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INVESTIGATION OF MODEL IMPROVEMENTS FOR THE U.S. ROD AND REEL LARGE (>177 cm) ATLANTIC BLUEFIN TUNA INDEX OF ABUNDANCE

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SUMMARY

Standardized catch rates from the U.S. Large Pelagics Survey have been used as an index of relative abundance for large (>177 cm) bluefin tuna (BFT) in the western Atlantic for decades. A series of online stakeholder meetings produced several recommendations to improve the U.S. Rod and Reel large fish index of abundance, including: 1) investigate changing participation in the fishery ("Wicked Tuna effect"); 2) explore models that capture the core spatial footprint of the fishery; 3) examine different effort statistics; and 4) evaluate the impact of ocean conditions that influence fish availability to relative abundance models. Twelve exploratory standardization models were developed using three alternative modeling approaches (generalized linear models (GLM), generalized additive models (GAM), and vector autoregressive spatio-temporal models (VAST)) to address issues highlighted by workshop participants. Exploratory models were then compared to the current model that was used in previous stock assessments. Results demonstrated a similar index across all alternative standardization models. We recommend future standardization models focus on the core spatial footprint of the fishery (Massachusetts, New Hampshire and Maine) and explore incorporating sea surface temperature.

RÉSUME

Les taux de capture standardisés obtenus dans le cadre de la prospection des grands pélagiques des États-Unis ont été utilisés comme un indice de l'abondance relative des grands thons rouges (>177 cm) dans l'Atlantique Ouest pendant des décennies. Plusieurs réunions en ligne avec les parties prenantes ont permis de formuler plusieurs recommandations visant à améliorer l'indice d'abondance américain des grands poissons capturés à la canne et au moulinet, comprenant: 1) étudier la participation changeante à la pêche (« Wicked Tuna effect »), 2) explorer des modèles qui capturent l'empreinte spatiale de la pêche, 3) examiner différentes statistiques d'effort et 4) évaluer l'impact des conditions océaniques qui influencent la disponibilité du poisson sur les modèles d'abondance relative. Douze modèles exploratoires de standardisation ont été élaborés au moyen de trois approches de modélisation alternatives (modèles linéaires généralisés (GLM), modèles additifs généralisés (GAM) et modèles spatio-temporels vectoriels autorégressifs (VAST)) afin d'aborder les questions soulignées par les participants à l'atelier. Les modèles exploratoires ont ensuite été comparés au modèle actuel qui a été utilisé dans les évaluations de stocks précédentes. Les résultats ont fait apparaître un indice similaire pour tous les modèles de standardisation alternatifs. Nous recommandons que les futurs modèles de standardisation se concentrent sur l'empreinte spatiale centrale de la pêcherie (Massachusetts, New Hampshire et Maine) et explorent l'incorporation de la température de surface de la mer.

RESUMEN

Las tasas de captura estandarizadas de la prospección de grandes pelágicos de Estados Unidos se han utilizado como un índice de abundancia relativa para el atún rojo grande (> 177 cm) en el Atlántico occidental durante décadas. Una serie de reuniones de partes interesadas celebradas en línea han dado lugar a diversas recomendaciones para mejorar el índice de abundancia de los grandes peces de caña y carrete de Estados Unidos, lo que incluye: 1) investigar la participación cambiante en la pesquería ("Wicked Tuna effect"), 2) explorar modelos que capturen la principal huella espacial de la pesquería, 3) examinar diferentes estadísticas de esfuerzo y 4) evaluar el impacto de las condiciones oceánicas que influyen en la disponibilidad de peces en los modelos de abundancia relativa. Se desarrollaron doce modelos de estandarización exploratorios usando tres enfoques de modelación alternativos (modelos lineales generalizados (GLM), modelos aditivos generalizados (GAM) y modelos espaciotemporales vectoriales autorregresivos (VAST) para abordar los problemas destacados *por los participantes en el taller. Los modelos exploratorios se compararon entonces con el modelo actual que se utilizó en evaluaciones de stock anteriores. Los resultados demostraron un índice similar entre los modelos de estandarización alternativos. Recomendamos que los futuros modelos de estandarización se centren en la principal huella espacial de la pesquería (Massachusetts, New Hampshire y Maine) y exploren la incorporación de la temperatura de la superficie del mar.*

KEYWORDS

Atlantic bluefin tuna, catch per unit effort, index standardization

1. Background

The current approach to stock assessment of western Atlantic bluefin tuna (*Thunnus thynnus;* BFT) relies heavily on fishery dependent indices of abundance in the form of flag and fleet-specific catch-per-unit-effort (CPUE) time series (ICCAT 2020). The Standing Committee of Research and Statistics Bluefin Tuna Working Group prioritized a review of the indices of relative abundance used in the stock assessments and management strategy evaluation (MSE). A technical workgroup was tasked with reviewing data, standardization methods, and results of current practices for creating the various indices.

In the United States (U.S.), indices of abundance are created from the Large Pelagics Survey (LPS), an intercept survey that is designed to capture rod and reel fishery catch rates (Salz et al. 2007, Foster et al. 2008). From the LPS, the 2020 stock assessment of western BFT included three separate size-based indices: 1) 66-114 cm; 2) 115-144 cm; and 3) >177 cm (ICCAT 2020). This report focuses on the U.S. rod and reel >177 cm index, proposes revisions to methodologies, and provides a recommended index for use in future assessments and MSE (Carruthers and Butterworth 2018).

2. Methodology

2.1. Stakeholder Meetings

A series of five joint U.S.-Canada stakeholder meetings were held in 2020 and 2021 (December 21, January 11, January 21, January 28, and March 4). Meetings focused on reviewing the U.S. LPS and Canadian data that informs indices of abundance for BFT. During meetings, discussions focused on potential issues/improvements to U.S. and Canadian indices and the feasibility of developing a joint U.S.-Canada index of abundance (Hansell et al. 2021). A diverse group of scientists and harvesters participated in these meetings (Appendix A) and through their feedback we identified areas of consideration for U.S. index standardization.

2.2. Data Description

In the U.S., the LPS is a dockside survey of private vessel and charter boat captains who have just completed fishing trips directed at large pelagic species (Salz et al. 2007, Foster et al. 2008). 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 and effort data. Information collected includes: date, landing area, boat type (charter or private), fishing area, number of anglers fishing, number of lines in the water, hours fished, type of fishing (primarily trolling or chumming), fishing target, and catch by BFT size category (Lauretta and Brown 2017). In 2002, the office that manages the LPS changed and thus, LPS data is stored in two separate repositories (period I: 1980 to 2001, Period II: 2002 to 2019). For a more detailed description of the LPS, the manual can be viewed here: https://www.st.nmfs.noaa.gov/Assets/recreational/pdf/LPIS%20Procedures%20Manual%202014.pdf. Starting in 1992, the U.S. started to implement domestic fishery regulations structured by the following size classes:

Young school	< 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

The large fish U.S. index focuses on the size classes “Large medium” and “Giant”. Several data filters were applied to the LPS data before model development. The data treatments were consistent with the index standardization procedure applied in the 2020 stock assessment (Lauretta and Brown 2017):

Year	1993 to 2019
Month	July to October
Gear	Rod and reel only
States	New Jersey to Maine
Target (Primary or secondary)	“Large medium” or “Giant”

2.3. Index Standardization

For all models, collinearity of explanatory variables was explored using generalized variance-inflation factor (GVIF) scores. Any covariate with a score greater than three was removed, and the GVIFs were recalculated (Zuur et al. 2012). Regardless of significance, year was kept in all models, because the primary objective was to detect relative abundance trends over time (Maunder and Punt 2004). Akaike Information Criterion (AIC) scores were used to determine the best-fitting model. If AIC scores were within two units of one another, the most parsimonious model was selected. Model diagnostic plots were examined (i.e., residuals versus fitted, quantile–quantile plot, scale–location, and residuals versus leverage; Zuur et al. 2007).

2.3.1. US Large BFT Index (US RR > 177cm)

The index for >177 cm BFT used in the 2020 stock assessment (Lauretta and Brown 2017) was updated with new data (2018-2020) and is used here as the status quo model and a basis for comparison with exploratory models. The status quo model is a generalized linear model (GLM):

$$\text{Catch} \sim \text{factor(Year)} + \text{factor(Month)} + \text{offset(log(Hours))},\ \varepsilon \sim NB(r, p)$$

and assumes a negative binomial error structure (log link function).

2.3.2. Exploratory Large BFT (> 177cm) Indices

During the workshops, we identified potential factors for consideration in index standardization, including: 1) the “Wicked Tuna” effect, 2) geographic scope of sampling, 3) effort metrics, and 4) influence of environmental variables on indices of abundance. The following changes to the index standardization methodologies were explored based on the recommendations made during stakeholder workshops:

1. *Wicked Tuna effect:* The “Wicked Tuna effect” was characterized as an increase in private vessels targeting BFT in recent years due to the popularity of the television show by the same name that has aired in the U.S. since 2012 (**Figure 1**). This change in trip type is thought to represent an influx of less experienced fishermen, with potential implications for lowering CPUE in comparison to previous years characterized by a more experienced fleet. To address this feedback, we explored the feasibility of developing indices that incorporated fishing experience and separated the effect of private and charter vessels. The model structure (GLM) and data filter criteria remained the same as the status quo model.

2. *Geographic scope of sampling:* It is hypothesized that shifting spatial distributions have complicated the interpretation of large BFT (> 177 cm) indices (see Hansell et al. 2021). Feedback from harvesters in the meetings highlighted that indices should reflect the core spatial footprint of the fishery in the Gulf of Maine. Only focusing on the core spatial component of the fishery simplifies spatial assumptions in the standardization model. To address this feedback, we explored two different options: 1) incorporate a spatial component into the standardization model, which was accomplished using generalized additive model (GAM) and a spatial delta GLMM (VAST; Thorson, 2019); 2) subset the LPS data to constrain the footprint of the fishery to the Gulf of Maine.
3. *Appropriate effort metrics:* During the meetings harvesters highlighted that hours spent fishing was the most appropriate effort metric to explain catch rates. However, scientist also suggested it would be worth exploring other effort statistics including: number of lines used and number of lines*number of hours spent fishing. Alternative GLM standardization models were run with each of the different effort statistics and compared to determine the influence of effort metrics on relative abundance trends.
4. *Influence of ocean conditions on catchability:* Prior research and harvester input highlighted that environmental conditions played an important role in BFT distribution. We explored inclusion of environmental variables as covariates in standardization models. Variables explored included: sea-surface temperature (SST), wind direction, sea *level* pressure, and chlorophyll (**Table 1**). All variables were analyzed at a weekly 1x1° latitude longitude scale. Environmental data were obtained from: NOAA Physical Science Laboratory and NOAA ERDDAP (available here: https://coastwatch.pfeg.noaa.gov/erddap/index.html).

3. Results and Discussion

In the U.S., LPS trips (positive and null) that caught BFT (>177 cm) ranged from Virginia to Maine. The majority of trips were concentrated in the Gulf of Maine (**Figure 2**) and originated in Massachusetts, New Hampshire, and Maine (**Figure 3**). 98 % of trips had > 177 cm BFT listed as the primary fishing target. All model applications estimated similar trends which suggests data plays an important role in model development and there is a clear signal of BFT (>177 cm) relative abundance.

1. *Wicked tuna effect:* Due to time constraints, we were unable to incorporate vessel identification into a standardization model. The model using only charter boat data either failed to converge or produced results that were biologically unrealistic (e.g., large (50 x) changes in year effects). The model using only private boat data converged and produced similar year effect estimates as the prior standardization model (**Figures 4,5**).
2. *Geographic scope of sampling:* Model selection included an interaction term for latitude and longitude in the GAM. The spatial GAM had the biggest difference in trend from the other models suggesting relative abundance was lower prior to 2002.The VAST model indicated a similar trend as the status quo approach except for in 2002 when it estimated relative abundance was higher (Figure 4, 5). The model run that only incorporated data from Massachusetts, New Hampshire and Maine successfully converged and produced very similar results as the prior standardization approach (**Figures 4, 5**).
3. *Appropriate effort metrics:* Four alternative model configurations were run examining various effort metrics. Results indicate that all effort metrics produce a similar trend in relative abundance. However, there are some minor differences prior to 2002 and after 2016 (**Figures 4, 5**). The relationship between different CPUE calculations and catch are similar (**Figure 6**).
4. *Influence of ocean conditions on catchability:* Chlorophyll and SST were colinear, so chlorophyll was excluded from all model runs. Using AIC, the optimal exploratory GLM and GAM both included SST as an important factor influencing catchability. In VAST, AIC selected SST as an important covariate influencing density (**Figures 4, 5**). During the Western BFT Data Preparatory meeting the group spent considerable time discussing the appropriateness of using SST in CPUE standardization because there were concerns that SST was an indicator of density not catchability. We were unable to explore incorporating warm core eddies and prey into standardization models. However, future work is underway to explore both of these variables in BFT catch rate standardization.

3.1 Recommendations

Though there are similarities between model versions we recommend the use of the standardization model that only uses trips that primarily target > 177 cm BFT, focuses on the Gulf of Maine (Massachusetts, New Hampshire and Maine) and incorporates SST (**Tables 3, 4** and **Figures 7, 8, 9**):

Catch ~ Year + Month + offset(log(Hours)) + s(SST), $\varepsilon \sim NB(r,p)$

We recommend this index because 94 % of all trips targeting BFT (>177 cm) occur from Massachusetts, New Hampshire and Maine. Focusing on these areas simplifies model spatial assumptions while still capturing the core footprint of the fishery (Figure 7). Further, harvesters and model selection both determined SST was an important variable influencing catch rates (Pershing et al. 2015). Comparison of year effect estimates and annual mean SST demonstrated a nonsignificant trend, indicating that SST is an appropriate indicator of catchability (**Figure 10**).

SST in the Gulf of Maine has increased in recent decades and is projected to continue to increase in the future (Pershing et al. 2015), including SST as a covariate in the model contributes to reconcile changes in catchability in this changing ocean climate. Currently for this index, we believe a GAM framework is most appropriate because of its ability to model nonlinear relationships and its strong track history of incorporating environmental covariates (Zuur et al. 2007). However, future standardization should continue to explore VAST due to its ability to account for spatial changes in the fishery, differences in catchability between vessels, and its ability to model covariates separately that affect catchability and density (Thorson, 2019). Additionally, work should continue to focus on understanding the effect of environmental covariates on catchability and density.

4. Conclusions

Twelve exploratory standardization models were developed, which attempted to address workshop participant feedback and potential limitations in the current index. Results demonstrated similar trends in relative abundance, suggesting alternative index standardizations are potentially refining the index by incorporating previously unaccounted for factors, but the major signals persist. For the standardization of BFT (>177 cm), we recommend a GAM that focuses on the core area of the fishery (Massachusetts, New Hampshire, Maine) and accounts for SST.

5. Acknowledgements

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Table 1. Description of covariates explored in standardization models for large BFT (> 177 cm).

Covariates	**Range/Units**
Year	1993-2020
Month	6-11
State	VA-ME
Hours	1-157
Lines	1-15
Trip	Private or Charter
Sea surface temperature (SST)	10-26 (C)
Sea level pressure (SLP)	996 – 1035 (mbar)
Wind speed	0 – 2.5 (m/sec)
Depth	1 – 2747 (m)
Chlorophyll	0.09 – 3 (mg/m^3)
Latitude; Longitude	37 – 44; -74 - -67

Table 2. Description of exploratory catch rate standardization models for large (> 177 cm) BFT. Group refers to considerations identified through working group meetings (see text for description); filters are a priori filters applied to the data before the model was applied; framework is the type of generalized model used to standardize catch rates; covariates are the terms selected in the optimal model.

Group	Data Filter	Framework	Covariates
Wicked Tuna	Charter vessels only	GLM	Catch ~ Year + Month + Hours
	Private vessels only	GLM	Catch ~ Year + Month + Hours
Geographic Scope	Massachusetts, New Hampshire, Maine	GLM/GAM	Catch ~ Year + Month + Hours + SST
		GAM	Catch ~ Year + Month + Hours + SST + s(lat,lon)
		VAST	Year + Month + Hours + bs(SST)
Effort		GLM	Catch ~ Year + Month + … lines, hours*lines, offset(lines), offset(hours*lines)
Environment		GAM	Catch ~ Year + Month + Hours + SST
		VAST	Year + Month + Hours + bs(SST)

Table 3. Model selection for recommended index of abundance for large (> 177cm) BFT.

Intercept	Covariates	df	logLik	AIC	delta AIC
-3.037	Year + Month + Hours + SST	41	-3941.517	7966.5	0
-3.267	Year + Month + Hours + SST + Trip type	43	-3940.937	7969.4	2.82
-2.752	Year + Hours + SST	38	-3956.102	7990.3	23.76
-2.983	Year + Hours + SST + Trip type	40	-3955.506	7993.1	26.55

Table 4. Summary statistics and recommended index of abundance for large (>177 cm) BFT caught in the LPS.

Year	n	# of BFT	Success	Index	CV
1993	54	3	0.06	0.53	0.13
1994	150	20	0.13	0.61	0.17
1995	97	28	0.29	1.66	0.27
1996	142	86	0.61	2.74	0.31
1997	326	80	0.25	1.17	0.21
1998	275	79	0.29	1.58	0.26
1999	169	60	0.36	1.56	0.25
2000	131	32	0.24	0.97	0.18
2001	40	18	0.45	2.00	0.29
2002	248	105	0.42	1.88	0.23
2003	295	35	0.12	0.54	0.15
2004	200	17	0.09	0.31	0.14
2005	230	20	0.09	0.41	0.16
2006	114	6	0.05	0.26	0.16
2007	192	11	0.06	0.27	0.14
2008	251	12	0.05	0.25	0.14
2009	285	19	0.07	0.29	0.14
2010	336	51	0.15	0.62	0.18
2011	318	50	0.16	0.74	0.18
2012	468	57	0.12	0.54	0.18
2013	458	34	0.07	0.39	0.14
2014	341	33	0.10	0.45	0.15
2015	583	94	0.16	0.80	0.19
2016	694	135	0.19	1.07	0.22
2017	677	219	0.32	1.54	0.27
2018	765	236	0.31	1.54	0.27
2019	659	247	0.37	1.76	0.30
2020	574	173	0.30	1.50	0.27

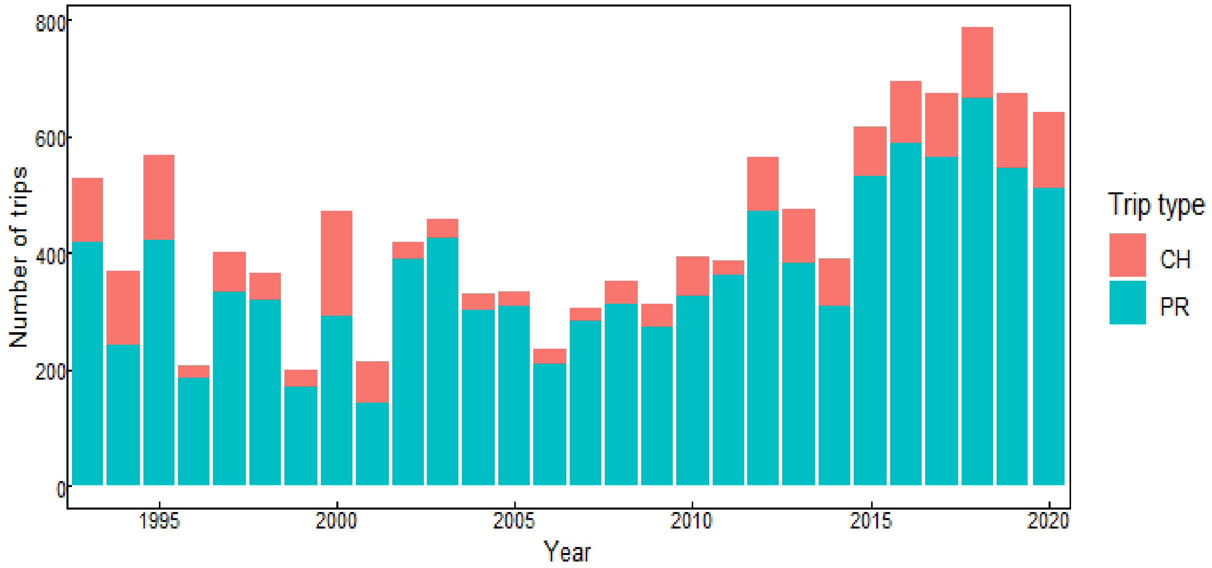

Figure 1. Number of trips targeting large (>177 cm) BFT in LPS by vessel category (CH: charter, PR: private vessel).

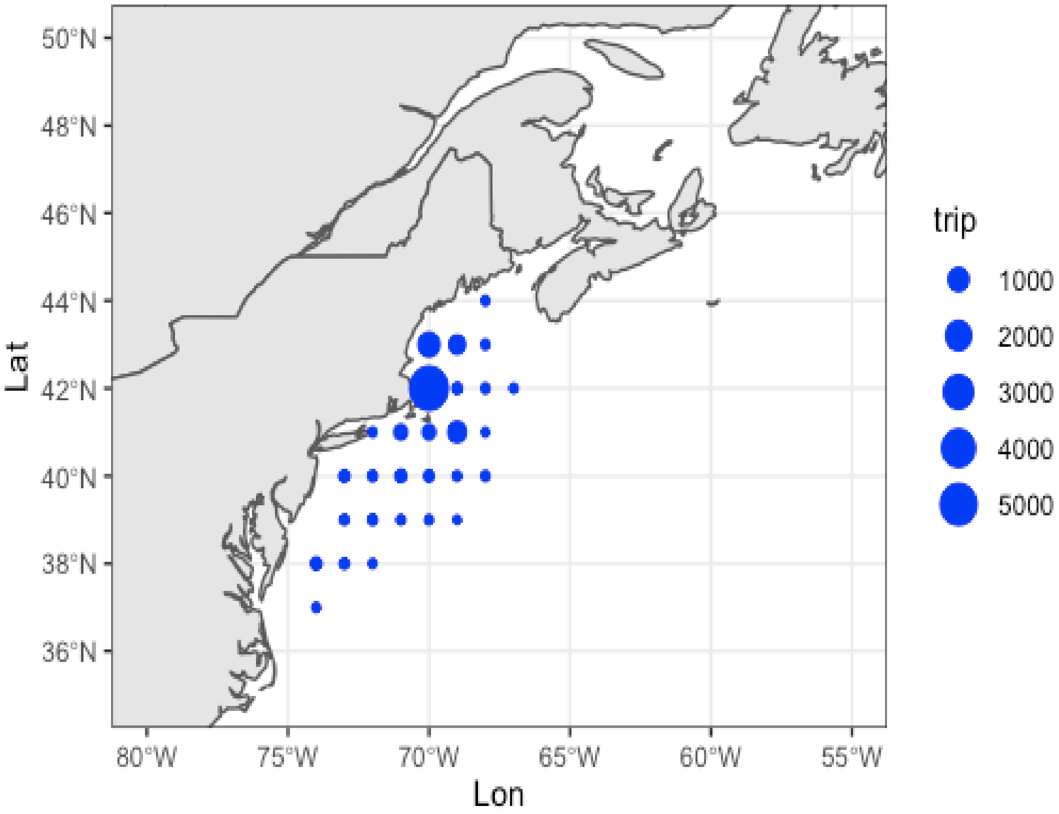

Figure 2. Spatial extent of LPS trips targeting large (>177cm) BFT. Coordinates weighted by number of trips surveyed.

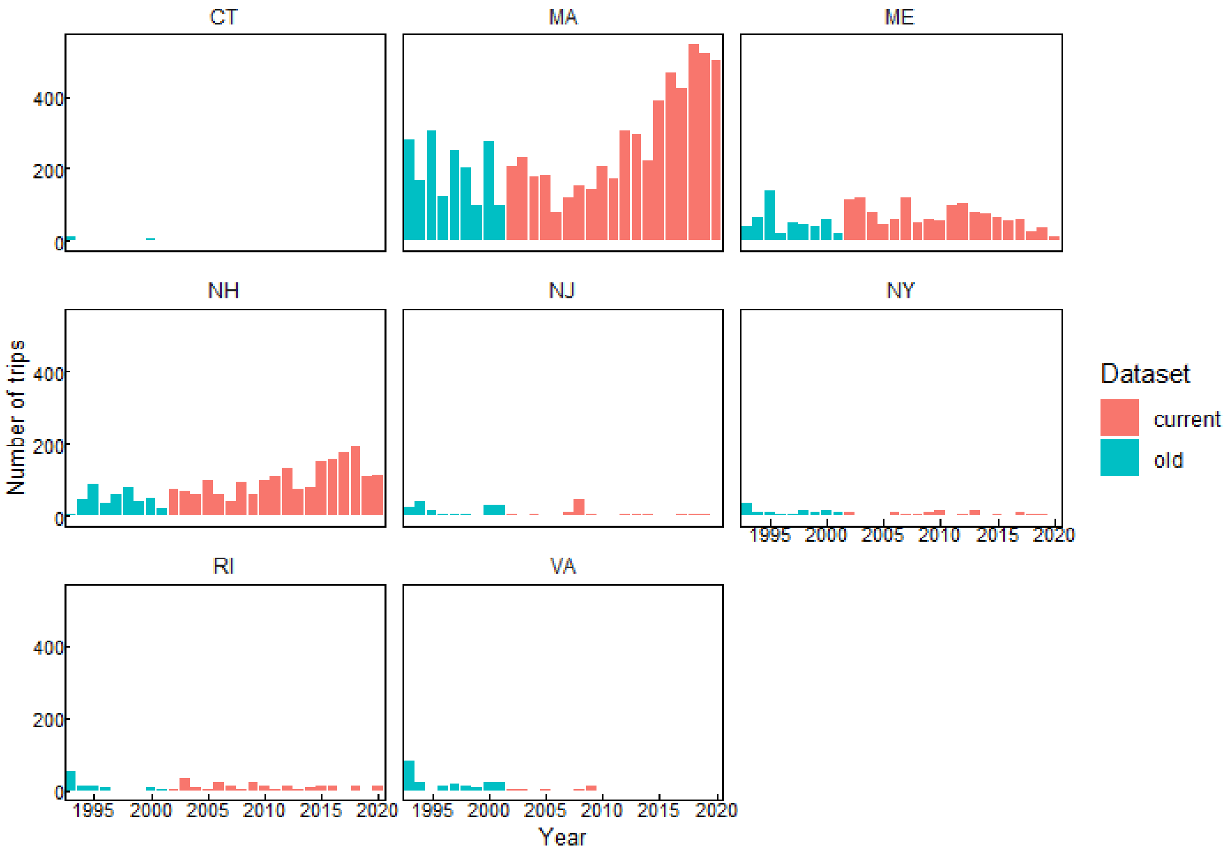

Figure 3. Number of trips targeting large (>177 cm) BFT in LPS by state. Bar color indicates different databases.

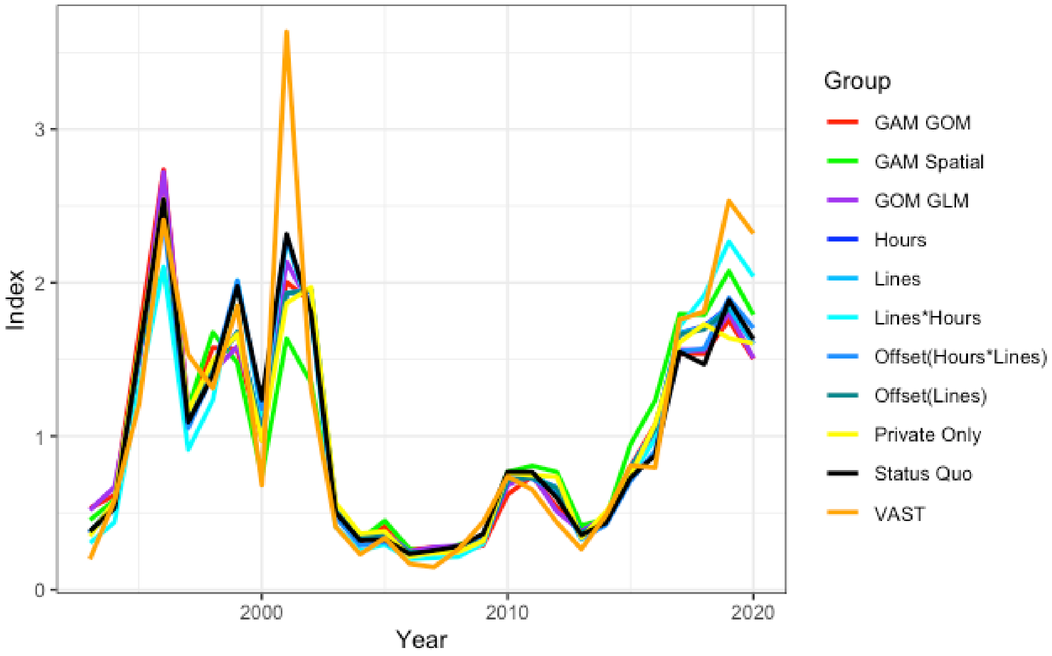

Figure 4. Index value comparisons across exploratory model runs for large (> 177 cm) BFT. See text and Table 2 for description on model runs.

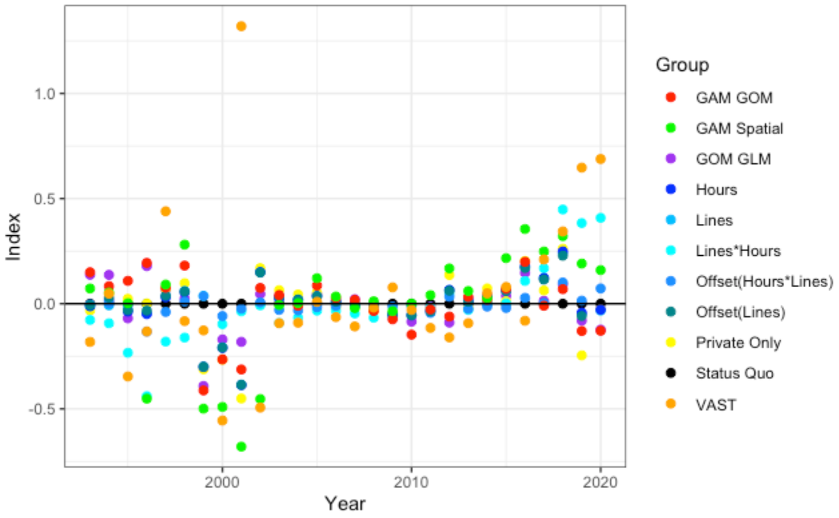

Figure 5. Comparison of exploratory model runs to status quo index for large (> 177 cm) BFT. See text and Table 2 for description on model runs.

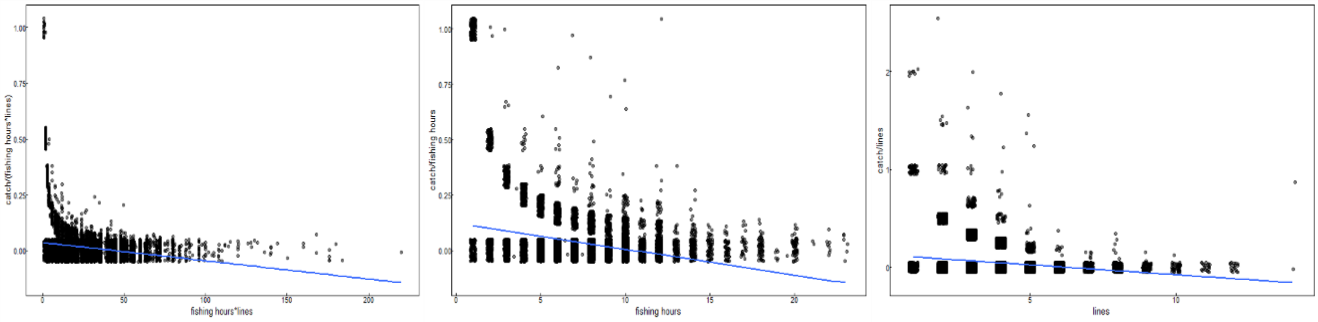

Figure 6. Comparison of different CPUE and effort for large (> 177 cm) BFT caught in the LPS.

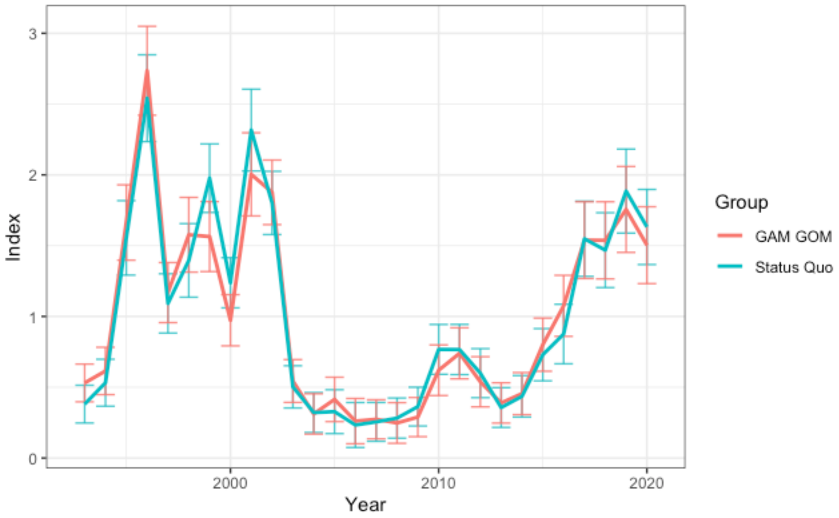

Figure 7. Recommended and status quo index of abundance for large (>177cm) BFT caught in LPS. Recommended index is in red while status quo index is blue. Error bars are index CVs.

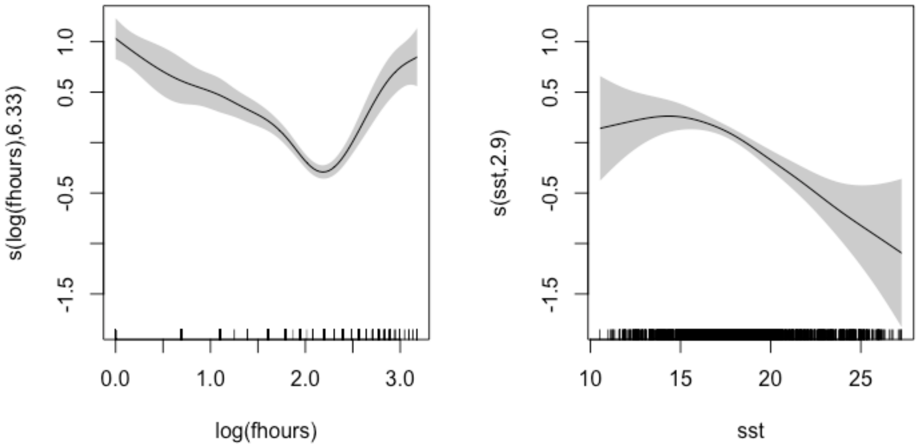

Figure 8. Smoothers for fishing hours and sea surface temperature from recommended index of abundance for large (>177 cm) BFT caught in LPS.

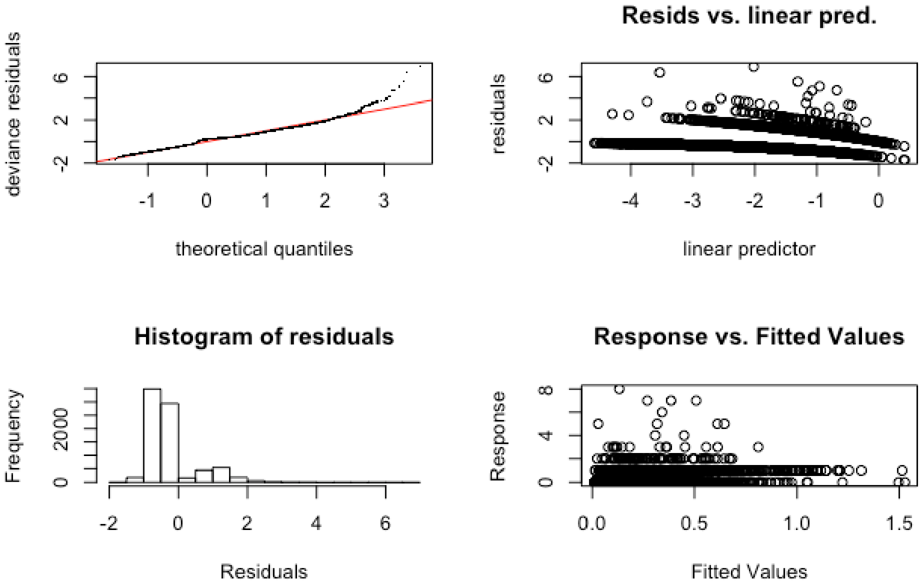

Figure 9. Residual plots for recommended index of abundance for large (>177 cm) BFT caught in LPS.

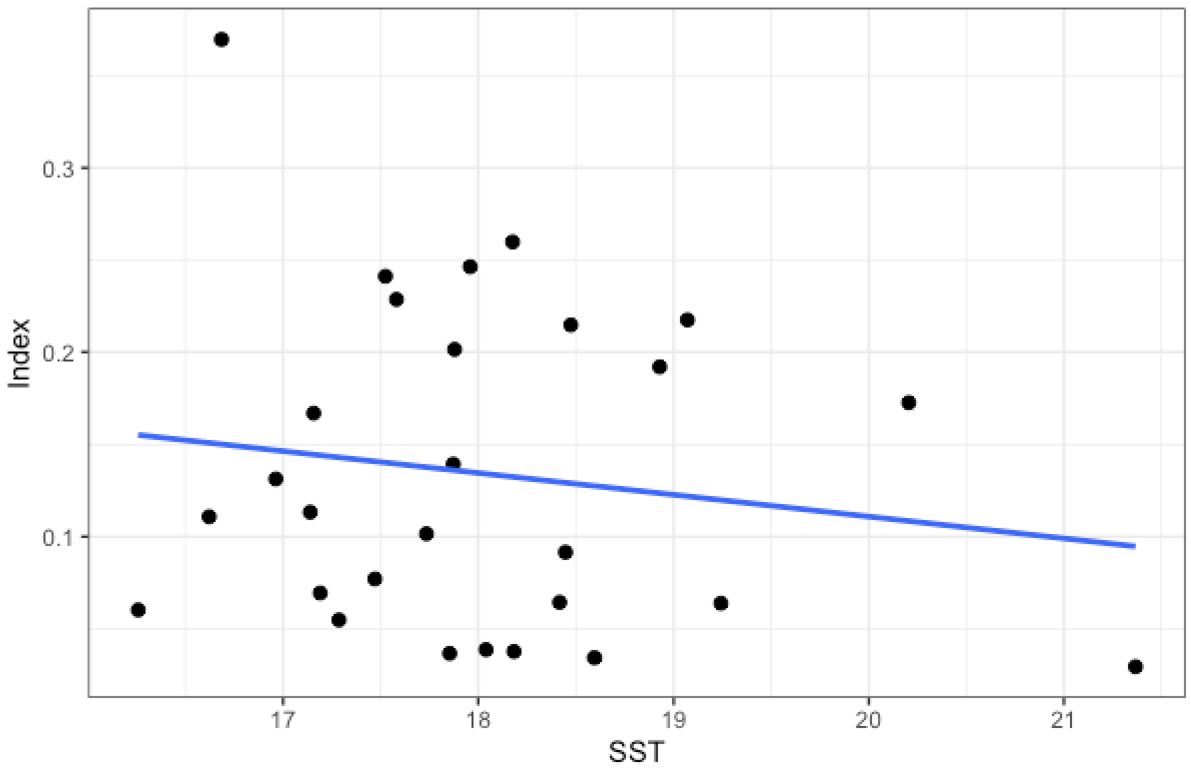

Figure 10. Correlation of year effect estimates from the optimal model without sea surface temperature (SST) and annual mean SST.

Appendix A. Workshop participants.

Joint Handline Index Working group	
Participant	Country/Contracting Party
Alex Hanke	Canada
Gary Melvin	Canada
Nick Duprey	Canada
Kyle Gillespie	Canada
Sam Elsworth	Canada
Kenny Drake	Canada
JJ Maguire	Canada
Troy Atkinson	Canada
Taryn Minich	Canada
Mauricio Ortiz	ICCAT Secretariat
Ai Kimoto	ICCAT Secretariat
Yohei Tsukahara	Japan
Doug Butterworth	Japan
Matthew Lauretta	USA
John Walter	USA
Craig Brown	USA
Steve Cadrin	USA
Walt Golet	USA
David Schalit	USA
Alexander Hansell	USA
Lisa Kerr	USA
Chris Weiner	USA
Steve Weiner	USA
Steven Getto	USA
Bruce Peters	USA
Bob DeCosta	USA
Christopher Comb	USA
Putnam Maclean	USA
Tyler Macallister	USA
Jay Goodwin	USA
Joe Dion	USA
Eric Stewart	USA
Mike Blanchard	USA