Update of standardized CPUE and Catch at Size for Pacific Bluefin tuna (*Thunnus Orientalis*) caught by Japanese coastal and offshore longline up until 2019 fishing year

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Summary

This document presents the update result of the standardized CPUE by spatiotemporal model. A predicted index showed consistent trajectory with previous one and continuously increase since 2011 fishing year. This index indicated there were no unexpected changes on the trend in SSB after last assessment in 2020. This documents also describes the update of size composition, e.g. catch at length data, caught by JPLL from January to March and from April to June, respectively. In recent years, small sized fish, which was less than 150cm and hardly observed until 2015 fishing year, was dominant in the size composition in both fishing seasons. This change in size composition was still observed and became noticeable in 2019 fishing year.

Introduction

The spatiotemporal generalized linear mixed model (spatiotemporal GLMM) incorporating fine spatial and temporal structures as random effects is one of the advanced and useful tools (Thorson et al., 2015 a, b). The spatiotemporal model enables us to predict spatial variation across multiple location, time intervals, for multiple categories such as size, age and sex. The spatiotemporal model is widely used in the CPUE standardization for highly migratory species, recently. The time series of CPUE of Japanese coastal longline fishery (JPLL), which was standardized by generalized spatiotemporal GLMM, had been used as an abundance index for large sized Pacific Bluefin Tuna (PBF) mostly corresponding to size of spawning stock biomass (SSB) since 2020 stock assessment (Tsukahara et al 2020, ISC 2020).

In order to estimate the selectivity for the removal by JPLL fishery and for the vulnerable biomass by this abundance index, length measurement in some major landing ports was conducted since 1993 fishing year (FY: July to June in following year). The measurement data in each prefecture was raised according to the coverage of size measurement to the total weight of landing and aggregated as two separate catch at size from January to March and from April to June, respectively. In recent year, small sized fish, which was less than 150cm and hardly observed until 2015 fishing year, was dominant in the size composition in both fishing season. Therefore, PBFWG decided not to use the size composition data after 2017 fishing year for estimation of selectivity on this fishery. PBFWG also recommended that more work will be needed to understand the potential effects of recent management measures on the stability of the model process linking to this and other data (ISC 2020).

This document presents the update results of the standardized CPUE by spatiotemporal GLMM and catch at size up until 2019 FY.

Materials and Methods

Data collection and filtering for CPUE standardization

The fishery operational data by JPLL, which is called logbook data hereafter, has been collected by Japan Fishery Agency and compiled by Japan Fisheries Research and Education Agency since 1994. For last couple of years, logbook is still not done compiled. The logbook data contains individual records of fishing operation: date (year, month and day) and location (latitude and longitude) of longline set, total number of hooks per set, number of hooks per basket (HPB), catch in number and cumulative catch in weight by various fish species including PBF. Some data in the logbook could be regarded as irrelevant operations and misreporting for PBF. To remove such data, data filtering was conducted by following criteria: (1) vessel size more than 20 gross register tonnages (GRT), (2) season other than April to June, (3) the catch in number more than 50 per a cruise, (4) number of hooks less than 1,000, (5) HPB less than 9 and more than 24, (6) the locations where PBF was not caught over 5 years through the data period from 1994 to 2020 (Fig. 1), (7) locations in the south of 23-degree north latitude, north of 35-degree of north latitude and east of 145-degree east longitude (Fig. 1), and (8) suspension and buffer period for the time of fishery association arranging the quota.

In terms of the longline fishery management in Japan, the fishery specific catch quota the large PBF (30 kg and larger) has been implemented since 2018 calendar year (WCPFC-NC 2019) to comply the conservation and management measure (WCPFC CMM 2018-02) adopted in the Western and Central Pacific Fisheries Commission (WCPFC). The catch quota was allocated from the national government to the longline fishery association and the association has been managed their quota under the supports of the government. Since 2017 FY, the most of JPLL was required to suspend their landings of PBF in the middle of fishing season of each year because their catch amount almost reached their own quota. In 2018FY, they resumed the landings after suspension at the later of the main fishing season in accordance with the additional quota from the reservation quota of the government. In 2019FY, a modification to the management for JPLL, which recognized additional allocation to the JPLL fishery with monthly quota, was applied to increase the number of operations for PBF from April to June. This would reduce the negative influence on this abundance index by suspension, although the landings at the turn of the month likely to be subject to the effects of management, which could be regarded as buffer periods of management. Further research on the practical information on quota management is needed for this area. In this document, therefore, the data during suspended and buffer periods was removed from this analysis, which were from 21st May in 2017FY, from 11th May to 19th June in 2018FY and from 21st April to 30th April, from 11th May to 31st May, from 11th June and first three days in each month in 2019 FY.

Spatiotemporal model

The filtered set-by-set logbook data including catch in number and fishing effort, number of hooks, were aggregated by spatial stratum (i.e., 1 x 1 degrees) and temporal strata (i.e., year and season) to improve the estimation efficacy of spatiotemporal model. The seasonal stratum, Day 10, was defined as intervals of every 10 days from April 1 to June 30 except for the end of May, only which have 11 days. The spatiotemporal modelling package, the Vector Autoregressive Spatio-Temporal (VAST) package, is currently available as an R-package (Thorson, 2019). However, the VAST was not directly used in this study. Instead of using the VAST, the original C++ codes of VAST were modified to conduct flexible modeling and R-package "TMB" (version 1.7.15) was used for the optimization of the model mainly to incorporate seasonal effects (Day 10) into spatiotemporal model. For PBF spatiotemporal model, one step model only by catchability was used to predict an abundance index as in the case of blue shark standardization (Kai et al, 2017). Since the catch number of PBF is count data which has overdispersion even after data filtering and aggregation by spatial and temporal strata, the negative binomial model (NB) were used as the observation models. Catch in number was used as a response variable. The models selected in last update based on the AIC have main effects of Year, t, Day10, d, Site, s, and three-dimensional interaction term between Year and Site day10, with offset terms by Hooks, h.

$$p(i) = \beta(t_i) + \xi(d_i) + \delta(s_i) + \upsilon(t_i, s_i, d_i) + h_i \qquad \text{(Eq. 1)}$$

where β, ξ,δ,υ is the inference of main effects of Year, Day10, Site and interaction of Year and Site. Only year effect, β, was treated as fixed effects and the other effects including interactions were treated as random effects which have correlation structure, either Gaussian Markov Random Field for site effects or one-dimension auto-regression for Year, Day10 effects.

Data collection and treatment for catch-at-size

The catch-at-length of PBF caught by Japanese coastal longliners was estimated using size-measurement and sales slip data for longline which were obtained at 10 main landing ports in five prefectures (Fig. 2), mainly collected by the "Research Project on Japanese bluefin tuna (RJB)". Some size-measurement data from other research projects such as observer data were also used. The data from January to March (3rd quarter) and from April to June (4th quarter) during 1993 to 2018 FY (1st and 2nd quarters of 1994 to 2019 calendar years) was used for the estimation in each quarter. Note that the data in the latest year should not be considered complete due to delay of data collection, thus the result of catch-at-length in 2018 FY is preliminary.

The catch-at-length was estimated using the same method as proposed by Hiraoka et al. (2015). The length frequency (fork length) was estimated by "number" of actual measured fish with relative "weight" for measured fish and total catch. When fish weight was not measured for the size measurement, the weight of measured fish was calculated from measured length using existing weight-length relationship (Kai 2007). The estimating method can be described by the following equations:

$$Coverage_{yqk} = w_{yqk} \,/\, c_{yqk} \qquad \text{(Eq. 2)}$$

$$N_{iyq} = \sum_{k=1}^{K} \left(n_{iyqk} \,/\, Coverage_{yqk} \right) \qquad \text{(Eq. 3)}$$

where N_{iyq} is the number of fish at the length bin of i occurred in the population at the quarter q of calendar year y. K is the total number of prefecture stratification. n_{iyqk} is the number of measured fish at the length bin of i in prefecture stratum k at quarter stratum q for year y. w_{yqk} is the total weight of them. c_{yqk} is the total catch weight in prefecture stratum k at quarter stratum q for year y. As the quarter stratum, a single quarter, either 1st or 2nd quarter of calendar year, was used for each catch-at-length. The prefecture stratum was following 5 prefectures: Miyagi, Chiba, Wakayama, Miyazaki, and Okinawa, where the size data was obtained (Fig. 2).

The coverage, which is the rate of the total weight of measured fish to the total weight of catch based on the sales slips for each prefecture, quarter and year, is used for the estimation of the catch-at-length. The number of measured fish divided by the coverage are raised to the estimated number of caught PBF (Eq. 1). However, the coverage of only Okinawa prefecture since 2007 has been over than 100% due to the deals outside of landing port. The fisheries cooperative sometimes deals with the PBF in other than their own port to sell it at higher price. When it often happens, there are measurement data at landing port, although there are not sales slip at landing port. It causes the number of caught PBF underestimated less than the number of measured PBF. Therefore, the present paper makes one change, that the coverage which is over than 100% was changed to 100 (actually "1.0" in the equation), and the number of caught PBF was estimated as same with the number of measured fish.

Results

The update index showed the consistent trajectory with previous one (Fig. 3). Since 1993 FY, index gradually decreased, while there was substantial increase around 2004FY. The index in 2011FY was the lowest and then it showed continuous increase trend to the present. The spatial distribution of abundance over year was shown in Fig. 4. There was high abundance area widely up until early 2000s. After that, high abundance area was gradually shrunk toward South west area around Nansei spawning grounds corresponding to the decrease of annual abundance index. On the other hand, the high abundance area was expanded broadly again in most recent year. Randomized quantile residual (RQR) was used for the diagnostics (Dunn and Smyth 1995). NB models where residuals are far from normality, aligning nearly parallel curves according to distinct response values, which makes it difficult to conduct visual inspections (Kai et al. 2019). Figure 5 showed the diagnostic plots by RQR. QQ plots showed somewhat skewed at the both edges, but there were no considerable negative signals in residual distributions and QQ-plot. Additionally, main parameters, directly related to each effect, have enough small final gradient and far from boundaries and initial values (Table 2). These indicate that fits to the CPUE of PBF caught by JPLL and result of standardization was reasonable.

Estimated catch-at-length data from April to March, which is 4th quarter in assessment model, showed that the main part of the Japanese coastal longline catch has been constituted by some strong cohorts (Fig. 6: blue lines). For example, before the previous strong cohorts consisted of 1990 and 1994 year-classes became small and mostly disappeared in 2012 FY, 2007 and/or 2008 year-class increased and started to consist a new strong cohort in 2010 FY. These results correspond to the size and age compositions of PBF caught by Taiwanese longline (Shiao 2017), which reported that 2005-2009 year-cohorts increased in 2013-2015 after strong 1994 and 1996 year-cohorts decreased. In addition to the cohort of 2007 and/or 2008 year-class, 2010 and/or 2011 year-class started to be seen in 2014 FY and now composes the strongest cohort.

In recent year, small sized fish, which was less than 150cm and hardly observed until 2015 fishing year, was dominant in the size composition in both fishing season. This change in size composition was still observed and became noticeable in 2019 fishing year. Those individuals were mainly caught in east water of 145-degree of east longitude, where the data excluded from CPUE standardization, and thus it is recommended that the catch-at-length after 2017 should not include the likelihood component to estimate selectivity for this index.

Conclusion

The relative abundance index and catch at length data were updated up until 2019FY. The updated index showed the consistent trajectory with previous one and continuous increase trend since 2011 to the present. The diagnostic had no negative signal on standardization, although CV gradually became larger possibly because of suspension periods. Since 2020 FY, the individual quota (IQ) system for JPLL was introduced to give a fair chance to each licensed vessel operating at the different area and month. This might enable to reduce the spatial and temporal bias in the data used for CPUE standardization. Regarding catch at length data, small sized fish, which was less than 150cm and hardly observed until 2015 fishing year, was dominant in the size composition in both fishing season. Those individuals were mainly caught in east water of 145-degree of east longitude, where the data excluded from CPUE standardization, and thus it is recommended that the catch-at-length after 2017 should not include the likelihood component to prioritize the consistency of selectivity for this index.

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Table 1 Annual catch in number, the number of longline operations and nominal CPUE in logbook data from April to June and predicted CPUE by spatiotemporal GLMM.

		Raw data in Logbook			Predicted abundance index	
Calendar Year	Fishing Year	Catch (inds.)	Effort (x1000 hooks)	Nominal CPUE	Relative Abundance index	CV
1994	1993	2707	5155	0.525	2.26	0.08
1995	1994	1595	4755	0.335	1.67	0.08
1996	1995	2501	5220	0.479	2.03	0.07
1997	1996	2629	5686	0.462	2.10	0.06
1998	1997	3109	6684	0.465	1.91	0.06
1999	1998	3830	9665	0.396	1.46	0.05
2000	1999	2304	8787	0.262	1.05	0.06
2001	2000	1813	9584	0.189	0.76	0.06
2002	2001	2109	9762	0.216	0.91	0.06
2003	2002	2622	8805	0.298	1.37	0.05
2004	2003	3501	10195	0.343	1.40	0.04
2005	2004	3830	9747	0.393	1.53	0.04
2006	2005	1992	9434	0.211	0.88	0.05
2007	2006	2976	9011	0.330	0.97	0.05
2008	2007	1471	9292	0.158	0.60	0.06
2009	2008	1280	10936	0.117	0.35	0.07
2010	2009	709	9025	0.079	0.22	0.09
2011	2010	496	8873	0.056	0.19	0.09
2012	2011	369	9455	0.039	0.15	0.09
2013	2012	738	9507	0.078	0.30	0.07
2014	2013	681	8543	0.080	0.30	0.08
2015	2014	511	6773	0.075	0.37	0.08
2016	2015	631	5710	0.111	0.41	0.08
2017	2016	1190	8014	0.148	0.64	0.07
2018	2017	407	2729	0.149	0.68	0.14
2019	2018	1182	5461	0.216	0.88	0.09
2020	2019	751	2016	0.372	1.61	0.15

Table 2. Initial and final condition of each parameter related to explanatory variables. ρ is the autocorrelation parameter for Day10 and HPB. The beta means fixed terms of year effect.

Parameter	Starting value	Lower boundary	Maximum likelihood estimation	Upper boundary	Final gradient
ρ (Year)	0	-Inf	0.686	Inf	3.1E-04
ρ (Day10)	0	-Inf	0.783	Inf	-6.2E-05
beta_1994	-5	-Inf	-8.894	Inf	3.9E-05
beta_1995	-5	-Inf	-9.220	Inf	-7.5E-05
beta_1996	-5	-Inf	-9.000	Inf	-1.3E-04
beta_1997	-5	-Inf	-8.961	Inf	-3.1E-05
beta_1998	-5	-Inf	-9.086	Inf	4.9E-05
beta_1999	-5	-Inf	-9.442	Inf	6.5E-05
beta_2000	-5	-Inf	-9.679	Inf	1.0E-04
beta_2001	-5	-Inf	-9.986	Inf	1.3E-04
beta_2002	-5	-Inf	-9.805	Inf	2.8E-05
beta_2003	-5	-Inf	-9.445	Inf	-4.9E-05
beta_2004	-5	-Inf	-9.406	Inf	-1.7E-05
beta_2005	-5	-Inf	-9.308	Inf	3.2E-05
beta_2006	-5	-Inf	-9.848	Inf	2.4E-05
beta_2007	-5	-Inf	-9.759	Inf	-2.3E-06
beta_2008	-5	-Inf	-10.172	Inf	-1.3E-06
beta_2009	-5	-Inf	-10.769	Inf	7.1E-05
beta_2010	-5	-Inf	-11.248	Inf	9.1E-05
beta_2011	-5	-Inf	-11.397	Inf	9.3E-05
beta_2012	-5	-Inf	-11.643	Inf	5.0E-05
beta_2013	-5	-Inf	-10.933	Inf	-3.3E-05
beta_2014	-5	-Inf	-10.868	Inf	-1.1E-04
beta_2015	-5	-Inf	-10.664	Inf	-9.4E-05
beta_2016	-5	-Inf	-10.582	Inf	8.0E-05
beta_2017	-5	-Inf	-10.136	Inf	1.1E-04
beta_2018	-5	-Inf	-10.091	Inf	-1.1E-04
beta_2019	-5	-Inf	-9.873	Inf	9.5E-08
beta_2020	-5	-Inf	-9.256	Inf	4.4E-05

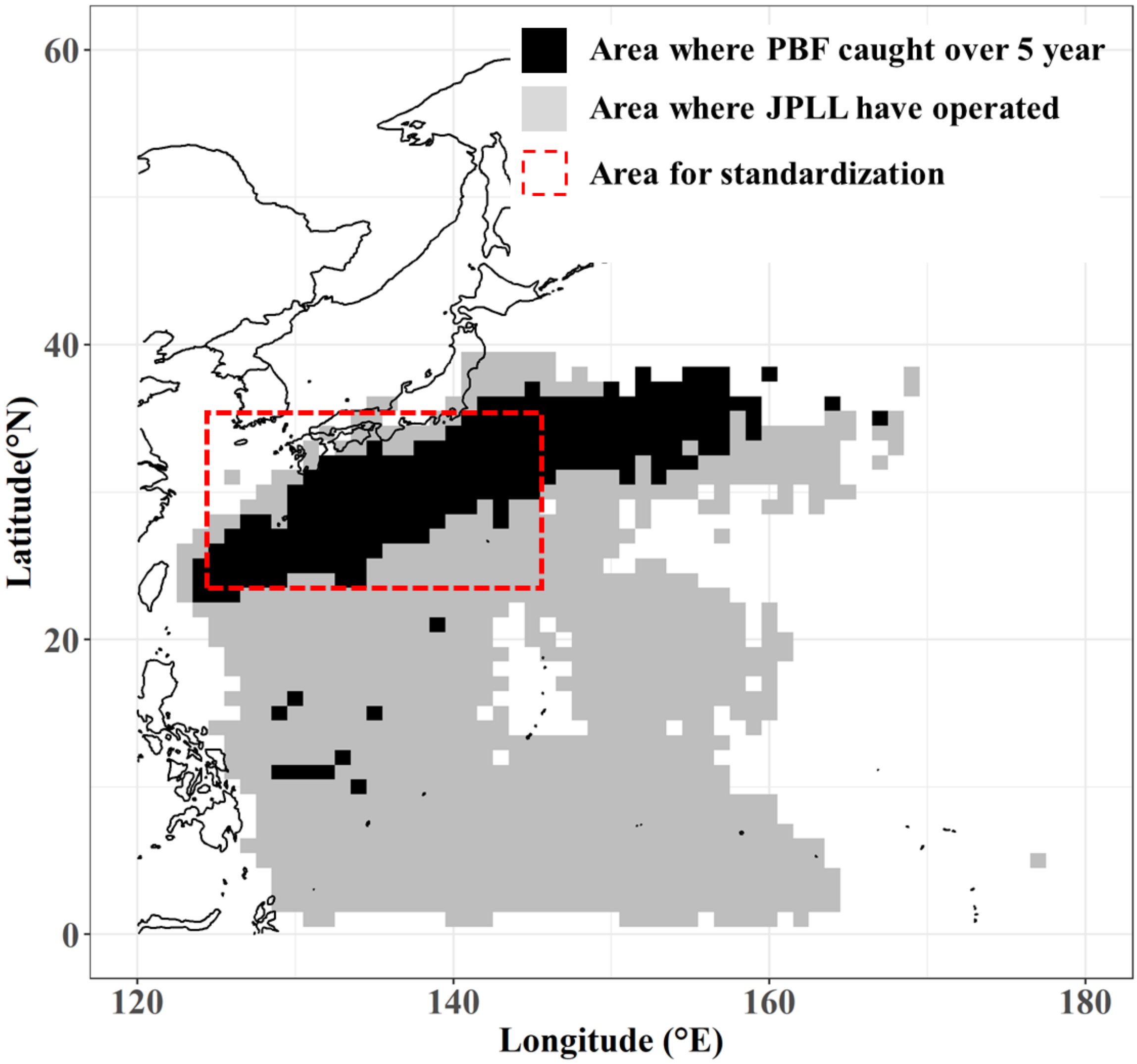


Figure 1. The spatial distribution of operation by Japanese coastal longline from 1994 to 2019.

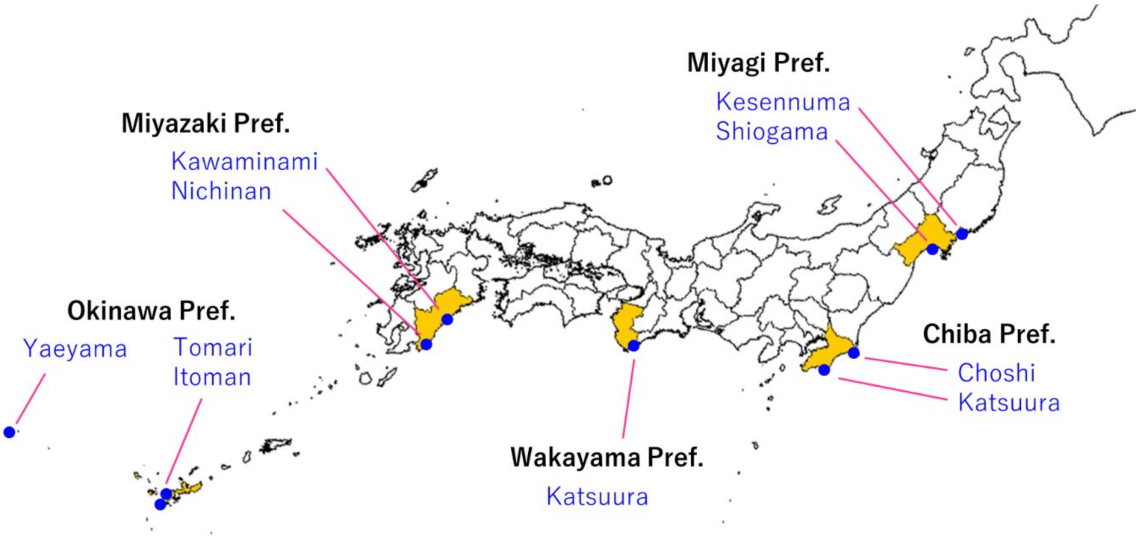


Figure 2. Location of prefectures (yellow area) and fishing ports (blue circle) where the PBF caught by Japanese coastal longliners was measured for size data.

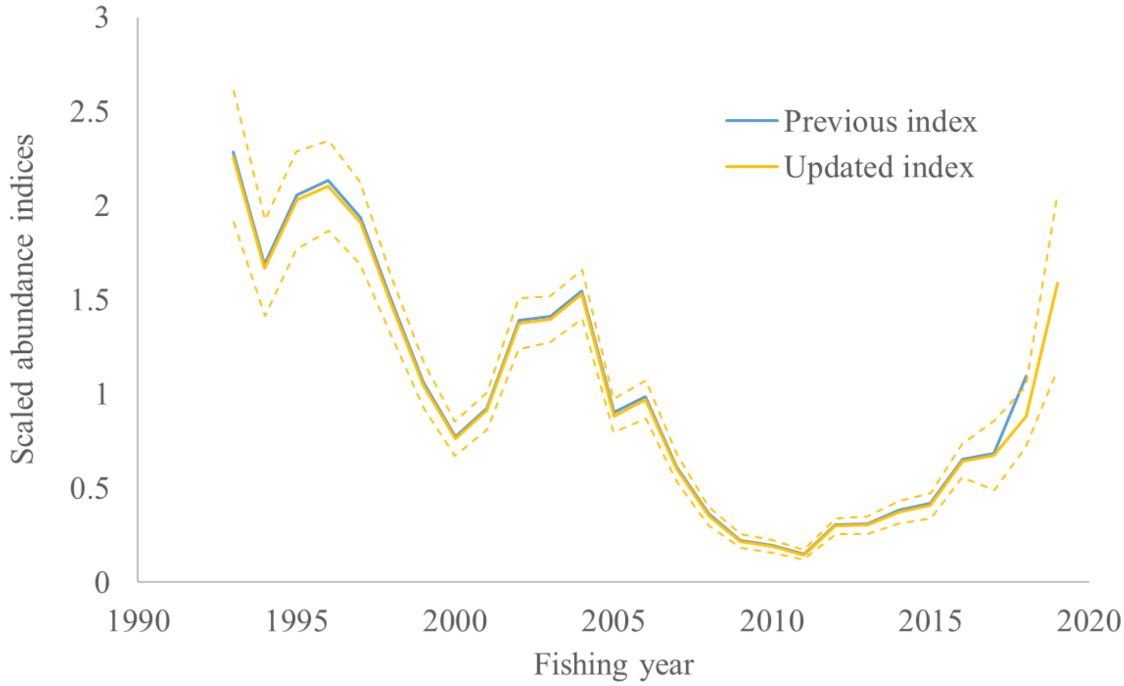


Figure 3. Comparison plot between updated abundance index with 95% confidential intervals and previous one without confidential interval.

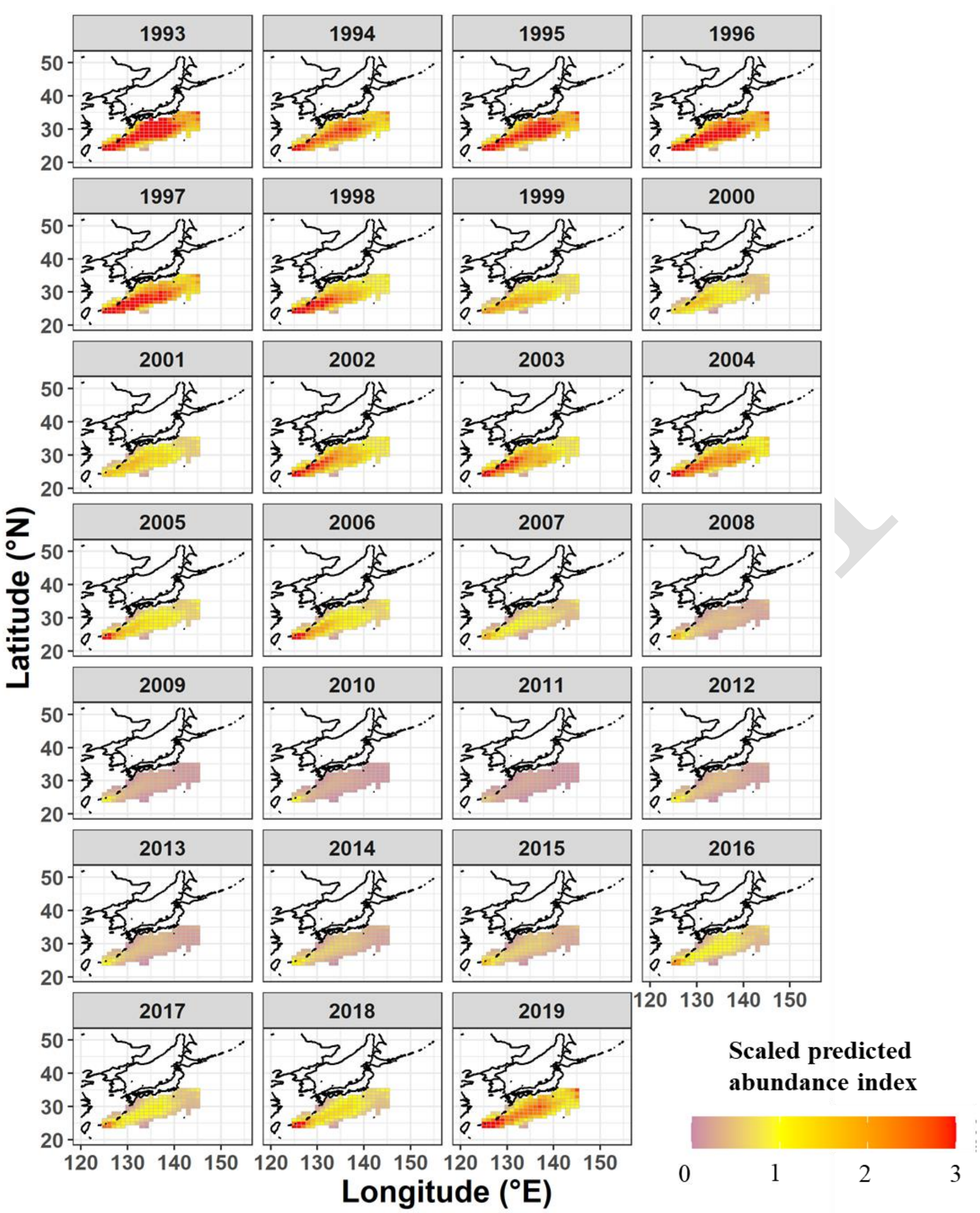


Figure 4. Annual and spatial trends by fishing year of scaled predicted CPUE.

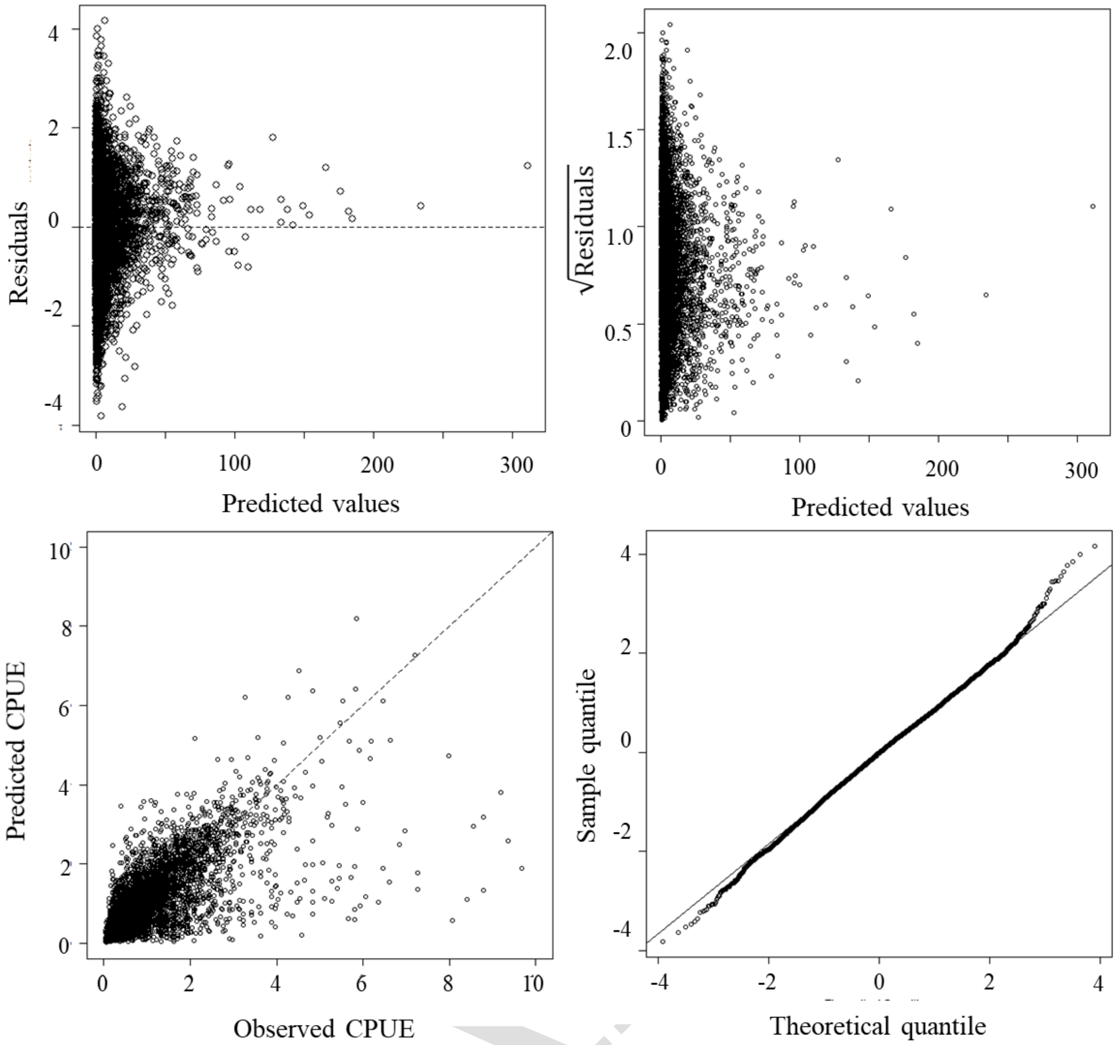
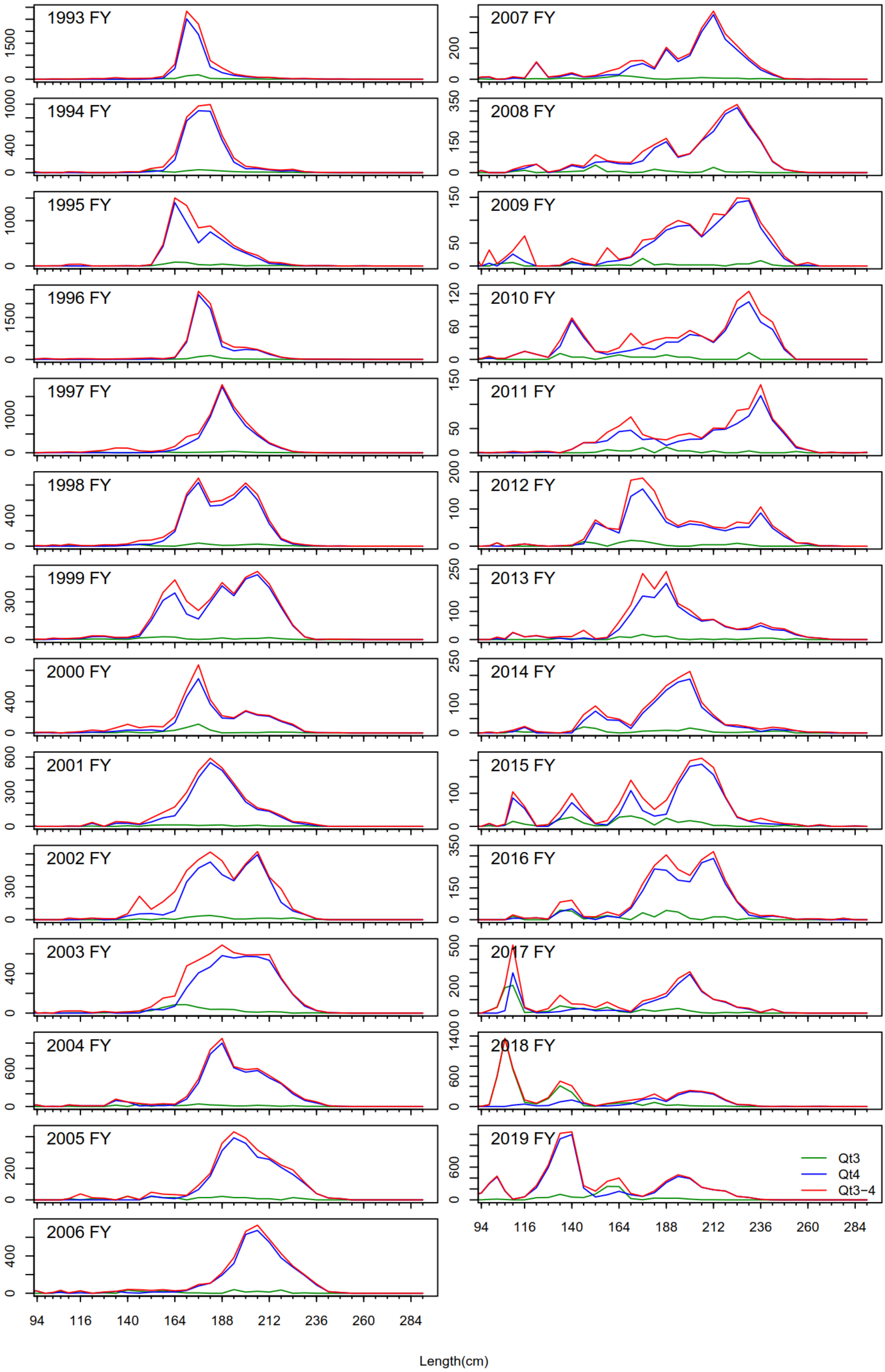


Figure 5. Diagnostic plots of goodness of fit for the spatiotemporal model for Pacific Bluefin Tuna for full model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Qt3
Qt4
Qt3-4
94
116
140
164
188
212
236
260
284
Length(cm)

Figure 6. Estimated catch-at-length of PBF caught by Japanese coastal longliners in 3rd (green line), 4th (blue line), and 3rd to 4th (red line) quarters of fishing year, respectively. Vertical axis indicates estimated number of caught PBF. Horizontal axis indicates fork length of PBF (cm). The catch-at-length of 2018 FY is preliminary.