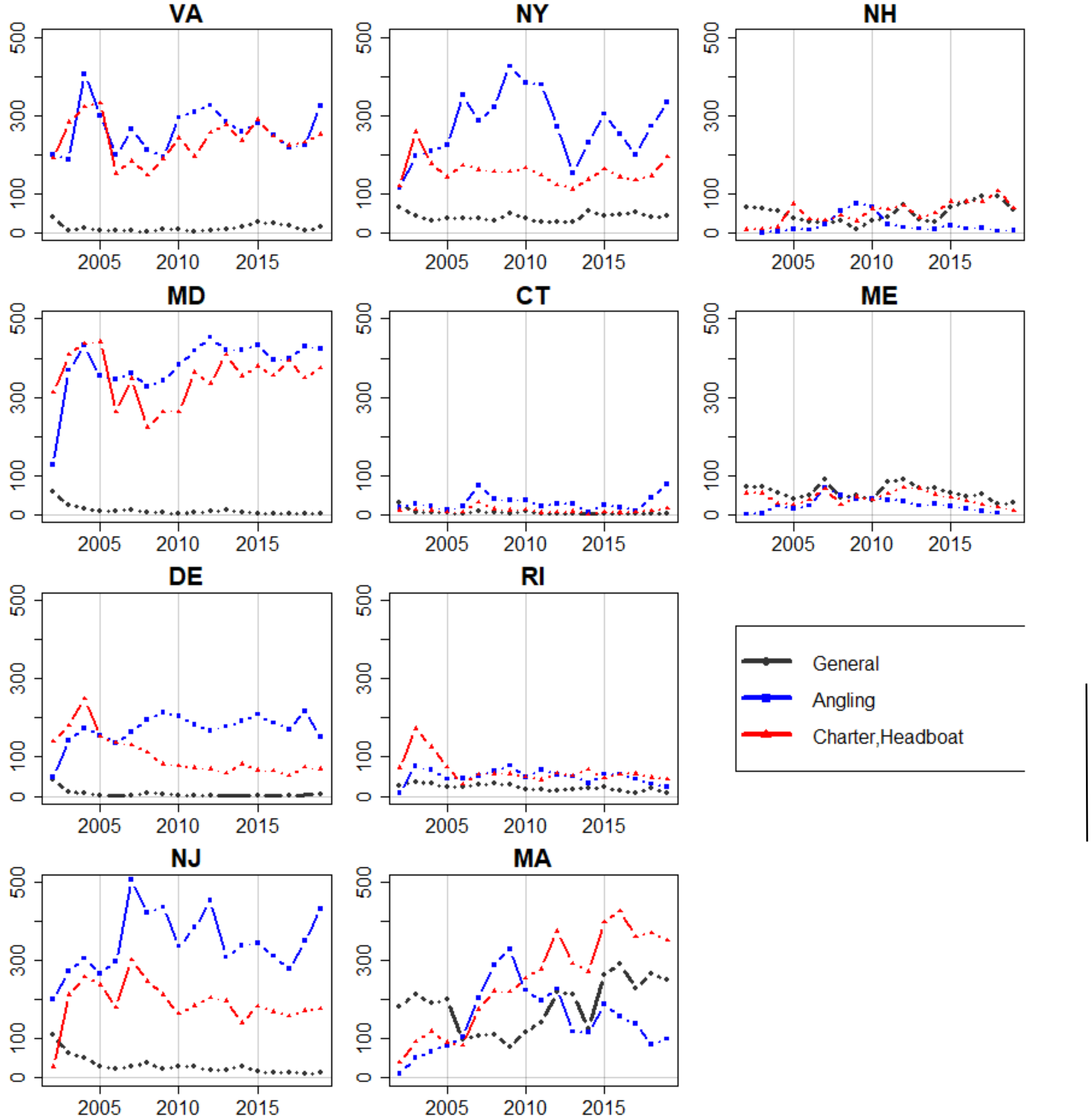

Figure 2. Total numbers of Large Pelagic Survey trip intercepts by state and permit type.

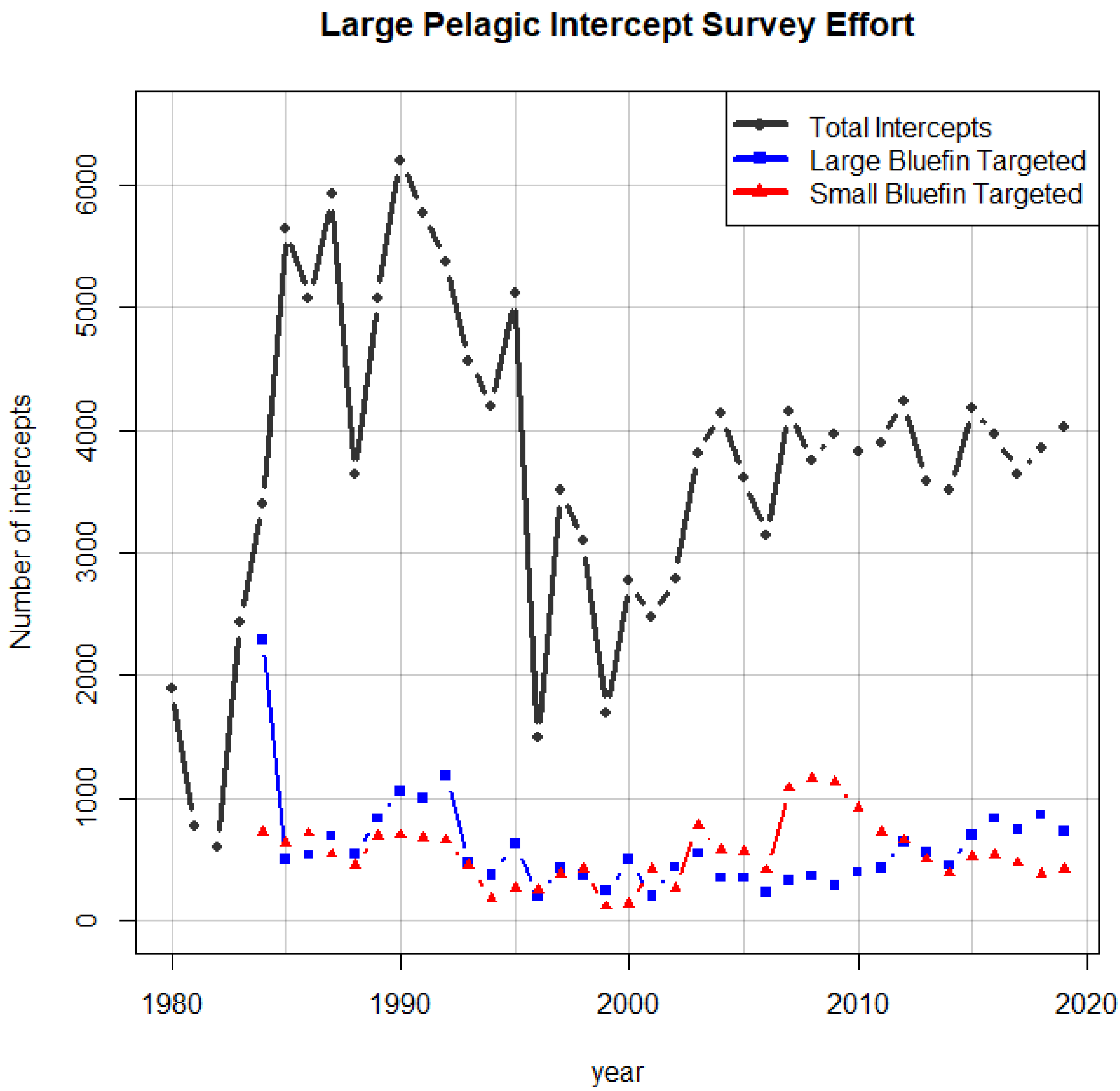

Figure 3. Number of survey intercepts per year, shown separately for total trips, large bluefin targeted trips, and small bluefin targeted trips.

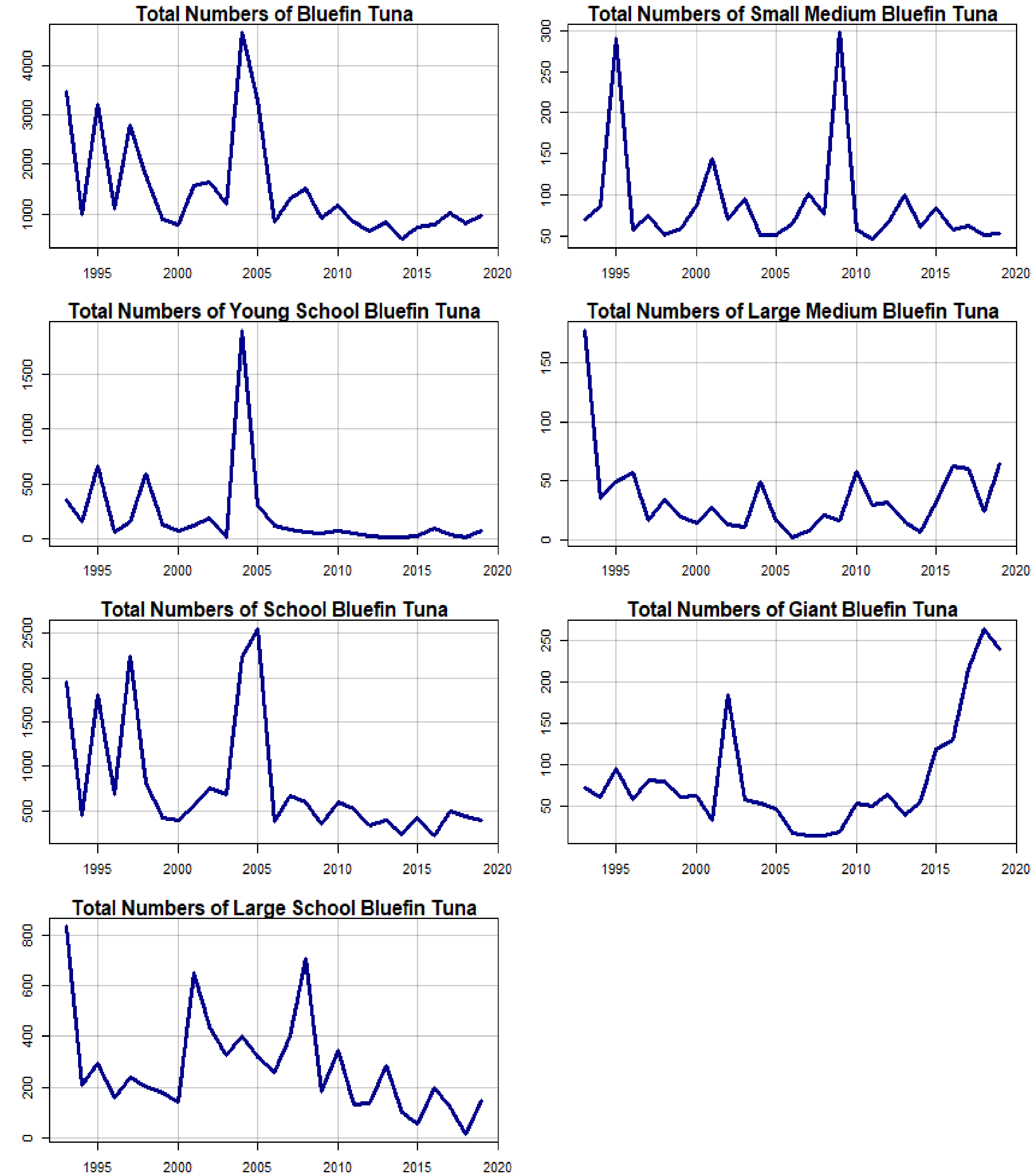

Figure 4. Total counts of bluefin tuna by year and sizeclass.

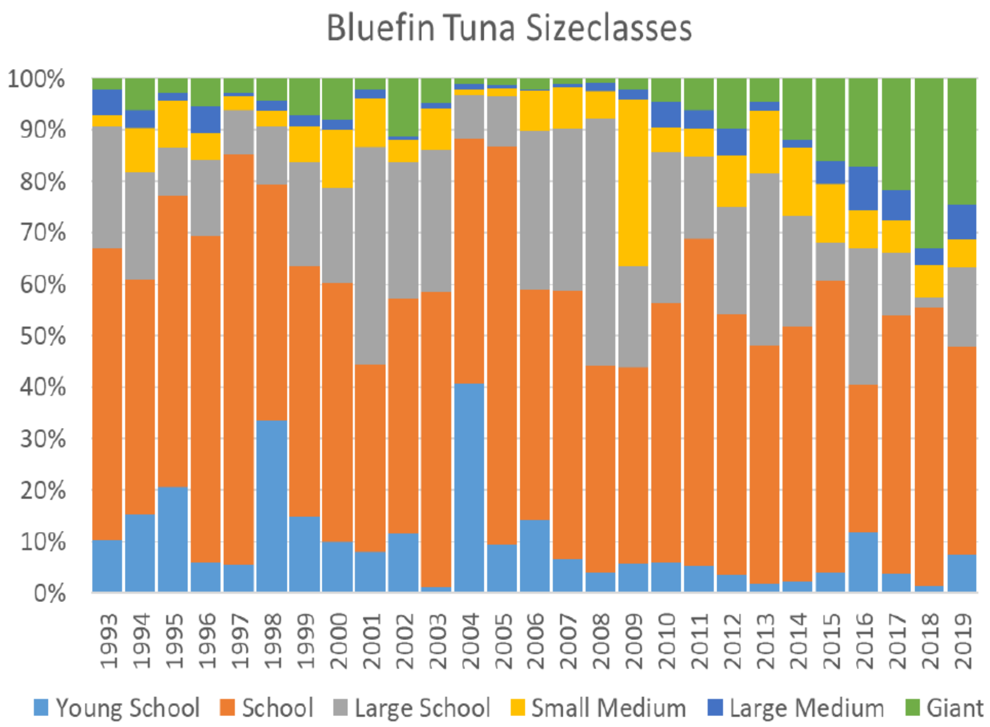

Figure 5. Percent composition by sizeclass of bluefin tuna counts in the Large Pelagics Survey.

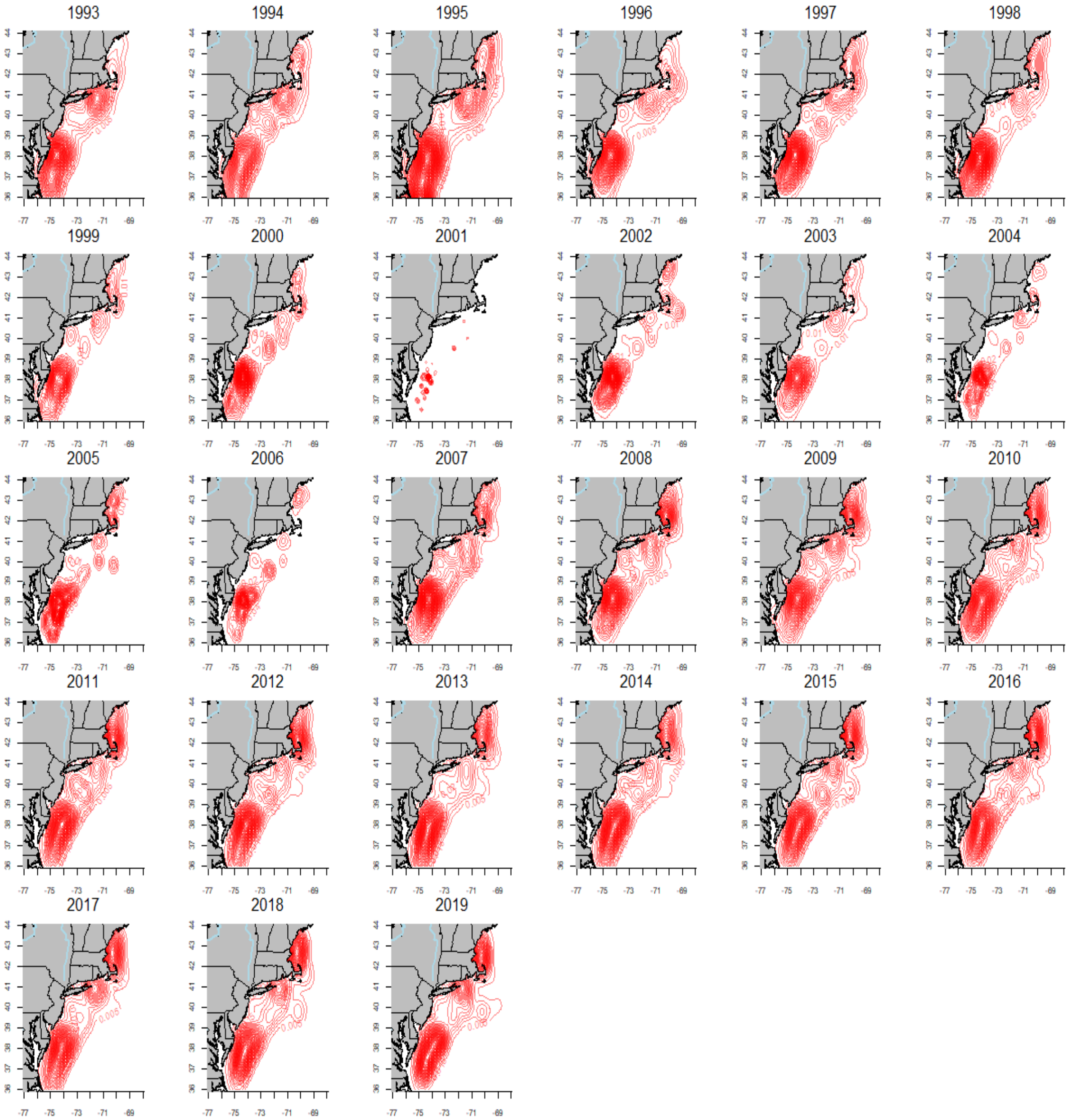

Figure 6. Spatial kernel density estimates of trip fishing locations, estimated across all trips in the Large Pelagics Intercept Survey.

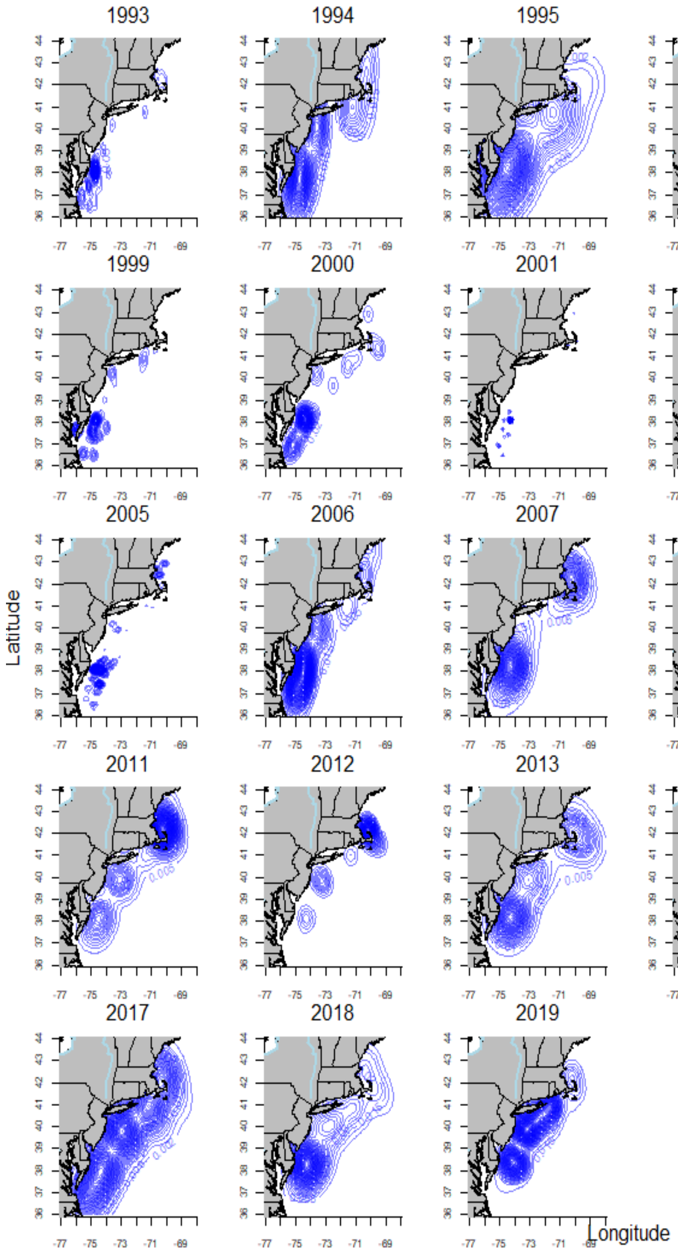

Figure 7. Spatial kernel density estimates of small bluefin targeted trip fishing locations.

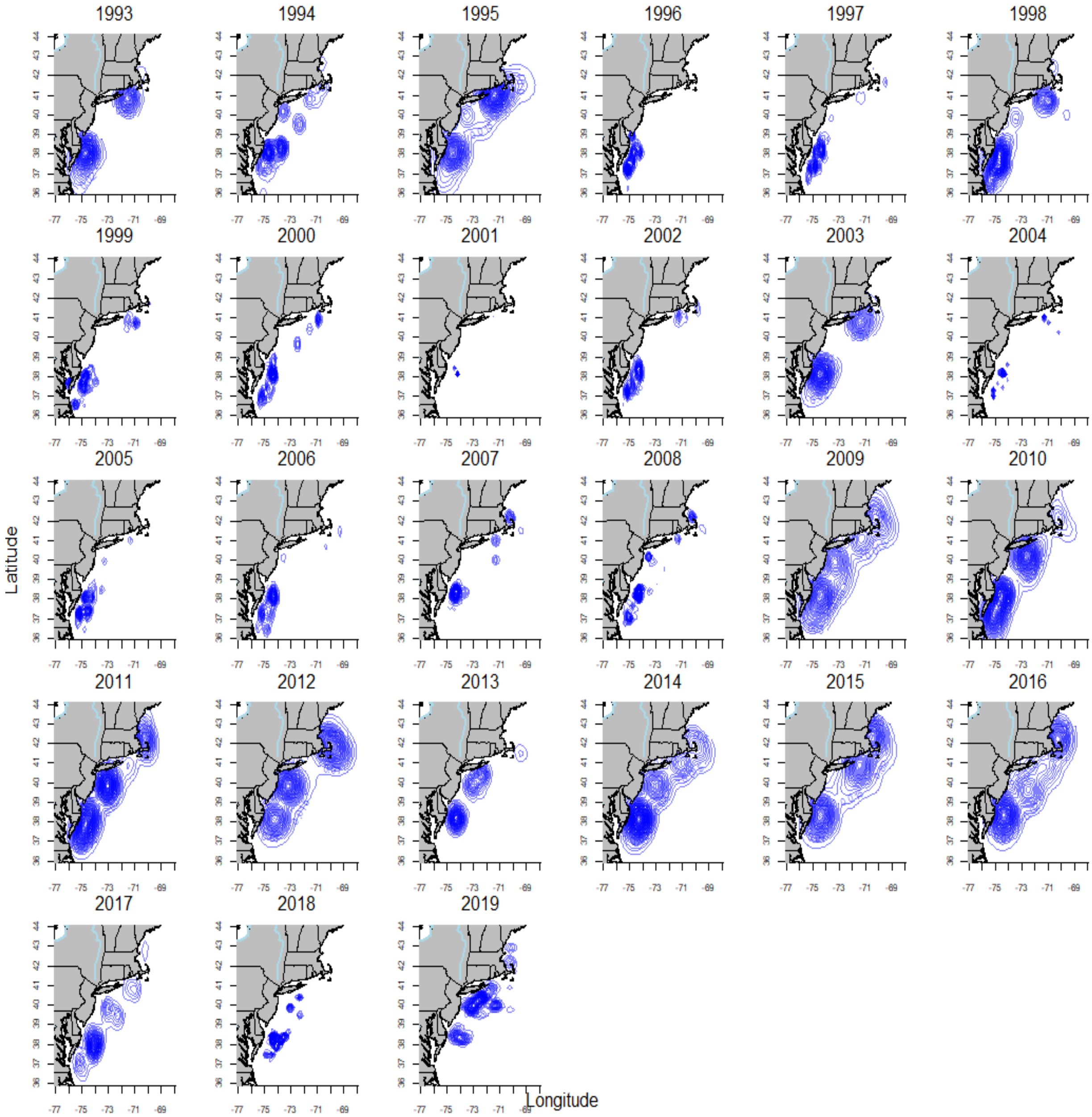

Figure 8. Spatial kernel density estimates of school and large-school bluefin tuna counts, estimated across all trips in the Large Pelagics Intercept Survey.

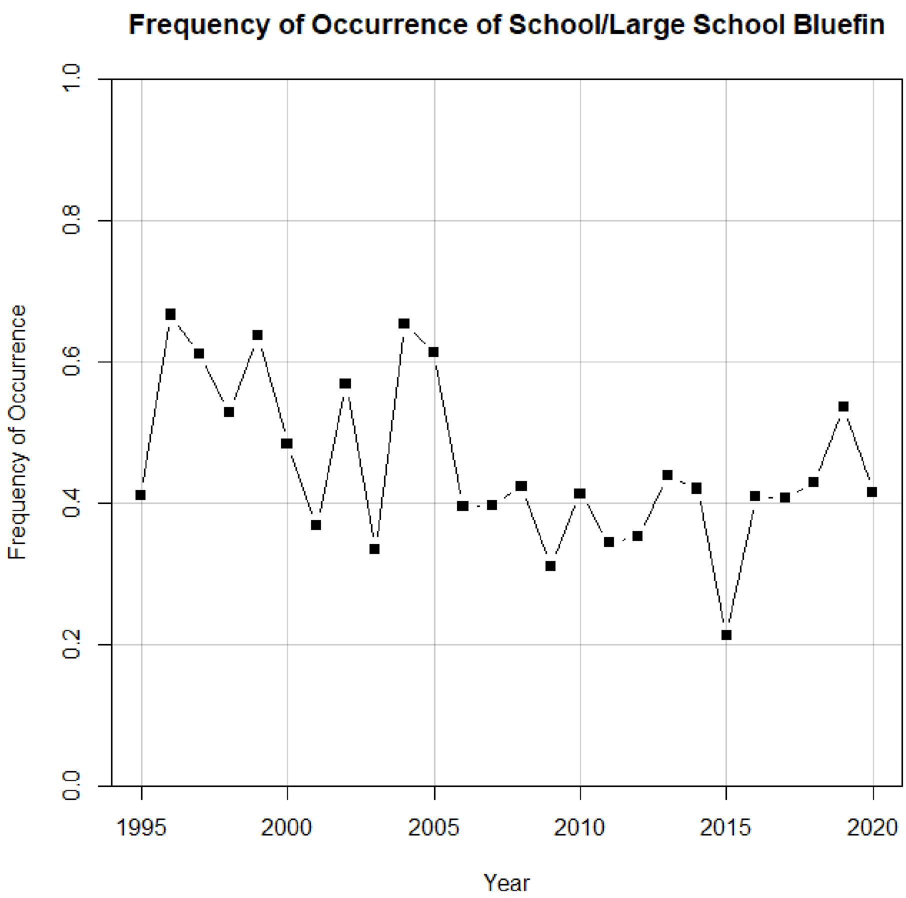

Figure 9. Frequency of occurrence of school or large-school bluefin tuna on targeted trips.

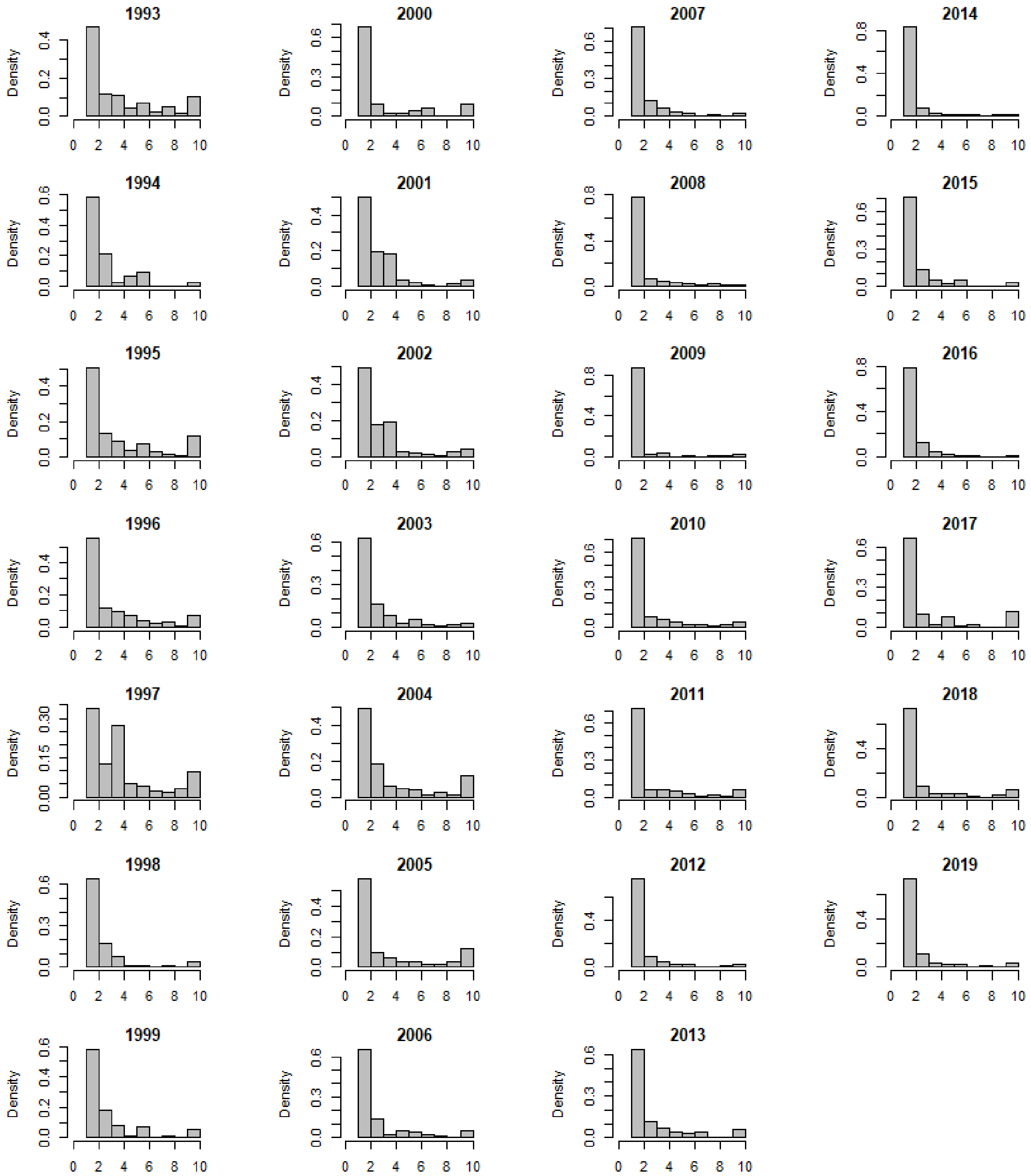

Figure 10. Positive catch distributions of school/large-school bluefin tuna on targeted trips documented in the Large Pelagics Intercept Survey.

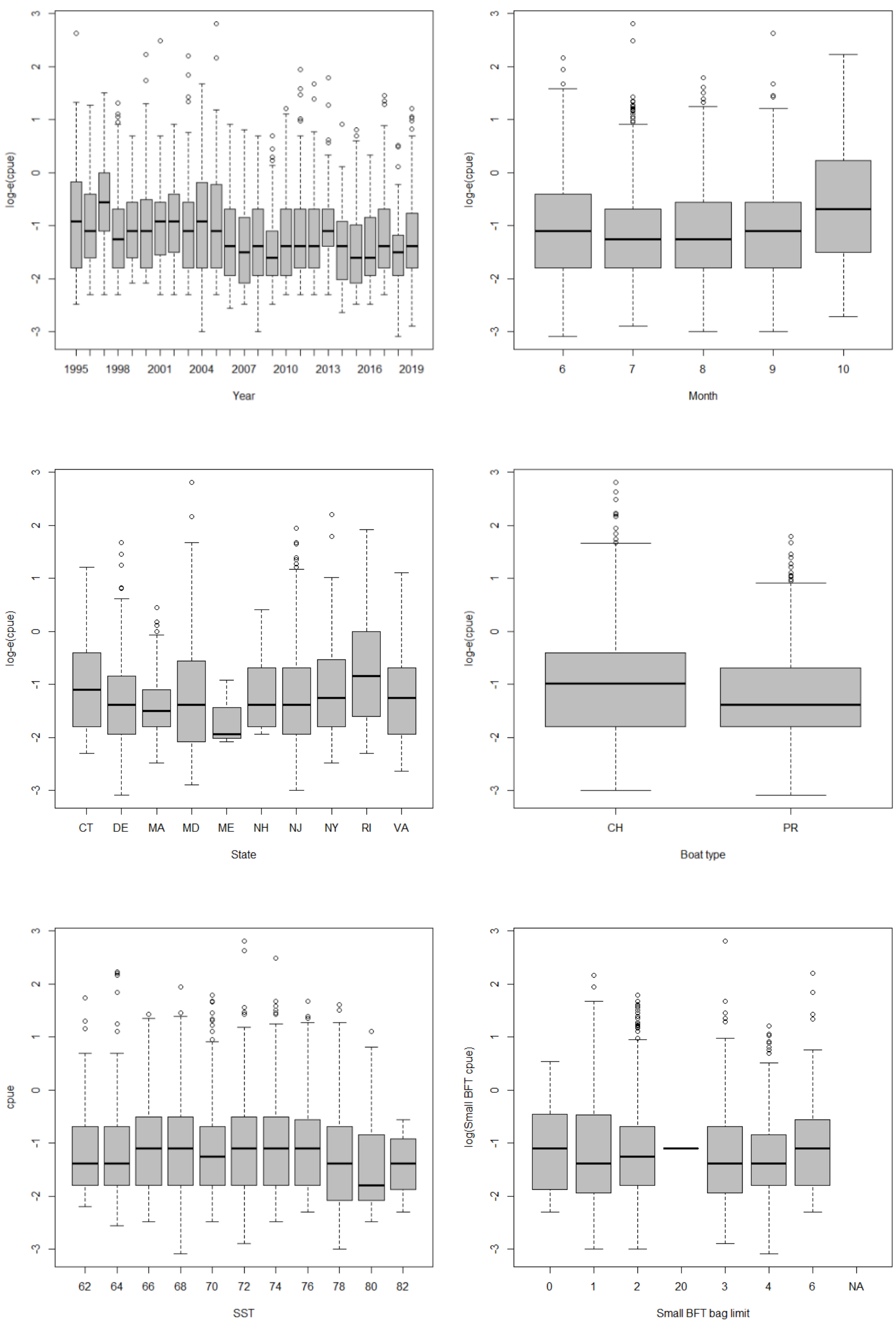

Figure 11. Catch rate percentiles (black line =median, gray box =60th, error bars = 95th) across years, months, states, vessel type, sea surface temperatures, and bag limits.

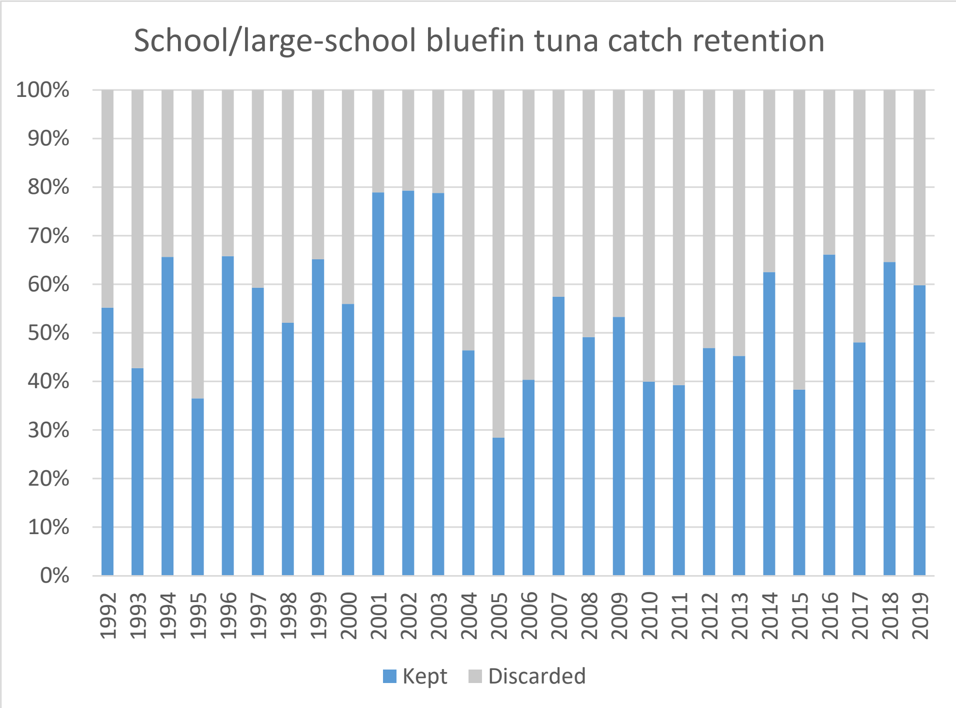

Figure 12. Proportion kept versus discarded school and large school bluefin tuna in the U.S. rod and reel fishery.

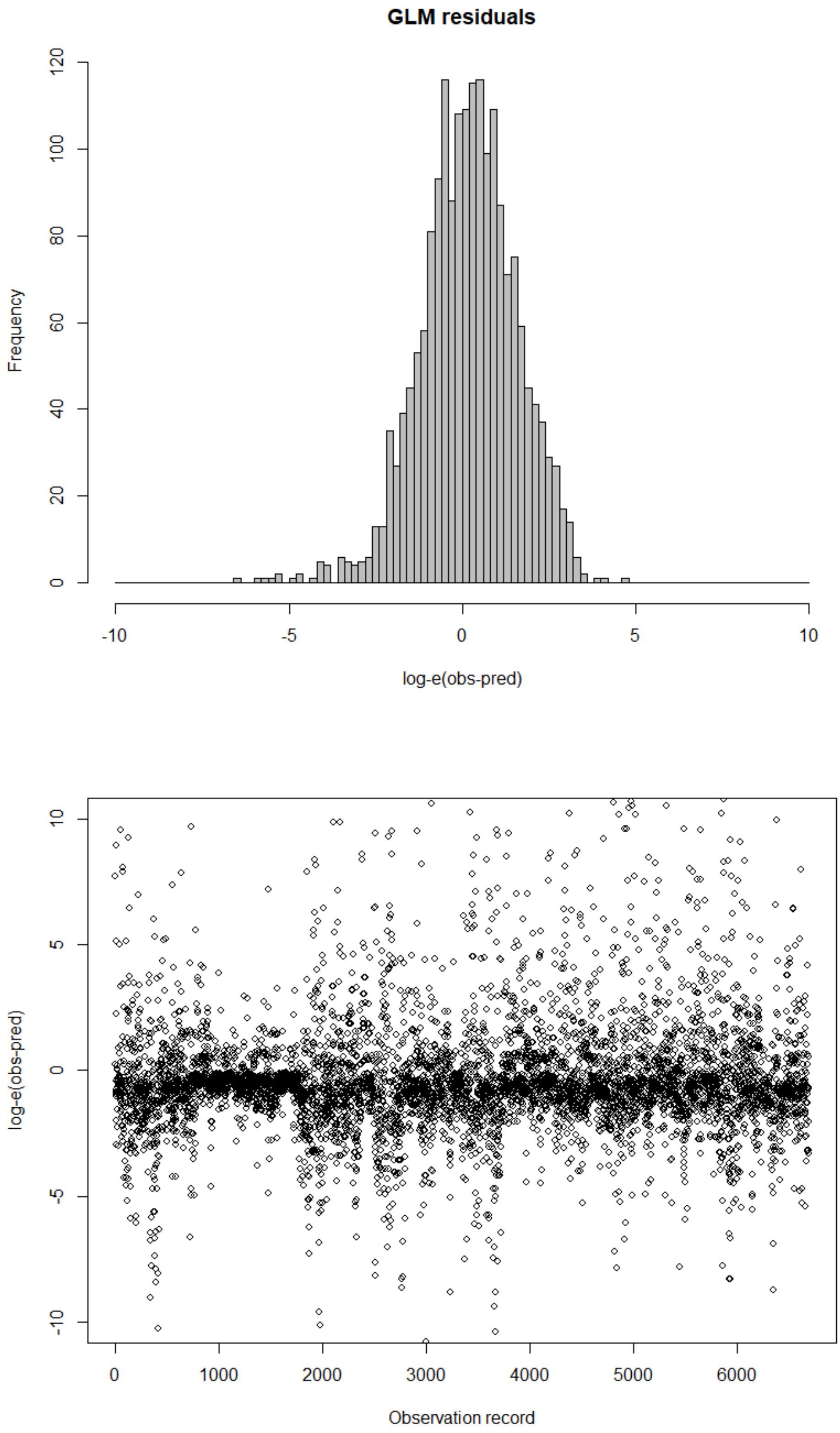

Figure 13. Generalized linear model residuals. Upper panel shows the distribution of the log-residuals, and the lower panel shows the residual error plotted by datapoint.

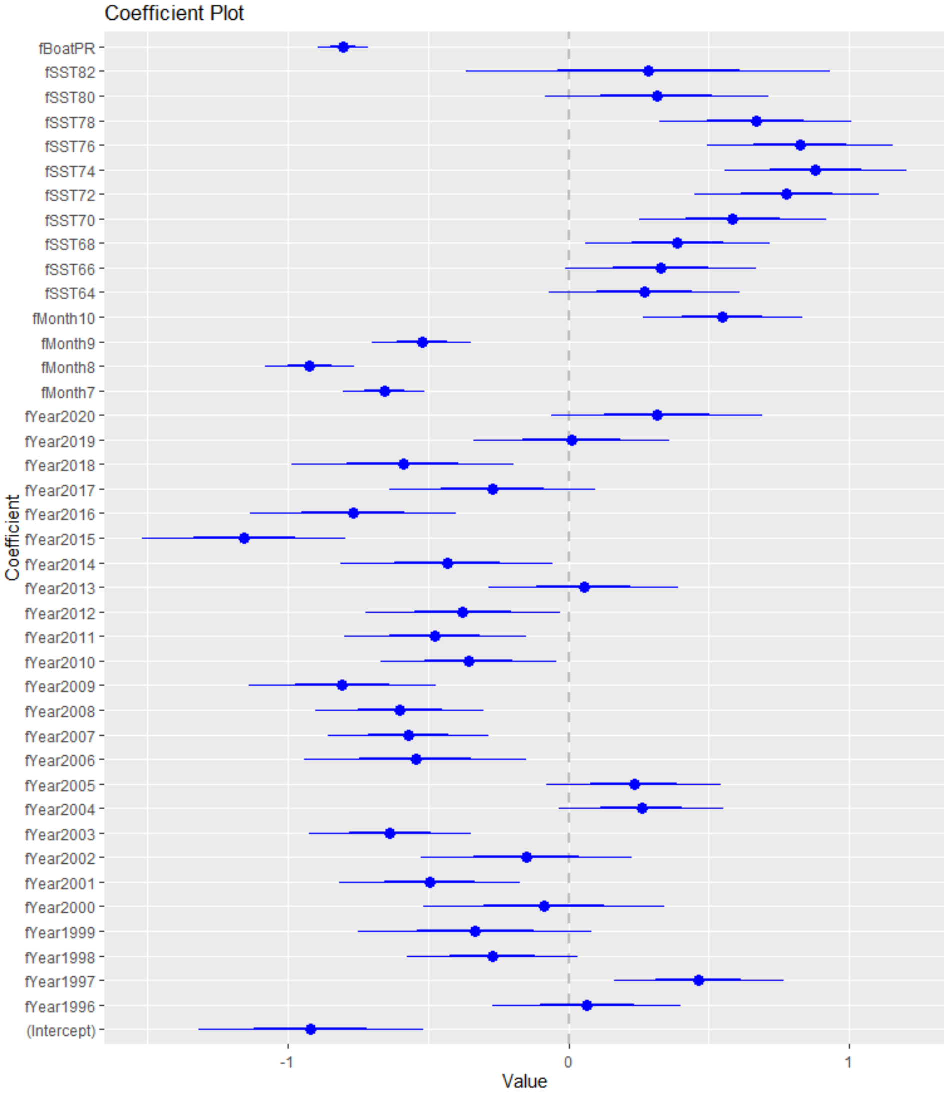

Figure 14. Generalized linear model estimated coefficients by factor level.

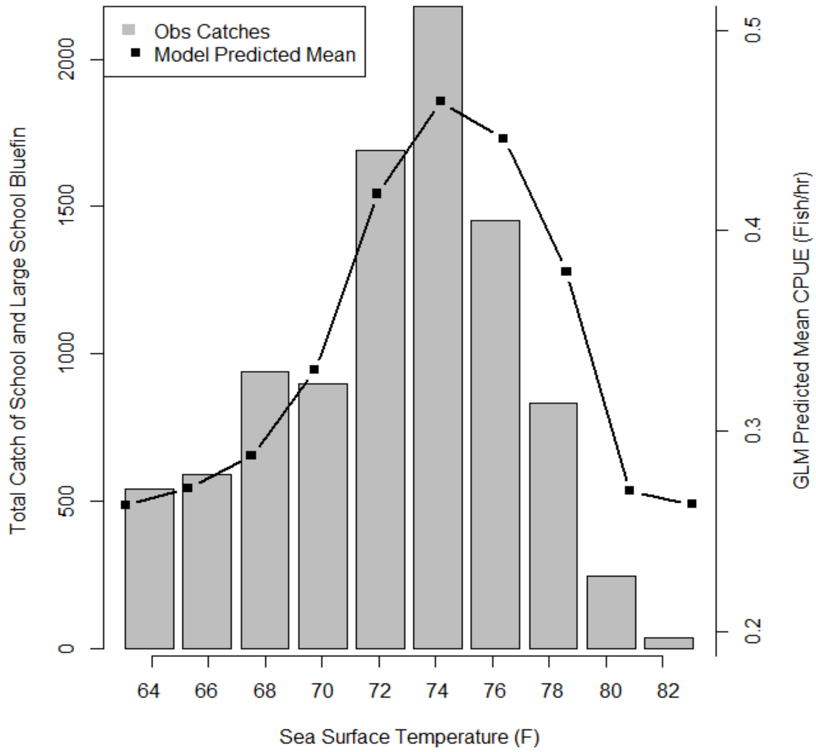

Figure 15. Observed distribution of catches at sea surface temperature (gray bars) compared to the model predicted mean catch rate (black line).

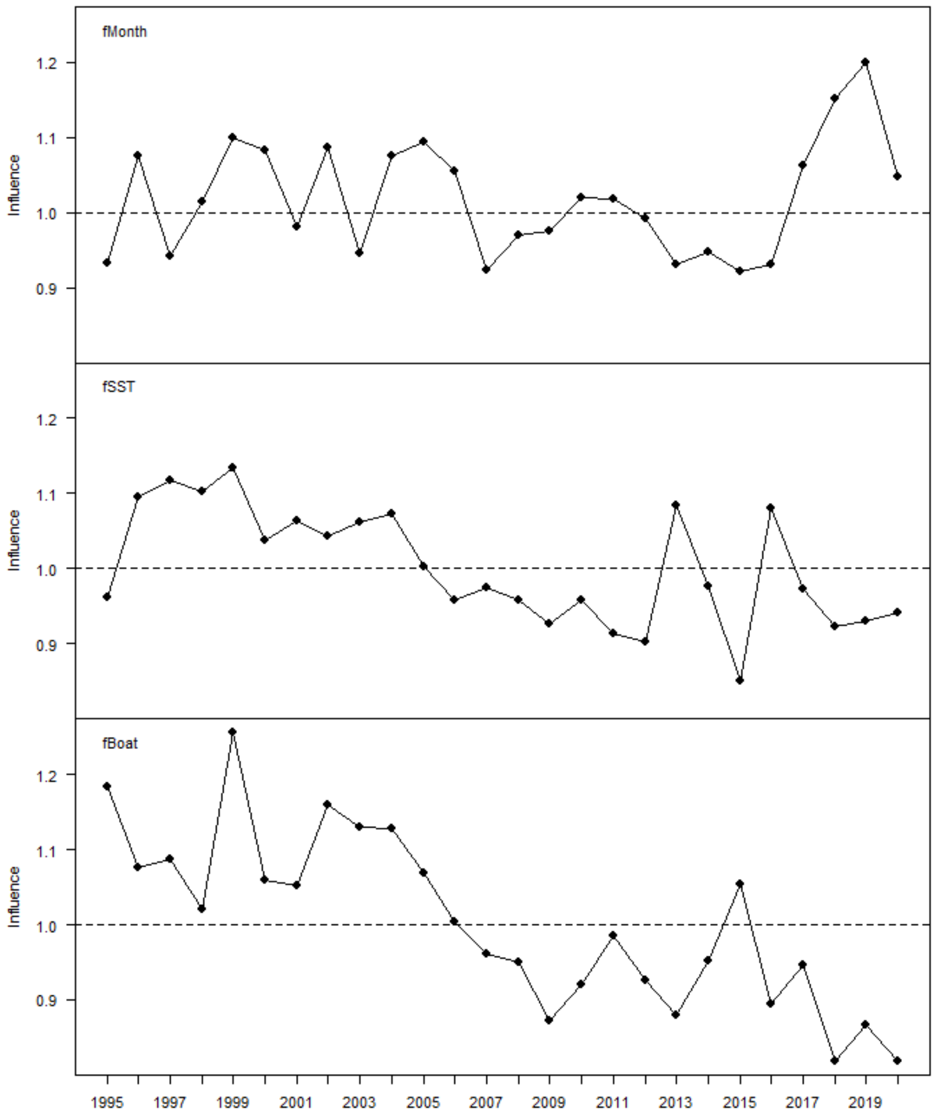

Figure 16. Influence diagnostic plots for each factor type.

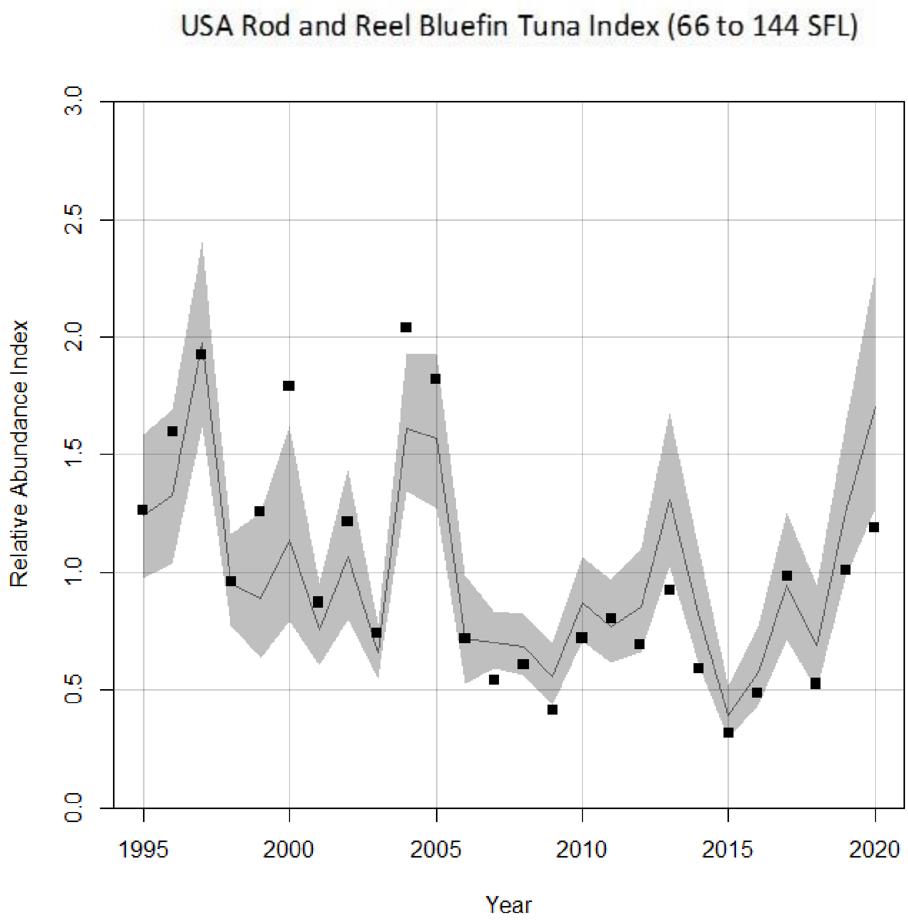

Figure 17. Index of smaller size class bluefin tuna (66 to 144cm SFL) in the West Atlantic from the U.S. rod and reel fishery. The black points show the observed mean catch rates, the black line shows the standardized yearly means, and the gray shaded area shows the 95% confidence interval of the means.

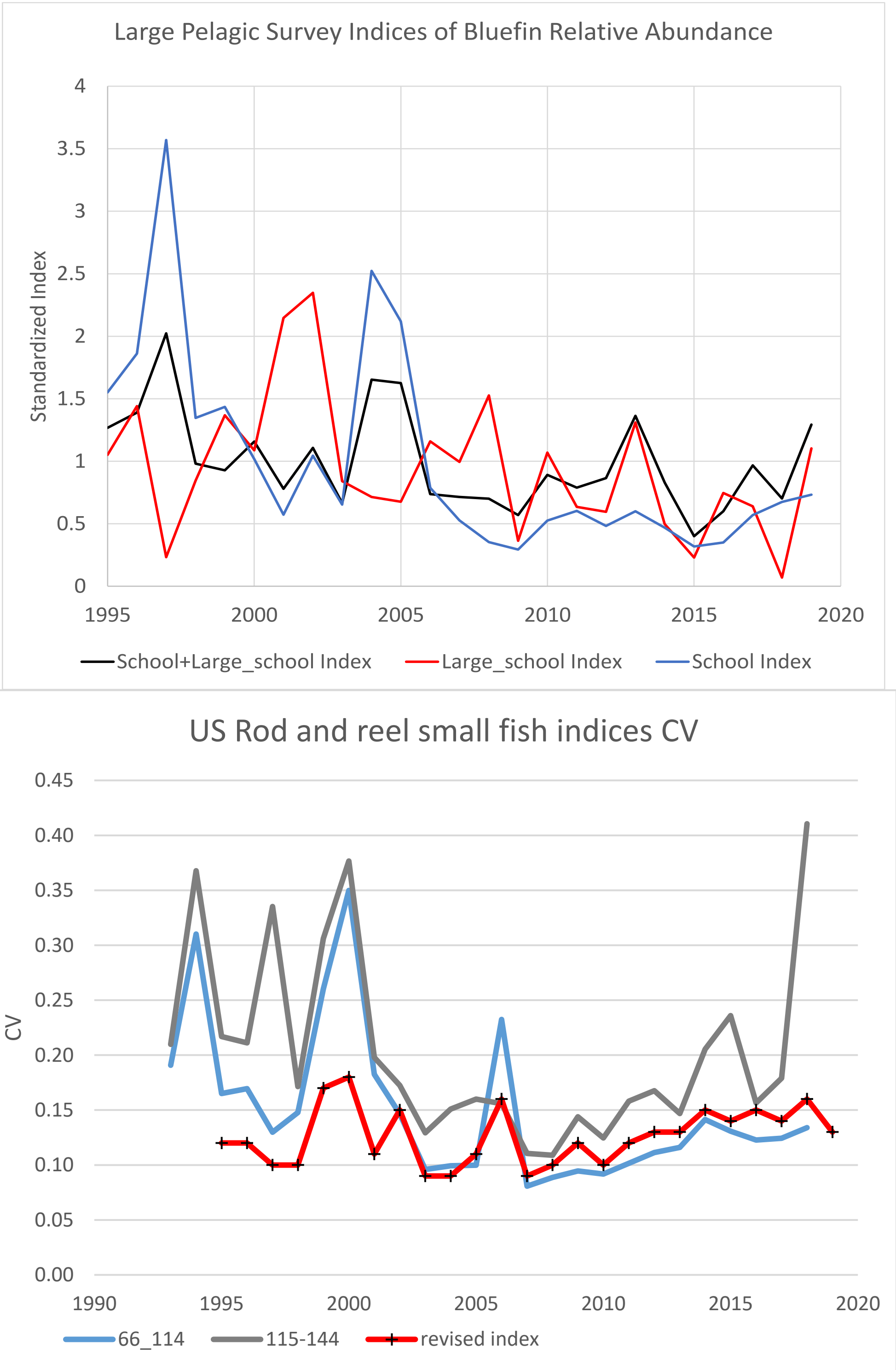

Figure 18. Comparison of previous indices with the revised 66-144 index. Upper panel shows the indices and lower panel the coefficients of variation.