Update of estimated recruitment index of Pacific bluefin tuna based on real-time troll monitoring survey data, added IQ-independent scientific survey data for 2021

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Summary

This paper provides an update of the real-time troll monitoring data operated in the East China Sea during the winter season (November to the following February) for the 2017-2021 fishing year. In the latest year, 2021, the IQ-independent scientific survey began chartering monthly real-time troll monitoring vessels to reduce the impact of fishing regulations. The chartered 13 vessels collected a total of 77 latitude/longitude grids and 124 days of operational data, while the conventional real-time troll monitoring was conducted on 71 grids for a total of 366 days. The ratio of the number of spatial grids in the charter survey to the number of spatial grids in the conventional survey was sufficiently high (92.8% of the monthly total). Therefore, the two types of real-time troll monitoring data sets (with/without chartered operation data) for 2021 were found to be useful that complement each other's spatio-temporal information. Based on this updated data, the standardized CPUE was calculated by Vector Autoregressive Spatio-Temporal (VAST) model which is a delta-generalized linear mixed model that separately calculates the encounter probability and the positive catch rate, as in Fujioka et al. (2021). The indices using two data sets estimated in this study were similar to previous ones for the period 2017-2020 (Fujioka et al., 2021), suggesting high value in the most recent year, 2021.

Introduction

The recruitment abundance index (i.e. standardized CPUE) is one of the most important input data for the Pacific bluefin tuna (PBF) stock assessment. The conventional troll data (sales slip data) used to calculate this recruitment index (age-0) has changed significantly since the fishing regulations for the 2017 fishing year and onwards (Nishikawa et al., 2021). Therefore, for the period after 2016 fishing year, PBF Working Group (WG) agreed to use real-time troll monitoring data conducted at the same season and in the same area for stock assessment analysis without fitting to the likelihood function of the base case model (ISC 2022). The real-time troll monitoring data provides geographic information on operations by vessels, allowing us to aggregate catch and effort data into a detailed latitude-longitude grids. The advantage of the monitoring data is that live release data and zero-catch operations can be obtained in a spatiotemporally fine-grained and timely manner (Tsukahara et al., 2019). However, as fishing regulations are tightened, even data from monitoring survey can become sparse by fishing suspensions or shutdowns when fishing quotas (e.g. IQ;

individual quota, local fisheries association based quota or area based quota, prefecture based quota) are exceeded throughout the fishing season. Therefore, in order to properly understand the recent trends of recruitment, Japan Fisheries Research and Education Agency (FRA) has started a scientific survey using charter operations of real-time troll monitoring vessels from the 2021 fishing year, adding to conventional real-time monitoring by commercial vessels.

In this working paper, we summarized the spatio-temporal (area and monthly) operational patterns of conventional and scientific charters real-time monitoring vessels in 2021 fishing year, and updated both data as real-time troll monitoring data from 2017 to 2021. Recruitment abundance index were then estimated based on the real-time troll monitoring data for the period of 2017- 2021, a period of strict fishing regulations. As the similar approach to Fujioka et al. (2021), we explored area-weighted recruitment index using the spatio-temporal delta-generalized liner mixed modelling method (VAST: Vector Autoregressive Spatio-Temporal) (Thorson, 2019) with the expectation of reducing bias due to reduced sampling area caused by fishing regulations.

Methods

Data collection and summary

Data from 14 real-time troll monitoring vessels, which targeted for age-0 PBF (i.e. 40-60 cm fork length) during the winter season (November to following February) in the ECS, have been collected since 2011 fishing year. This paper updates the operational data for 13 vessels for the 2021 fishing year for the analysis period of 2017-2021 (Table 1-1). A vessel out of 14 vessels could not operate in 2021 due to an accident occurred in 2021. These vessels are equipped with the GPS receiver and numeric keypad to input species and number of fish caught at the fishing location. The GPS data is recorded at intervals of 1 second during all trips. The vessel velocity can be estimated by the moving distance based on the GPS data. The estimated velocity was smoothed by the trimmed mean to exclude the obvious outlier due to the unsettled GPS data. These trace of fishing behavior and catch position can be used to estimate more precise efforts in an operation, i.e., actual operation time, than the catch per day used for sales slip data. PBF operation was defined as continuous vessel's velocity in the range of 2-7knot for more than 30 minutes. The PBF catch and effort (residence time in minutes) data were aggregated in a 0.1×0.1 degree latitude/longitude grids and formatted into the following data; vessel name, year, month, day, latitude, longitude, catch, effort.

For the 2021 fishing year, in addition to conventional real-time monitoring, 13 vessels equipped with the data logger were chartered for several days in each month from November 2021 through February 2022 to secure operations in the monitoring period. They can operate independently with individual quota as the catch from chartered operations for the 2021 fishing year were reported as part of the national government authorized FRA survey quota. The spatial distribution of operations by year is shown in Figure 1. A summary of the 2021 data is presented in Table 1-2 and Figure 4, showing the spatio-temporal (area and monthly) differences between both types of real-time monitoring operations. Histograms of fishing effort (in minutes) and PBF catch records for a total of five years from 2017 to 2021 are shown in Figure 2. For 0.1 degree grid aggregated data, the mean and standard deviation of fishing effort for 2017-2021 was 122.3 ± 123.1 minutes, ranging from 5 to 735 minutes. The mean and standard deviation for PBF catch was 4.0 ± 12.3 with a range of 0 to 265. Over the entire period (2017-2021), the zero-catch rate operation was 69%, the positive catch rate was 31%, and the coefficient of variation of PBF catch (S.D./Mean) was 3.10. Nominal CPUE for each month and fishing year is shown in Figure 3.

Vector Autoregressive Spatio-Temporal (VAST) model

VAST is a delta-generalized linear mixed model that separately calculates the encounter probability and the positive catch rate, and is available from the R package "VAST" version 3.8.2 on the website (https://github.com/James-Thorson-NOAA/VAST) (Thorson, 2019). In our study, the encounter probability (*p*) at observation *i* was modeled using a logit-linked linear predictor, and the positive catch rate (*r*) at observation i was modeled using a log-linked linear predictor, as in the following equation:

$$(1)\ \ \mathrm{logit}(p_i) = \beta_1(t_i) + L_{\omega 1}\omega_1(s_i) + L_{\varepsilon 1}\varepsilon_1(s_i, t_i) + \zeta_1(s_i, m_i) + L_{\eta 1}\eta_1(v_i)$$

$$(2)\ \ \log(r_i) = \beta_2(t_i) + L_{\omega 2}\omega_2(s_i) + L_{\varepsilon 2}\varepsilon_2(s_i, t_i) + \zeta_2(s_i, m_i) + L_{\eta 2}\eta_2(v_i)$$

where $\beta(t_i)$ is the intercept in year t_i, $\omega(s_i)$ is the time-invariant spatial variations at location s_i, $\varepsilon(s_i, t_i)$ is the time-varying spatio-temporal variations at location s_i in year t_i, $\zeta(s_i, m_i)$ is the s_i month effect m_i as a catchability covariate which is either spatially varying at location at s_i

or spatially constant by configuration and $\eta(v_i)$ is the effect of vessel v_i as a factor of overdispersion, and L_ω , L_ε and L_η are the scaling coefficients of the random effect distributions (Fujioka et al., 2021).

The probability of the density c is specified in this study as follows for a zero-inflated Poisson distribution:

$$(3)\ \Pr(c_i = c) = \begin{cases} 1 - p_i & \text{if } c = 0 \\ p_i \times ZeroInflated\ Poisson(c_i | \log(r_i), \sigma^2) & \text{if } c > 0 \end{cases}$$

where σ^2 is a dispersion parameter.

Then, the abundance index was predicted using an area-weighted approach, which calculates total abundance as a weighted sum of the estimated densities in a pre-defined spatial domain of knots. The number of knots was set equal to the number of observation locations (144 knots for 2017-2021).

Regarding the configuration of spatial structure with Gaussian Random Markov field (GRMR), this analysis used the anisotropic estimation of correlation, which estimate two different parameters for the correlation of two independent directions. In terms of temporal configuration, there is no assumption of correlated structure both year effect itself and spatio-temporal variation because the recruitment strength was highly variable over years based on the PBF assessment result.

Results and Discussion

This study provides updated data on real-time troll monitoring of age-0 PBF in the ECS during winter based on five years (2017-2021) of the fishing regulation period. Operational data of real-time monitoring survey were obtained over 96-490 days with ranging 54-214 latitude/longitude grids from 14 vessels in each year (Table 1-1, Figure 1). In 2021 fishing year, IQ-independent charter real-time monitoring surveys were initiated to ensure sufficient operations in each spatial and temporal stratum. Operational patterns of conventional real-time monitoring and chartered real-time monitoring in the 2021 were examined with a focus on the ratio of spatial grids to each other (Table

1-2, Figure 4). The results showed that the ratio of the number of spatial grids in the chartered survey to the number of spatial grids in the conventional survey was sufficiently high (92.8% of the monthly total). In other words, the monthly spatial distribution of the chartered survey improves the data set for estimating recruitment abundance index.

For the 2017-2021 data period, the model that assumed spatial and spatio-temporal effects, month effect as catchability covariate which was spatially varying for each of encounter probability and positive catch rate (Case 7) was judged to be the best model in terms of the AIC criteria although excluded spatial effect of encounter probability (Table 2). The model converged successfully and the final gradients on each parameter were well below 4.96×10^{-8} for the period (Table 3). Quantile diagnostics of these models also showed no considerably negative signs in the standardization (Fig. 9). The result of distance of 10% correlation of both encounter probability and positive catch rate was estimated as anisotropic shapes with 30-60km of longitude axis mainly from south to north in each period of time (Fig. 6), so that the estimation in certain grids have some impacts on estimation in the approximately 3-6 grids away from there in 0.1 by 0.1 degree grid. This means that spatial correlation seems to be limited for availability of age-0 PBF. Changes in the center of the PBF biomass distribution in the east-west and north-south directions did not show a clear pattern with the estimated biomass in this short period (Fig. 7).

The comparison of the standardized indices by VAST (reported ISC21 for 2017-2020 and Case 7 for 2017-2021 in this study) and traditional GLM index is shown in Figure 10. The indices estimated in this study were generally consistent with the past ones for 2017-2020, and the index for 2021 estimated as a high value. In addition, the latest increase trends of recruitment abundance index did not change when estimated using data with/without chartered real-time monitoring survey (Appendix). It suggested that both types of real-time monitoring data are considered reasonable and can be a compensate spatio-temporal scale each other. Going forward, the charter survey will be maintained beyond 2022 fishing year.

References

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Table 1-1 Total number of efforts (in days) and number of latitude/longitude grids (in 0.1 grid units) by troll operation for 14 real-time monitoring vessels per month from 2017 to 2021 fishing year.

	Total number of troll operations (days)				
	in 2017	in 2018	in 2019	in 2020	in 2021
November	57	67	35	30	90
December	39	112	88	49	165
January	0	132	176	30	114
February	0	120	107	23	121
Total	96	431	406	132	490

	Total number of operations (grids)				
	in 2017	in 2018	in 2019	in 2020	in 2021
November	24	31	25	25	48
December	30	28	30	36	69
January	0	62	30	32	59
February	0	63	44	29	38
Total	54	184	129	122	214

Table 1-2 Monthly effort (in days) and grid (in 0.1 grid units) of conventional real-time monitoring and chartered real-time monitoring by 13 troll operations in the 2021 fishing year. *See* Figure 4 for the difference in the monthly spatial distribution of operations for both monitoring vessels.

	Total operation		Conventional		Charter		Ratio of chater to conventional	
	days	grids	days	grids	days	grids	days (%)	grids (%)
November	90	48	70	20	20	31	28.6	155.0
December	165	69	128	42	37	45	28.9	107.1
January	114	59	72	43	42	42	58.3	97.7
February	121	38	96	34	25	11	26.0	32.4
Total	490	214	366	139	124	129	33.9	92.8

Table 2 Combinations of explanatory variables for encounter probability (p) and positive catch (r) in a delta model and the values of Akaike information criterion (AIC) for the period 2017-2021. Delta AIC indicates the difference between the case 7 model with the lowest AIC. Blank means no convergence.

Case	Model for *p*	Model for *r*	AIC	⊿AIC
1	Yr + Station + Yr:Station + Month(spatially varying) + Vessel	Yr + Station + Yr:Station + Month(spatially varying) + Vessel		
2	Yr + Station + Yr:Station + Month(spatially constant) + Vessel	Yr + Station + Yr:Station + Month(spatially varying) + Vessel		
3	Yr + Station + Yr:Station + Month(spatially constant) + Vessel	Yr + Station + Yr:Station + Month(spatially constant) + Vessel	25784	478
4	Yr + Station + Yr:Station + Month(spatially varying)	Yr + Station + Yr:Station + Month(spatially varying)		
5	Yr + Station + Yr:Station + Month(spatially constant)	Yr + Station + Yr:Station + Month(spatially varying)		
6	Yr + Station + Yr:Station + Month(spatially constant)	Yr + Station + Yr:Station + Month(spatially constant)	26476	1170
7	**Yr + Yr:Station + Month(spatially varying)**	**Yr + Station + Yr:Station + Month(spatially varying)**	**25306**	**0**
8	Yr + Station + Month(spatially varying)	Yr + Station + Yr:Station + Month(spatially varying)		

Table 3 Initial and final condition of each parameter related to explanatory variables in the 2017-2021 period. The list of parameters is as follows:

beta; intercept for 1st or 2nd linear predictor (1st; encounter probability, 2nd; positive catch rate) each fishing year (2011-2020)

L_eta; overdispersion factors (vessels) for 1st or 2nd linear predictor

L_omega; spatial factors for 1st or 2nd linear predictor

L_epsilon; spatio-temporal factors for 1st or 2nd linear predictor

logkappa; decorrelation rate for 1st or 2nd linear predictor

log_sigmaPh; conditional variance between each month for intercepts of 1st linear predictor

Parameter	Starting value	Lower boundary	Maximum likelihood estimation	Upper boundary	Final gradient
ln_H_input	-0.298	-5	-0.298	5	-1.10E-08
ln_H_input	0.288	-5	0.288	5	1.96E-08
beta1_ft_2017	-0.078	-Inf	-0.078	Inf	-1.33E-10
beta1_ft_2018	-1.112	-Inf	-1.112	Inf	-1.49E-10
beta1_ft_2019	-1.922	-Inf	-1.922	Inf	1.63E-10
beta1_ft_2020	-1.398	-Inf	-1.398	Inf	-2.15E-10
beta1_ft_2021	0.238	-Inf	0.238	Inf	-8.56E-10
L_epsilon1_z	-1.662	-Inf	-1.662	Inf	4.40E-09
logkappa1	-3.242	-4.766133	-3.242	-1.174951	1.11E-09
log_sigmaPhi1_k	0.388	-Inf	0.388	Inf	-5.37E-10
log_sigmaPhi1_k	0.111	-Inf	0.111	Inf	-4.02E-10
log_sigmaPhi1_k	0.316	-Inf	0.316	Inf	-6.34E-10
beta2_ft_2017	-3.096	-Inf	-3.096	Inf	-6.94E-10
beta2_ft_2018	-2.793	-Inf	-2.793	Inf	-1.44E-10
beta2_ft_2019	-3.897	-Inf	-3.897	Inf	5.09E-10
beta2_ft_2020	-3.688	-Inf	-3.688	Inf	-1.79E-10
beta2_ft_2021	-2.825	-Inf	-2.825	Inf	3.20E-10
L_omega2_z	0.000	-Inf	0.000	Inf	2.47E-10
L_epsilon2_z	-1.082	-Inf	-1.082	Inf	5.10E-08
logkappa2	-2.415	-4.766133	-2.415	-1.174951	3.62E-09
log_sigmaPhi2_k	-0.008	-Inf	-0.008	Inf	-2.96E-09
log_sigmaPhi2_k	0.079	-Inf	0.079	Inf	-2.35E-09
log_sigmaPhi2_k	-0.084	-Inf	-0.084	Inf	-2.08E-09

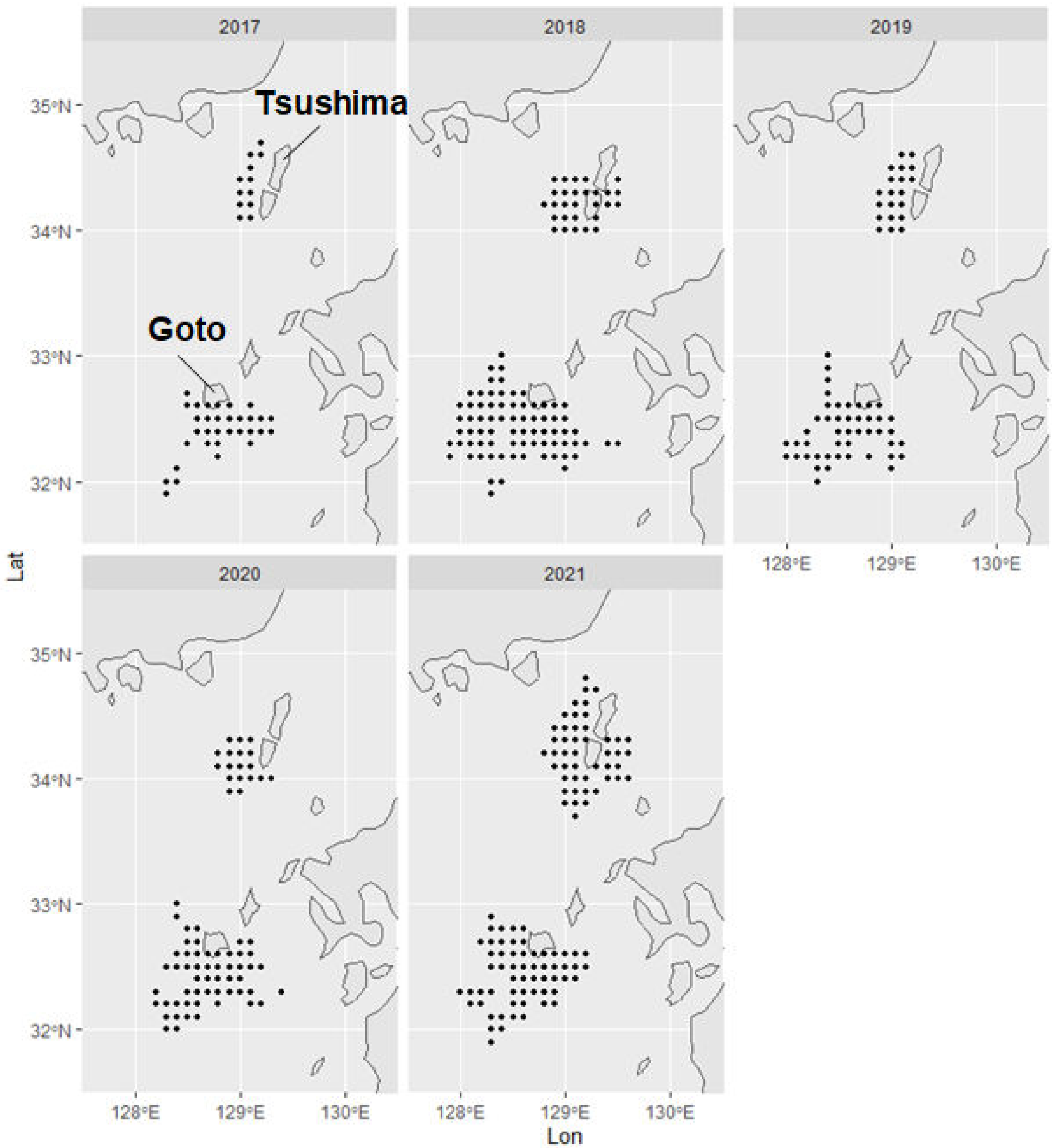

Figure 1 Distribution of troll operations of 14 real-time monitoring vessels from 2017 to 2021 fishing year. Data for the 2021 fishing year includes chartered real-time monitoring in addition to conventional real-time monitoring as in 2017-2020.

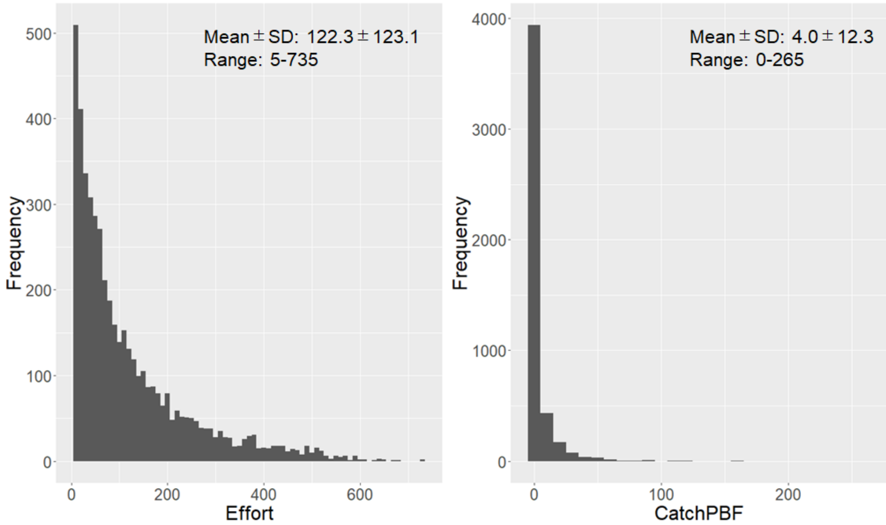

Figure 2 Frequency of fishing efforts (left) and PBF catches (right) for 2017-2021 based on 0.1 degree grid aggregate data.

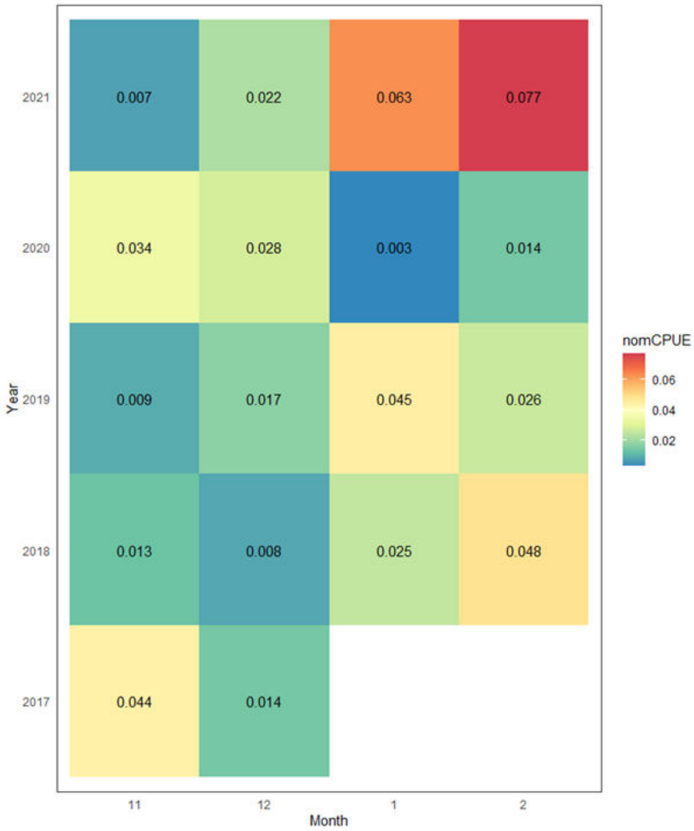

Figure 3 Nominal CPUE during 2017-2021 fishing year for each month (November to following February). No operations during the months of January and February of 2017 due to fishing regulations.

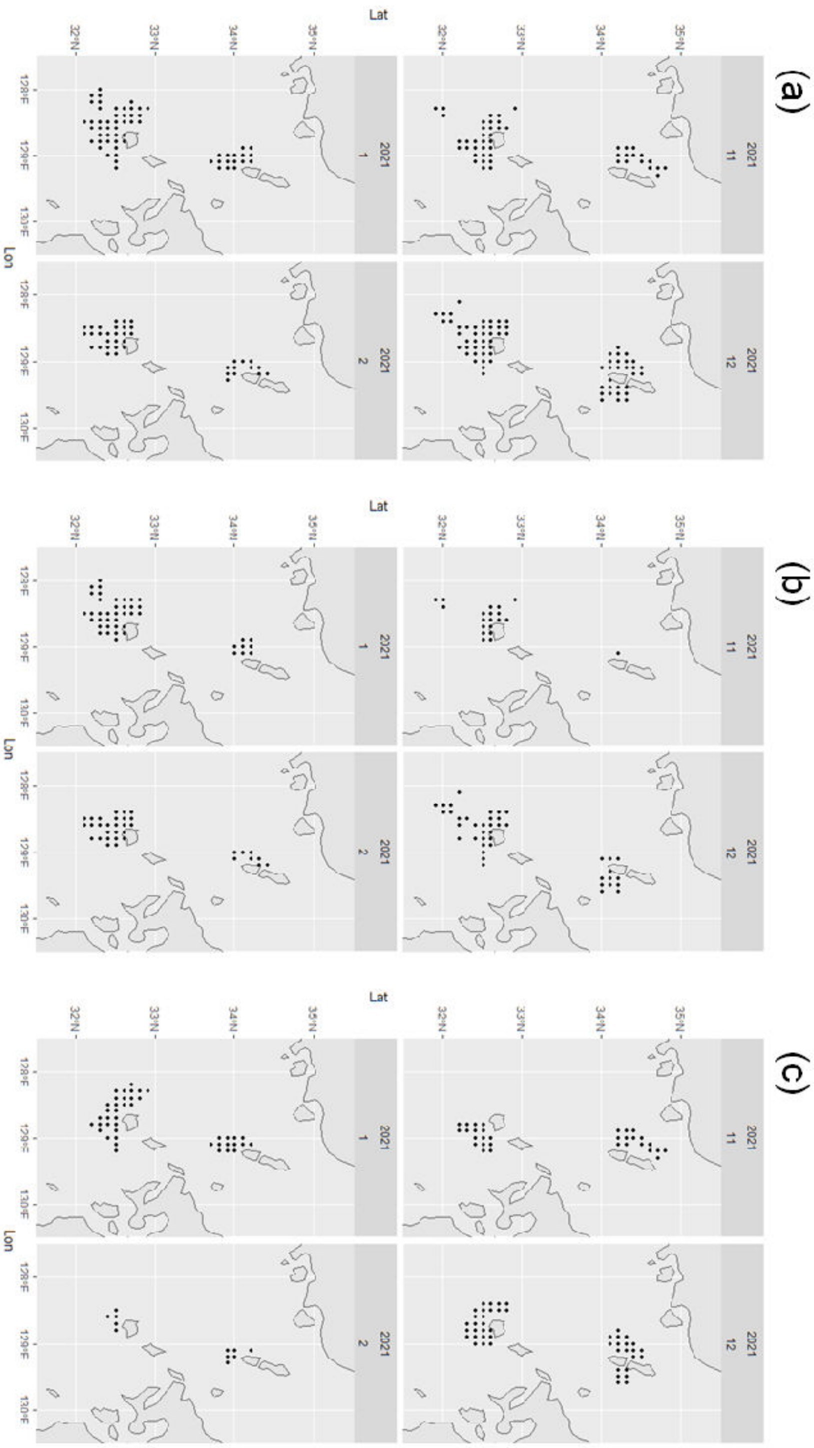

Figure 4 (a) Monthly spatial distribution of troll operations of 13 real-time monitoring vessels for the 2021 fishing year, and of these, (b) conventional real-time monitoring and (c) chartered real-time monitoring.

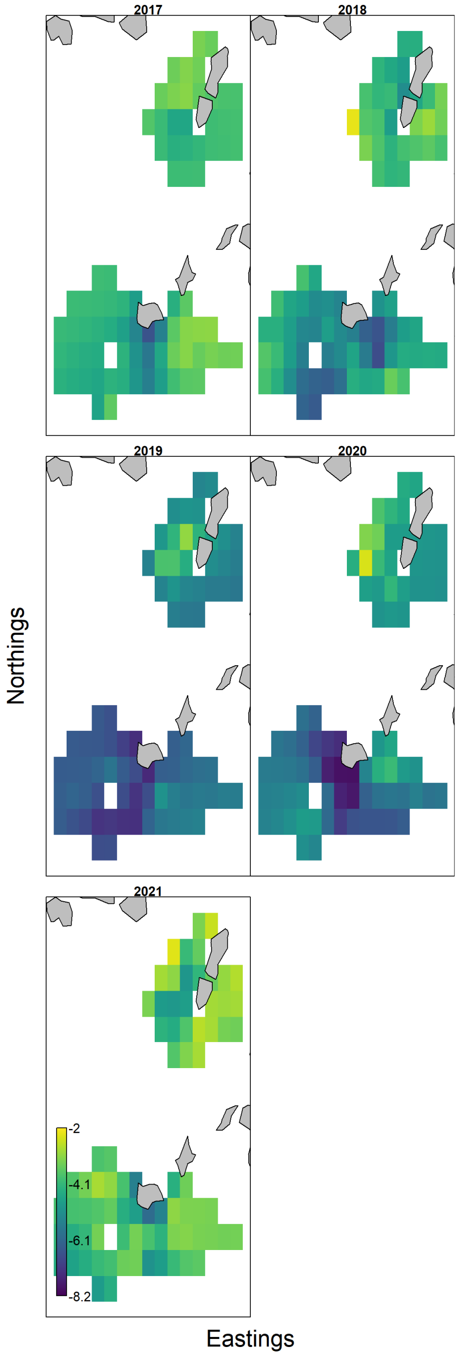

Figure 5 Spatio-temporal distribution of the log-transformed predicted densities of PBF for the 2017-2021 fishing year analyzed by VAST model. Warmer and cooler colors indicate high and low values, respectively.

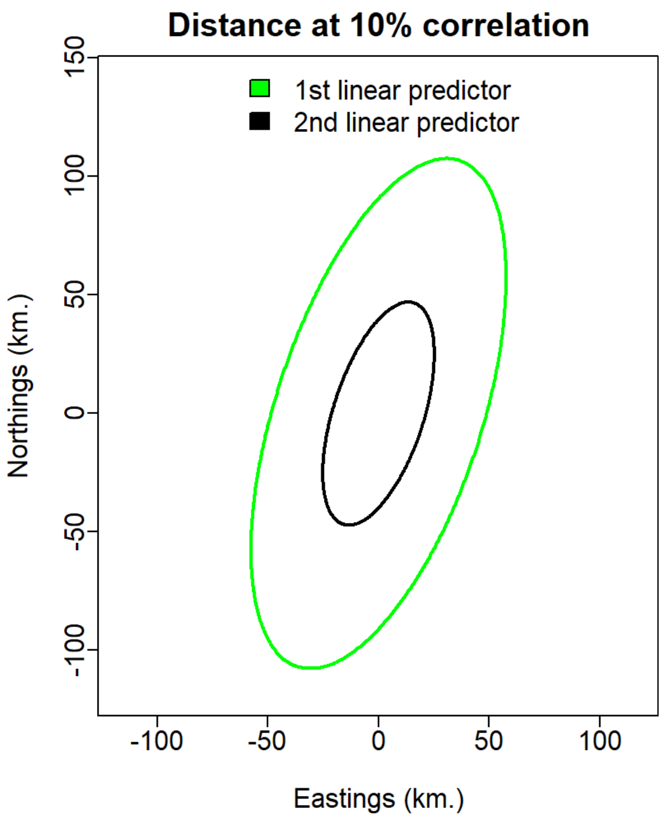

Figure 6 Decorrelation distance for different directions relative to encounter probability and positive catch rate for each of the two data periods 2017-2021. Indicating the magnitude of 2-dimensional spatial autocorrelation, and the ellipse signifies the distance (from a point located at position (0,0)), where the correlation drops to 10 %. The predicted densities correlated over a longer distance in the north-south direction than in the east-west direction.

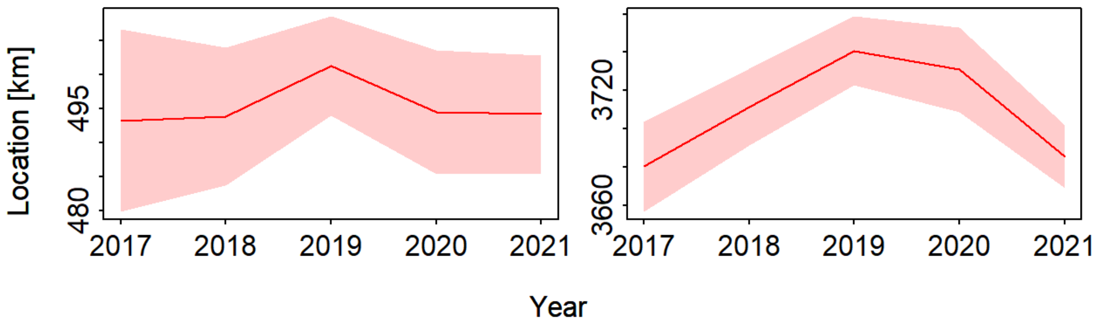

Figure 7 The center of gravity of PBF recruitments indicating the sift in distribution (distance (km)) in the east-west (left) and north-south (right) directions for the periods of 2017-2021. The thick line with shading indicates the mean value and standard error.

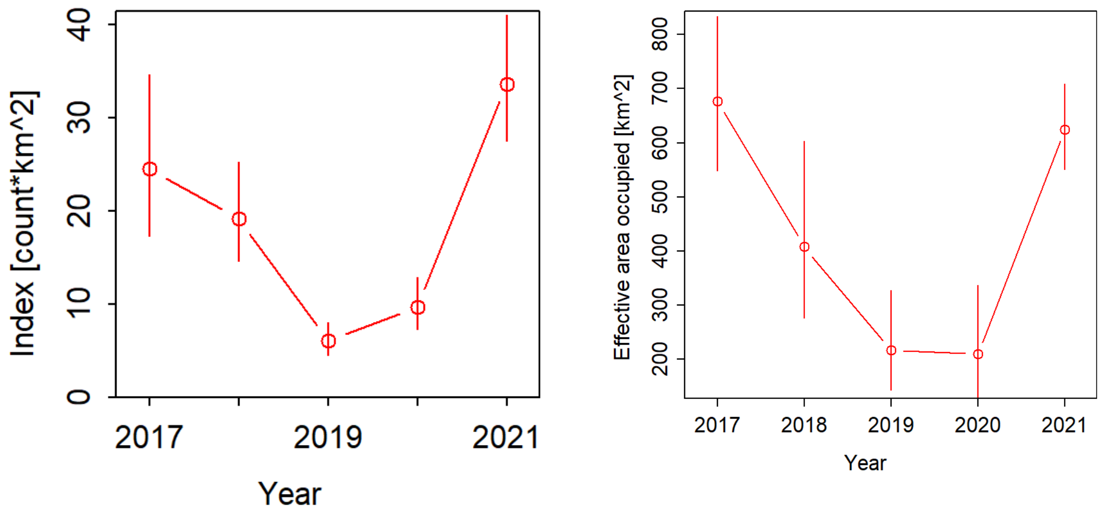

Figure 8 Standardized index of relative abundance of PBF (left) and estimated of the effective area occupied by PBF indicating range expansion/contraction (right) for the periods of 2017-2021. The open circles with vertical lines denote point estimates with standard errors.

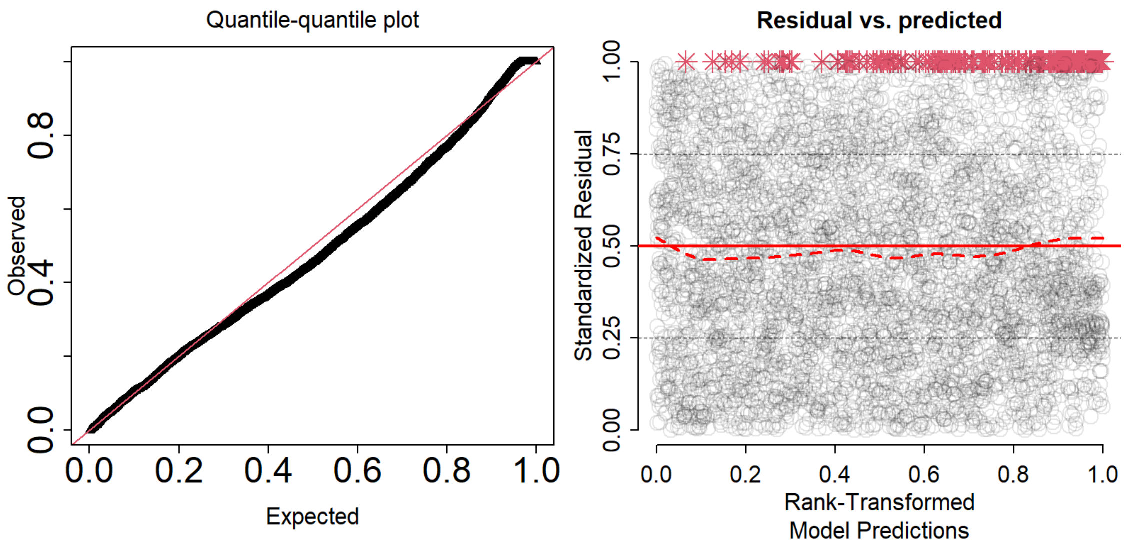

Figure 9 Diagnostic Q-Q plot (left) and residual plots (right) comparing the observed and predicted quantiles for the periods of 2017-2021. The residual plot calculating a quantile regression to compare the empirical 0.5 quantile in y-direction (dashed red lines) with the theoretical 0.5 quantile (red solid line).

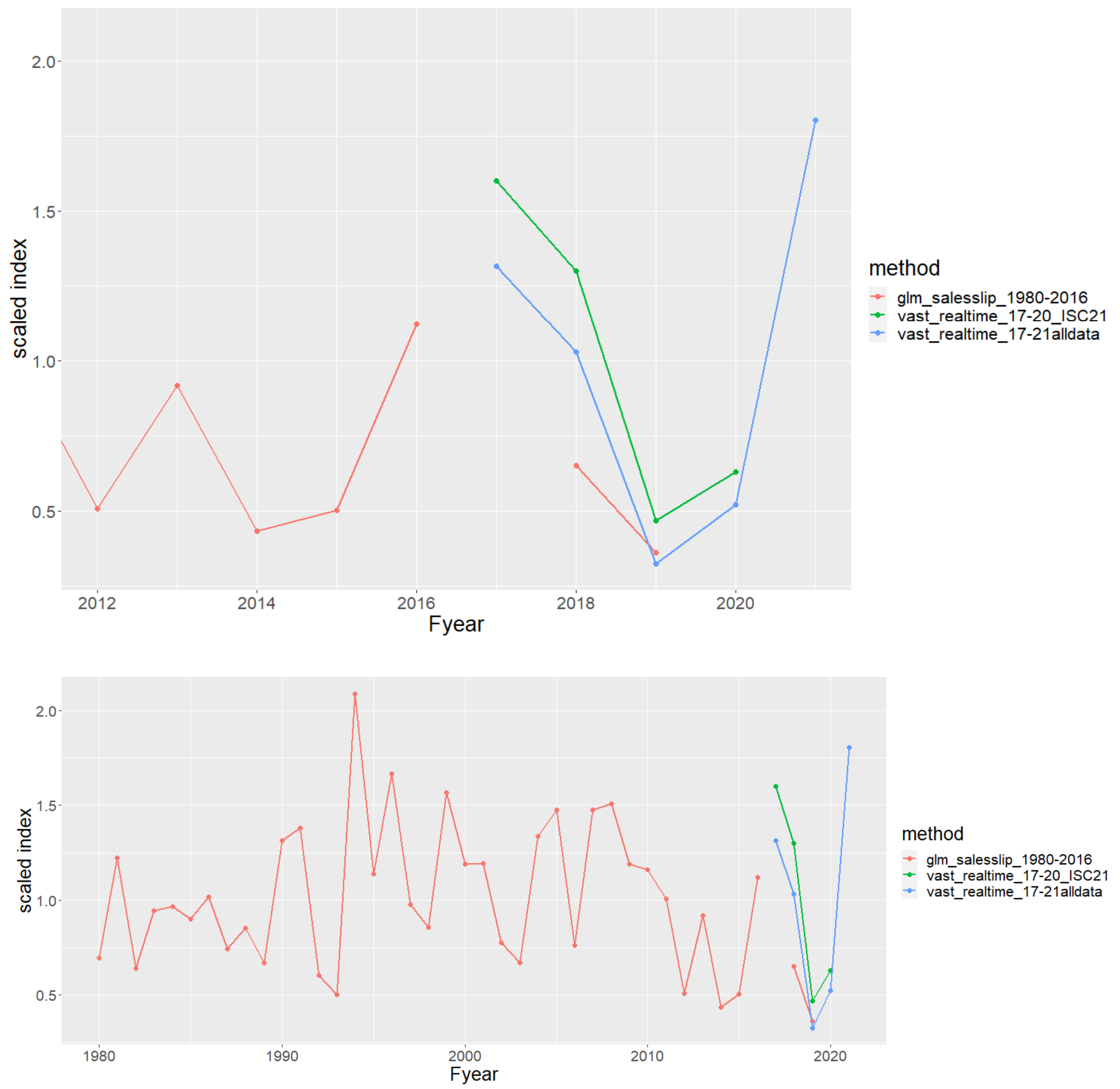

Figure 10 Recent trends of scaled abundance indices on results both traditional GLM (red line) using sales slip data (Nishikawa et al., 2021), VAST analyses for the periods 2017-2020 (green line; Fujioka et al., 2021), and 2017-2021 (blue line; this study) using real-time monitoring data (top). Also, full time-series indices are shown (bottom).

Appendix Recent trends in scaled abundance indices for results from traditional GLM (red line) using sales slip data (Nishikawa et al., 2021), VAST analyses for the period 2017-2020 (green line; Fujioka et al., 2021), and both the 2017-2021 indices based on all real-time monitoring data (blue line) and non-charter real-time monitoring data (purple line).