Update of relative CPUE (up to 2021) of Taiwanese PBF fisheries using delta-generalized linear mixed models (GLMM) and vector-auto-regressive spatiotemporal model (VAST)

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Summary

Total catch of PBF of Taiwanese coastal and offshore fisheries (mainly from longline fishery) reached the highest record of 3,089 mt in 1999 and then declined continuously to the lowest record of 214 mt in 2012. After a slow increase for a period, the catch recovered to 1,154 mt (including 2 mt from south of the equator) in 2020 and 1,475 mt in 2021. Applying traditional delta-generalized linear mix model (delta-GLMM) (without consideration of spatial effect) and vector-auto-regressive spatiotemporal model (VAST) (considered spatial effect in the model) to the reconstructed data, standardized relative CPUE was estimated for three regions: southern fishing ground, northern fishing and two fishing grounds combined. The resulted index of the GLMM exhibited a strong increase in 2020 and 2021 for the southern fishing ground where its series was considered more representative in previous PBFWG meetings. The 2021 CPUE has recovered almost to the level of 2004. On the other hand, while the relative CPUE from VAST showed a similar, but more drastic, increasing trend as the GLMM result after 2012, the increase slowed down in 2021 for unknown reason, which was different from the signal from the nominal CPUE. For the northern fishing ground, the relative CPUE of 2021 from both models apparently declined after a strong increase in 2020. Size of PBF was measured through official port sampling program, with data coverage higher than 95% since 2010. Average fish size in the northern fishing ground was stable at 218-224 cm since 2009, while the size in the southern fishing ground was showing an increasing trend from 212 cm in 2007 to 235 cm in 2012 when the PBF catch was at the historical lowest level, and then a continuous declining trend to 209 cm in 2021 when the catch was recovered to highest record.

Introduction

PBF is an important seasonal target species for the Taiwanese coastal and offshore fisheries. Total catch (including catches from longline fishery and some small coastal fisheries) peaked in 1999 (3,089 mt) and then continuously declined to the lowest level of 214 mt in 2012, less than 10% of the peak catch, and recovered slowly thereafter. After stayed at a low level, the catch recovered to 1,154 mt in 2020 (including 2 mt from south of the equator), and to 1,475 mt in 2021, about the level of 2007 (Fig. 1). Small scale port sampling program to collect length data of PBF was conducted since 2000. The scale gradually increased and since 2010, over 95% of PBF landed were measured.

This study provides an update of historical catch and size information of PBF from Taiwanese offshore longline fishery as well as relative CPUE series standardized by delta-generalized linear mix model (delta-GLMM) (without consideration of spatial effect) which result was adopted for stock assessment purpose in previous years (Chang and Liu, 2016, 2017; Liu and Chang, 2019; Yuan et al., 2019; Chang et al., 2020) and vector-auto-regressive spatiotemporal model (VAST; Thorson and Barnett, 2017) (considered spatial effect in the model) (Chang et al., 2020).

Materials and Methods

Catch and effort data (number of fish and fishing days per trip) was the same as that used in Yuan et al. (2021, ISC/21/PBFWG-1/03), with additional one year data of 2021. The data was reconstructed and compiled using the approach documented in Chang et al. (2017). As in ISC/21/PBFWG-1/03, this study used data of 2003–2021 for GLMM analyses and 2007–2021 for spatiotemporal VAST analyses.

The design of traditional non-spatial model is identical to the one used in ISC/21/PBFWG-1/03: standardizing the catch and effort data using delta-GLMM which separately estimates the proportion of positive PBF catches assuming a binomial error distribution (zero-proportion model), and the mean catch rate of positive catches by assuming a lognormal error distribution (positive-catch model). Akaike and Bayesian information criteria was used to determine the most favorable variable composition of standardization models. Covariates considered in the model included: year (2003–2021), month (May–July), fishing area (northern and southern fishing ground separated by 24.3°N), and vessel size (CT1–CT4). Three standardization runs were performed: on the area-combined data, on the data from the southern fishing ground (the southern region) and the northern fishing ground (the northern region).

The R package VAST (Thorson and Barnett, 2017, version 3.7.1) was also applied to the abovementioned data. VAST is a delta-generalized linear mixed model that separately estimates the proportion of positive PBF catches and the mean catch rate of positive catches, and in this study, considered time-invariant spatial variations, time-varying spatiotemporal variations, and the effect of vessel on catchability.

Results and Discussions

<u>Catch trend and size pattern</u>

PBF catch had been as high as 3,089 mt in 1999 but continuously declined to the lowest record of 214 mt (210 mt from longline fishery) in 2012 (Fig. 1). Thereafter, the catch slowly bounced back and stayed at the level of 400–550 mt during 2014–2019. After this period, the catch jumped up to 1,154 mt in 2020 (including 2 mt from south of the equator) and reached 1,475 mt in 2021. The number of longline vessels in 2020 has slightly increased from 2019 level (7% increase), however, the catch in 2020 is doubled than that in 2019. Number of vessels further increased in 2021 (24% increased) and catch also increased by 27%, comparing to 2020.

Catches in 2021 have increased both in the northern and southern regions. The increase of catch from 2020 to 2019 was more substantially in the southern region (500 mt more) than in the northern region (10 mt more). For 2021, the increase was about 150 mt in the southern region and about 100 mt in the northern region, comparing to 2020. Over 80% of the catch in 2020 and 2021 was made in the southern fishing ground. Comparing nominal CPUE of the vessels that have fished for PBF, 57% of them shows higher CPUE in 2021 than in 2020 (Fig. 2).

Average size of PBF caught by the Taiwanese longline fishery was around 212–220 cm before 2008 (Fig. 3). Thereafter, the average in the northern region stably maintained at 218–224 cm during 2008–2021; while in the southern region, the average size gradually increased since 2008, to 235 cm in 2012, and declined to 210 cm and 209 cm in 2020 and 2021, respectively, showing a different trend from the northern region. The substantial increase of average size in the southern region was considered resulting from the decline of recruitment to the fishing ground; and the decrease since 2013 was a response to more smaller fish recruited to the fishing ground and more large fish removed from the fishing ground (Fig. 4).

Nominal CPUE and preliminary standardization results

Nominal CPUE of the data sets for GLMM analyses and VAST analyses were different due to that the VAST analyses needed geo-location information and so those records without the information were excluded. However, both nominal series showed same trends for 2021: increase in the southern region and the whole region, decrease in the northern region (Fig. 5).

GLMM run fitted the data well (based on the qq-plots and the residual histograms, Fig. 6) for the sub-models on the southern, northern, and whole fishing grounds. From AIC and BIC analyses, standardization separately by fishing grounds has better performance than the one combined both fishing grounds (Table 1); area-separate models were thus considered preferable because the size composition of the two fishing grounds apparently different. The index of the southern region was considered relatively better representing the PBF abundance index than the northern one considering its features of better data stability and with much higher proportion of historical catches; and was recommended to be used for the PBF stock assessment by the PBFWG since 2016.

All the spatiotemporal models have successfully converged, which were confirmed by the fact that the Hessian matrix was positive definite, and the maximum gradient component was smaller than 0.001. Moreover, quantile diagnostics suggested the spatiotemporal model fitted the catch and effort data well (Fig. 7).

Distribution of fishing effort in the core area (fishing days, Fig. 8) showed two major fishing grounds. Pronounced spatiotemporal variations in density were predicted for the period of 2007–2021 (Fig. 9): the densities decreased from the starting year of the study (2007) to the lowest level in 2011 and 2012, and then started to increase gradually toward the end year of the study, while the increase in 2020 and 2021 was substantial apparently. The density pattern in southern region was similar to (for 2020), or higher than (for 2021), that of 2007, with eastward expanding of high-density area.

The standardized CPUE indices by the GLMM and the VAST were plotted together in Fig. 5 for comparison. Index of the southern region from the GLMM showed a strong increase trend since the lowest level of 2012 to 2021, same as the nominal CPUE. Nevertheless, index of the northern region showed a decline in 2021 after a strong increase in 2020. Index of the whole region was mainly affected by the southern index and showed similar trend with the southern index. On the other hand, indices from the spatial VAST standardizations generally showed similar trends with those from the non-spatial GLMM results, but the VAST results exhibited substantial fluctuations of relative CPUEs in both the beginning and the ending years. However, it is worth to note that, for unknown reason, the relative CPUE of 2021 for the southern region did not show a strong increase from 2020 as seen in nominal CPUE and needs further exploration.

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Table 1. Best variable combinations of the delta-lognormal mixed models for GLMM, and the Akaike information criterion (AIC) and Bayesian information criterion (BIC).(ZPM: zero-proportion model; PCM: positive-catch model)

Model type	Final Model formulation	AIC	BIC
Southern fishing ground			
ZPM	Year+Month+CT	23291.88	25355.09
PCM	Year+Month+CT+Year*Month	23483.32	25539.87
Northern fishing ground			
ZPM	Year+Month+CT+Year*Month	8033.735	7283.008
PCM	Year+Month+CT+Year*Month	8185.463	7421.124
Combined southern and northern fishing grounds			
ZPM	Year +CT+Area	40197.36	40405.45
PCM	Year+Month+CT+Area +Year*Month	35365.38	35581.96

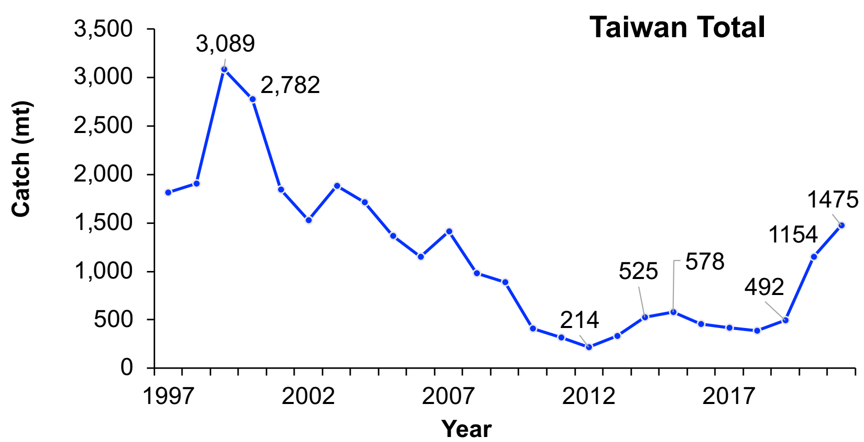

Fig. 1. Annual PBF catches by Taiwanese offshore fishery (mainly longline fishery with minor catches from other small coastal fisheries).

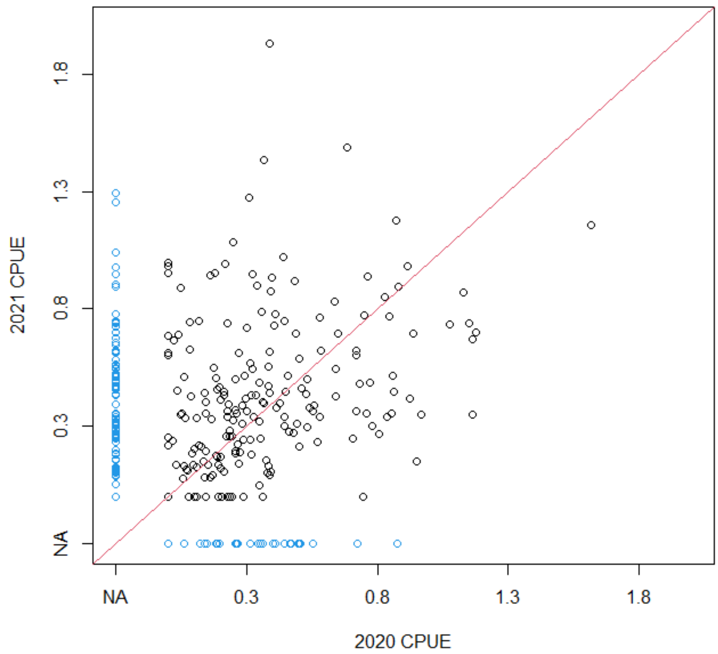

Fig. 2. Nominal CPUE of the vessels that have fished for PBF in 2020 and 2021 (black circles). The blue circles indicate the CPUE of vessels have either fishing in 2020 or 2021 only.

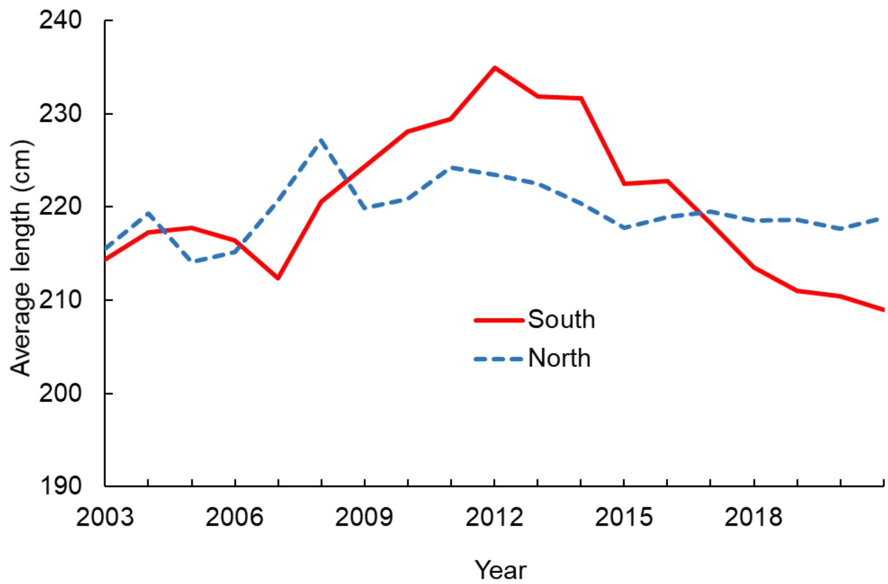

Fig. 3. Annual trend of average length of PBF of Taiwanese longline fishery, by southern and northern fishing grounds.

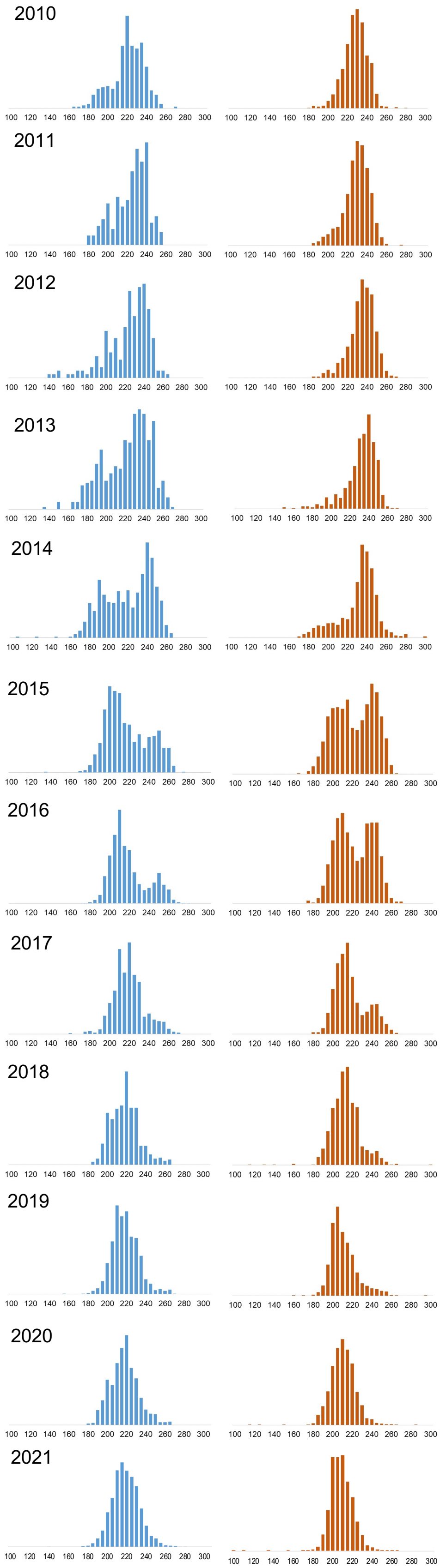

Fig. 4. Length frequencies of Taiwanese PBF during 2010 – 2021 for northern fishing ground (left in blue) and southern fishing ground (right in red).

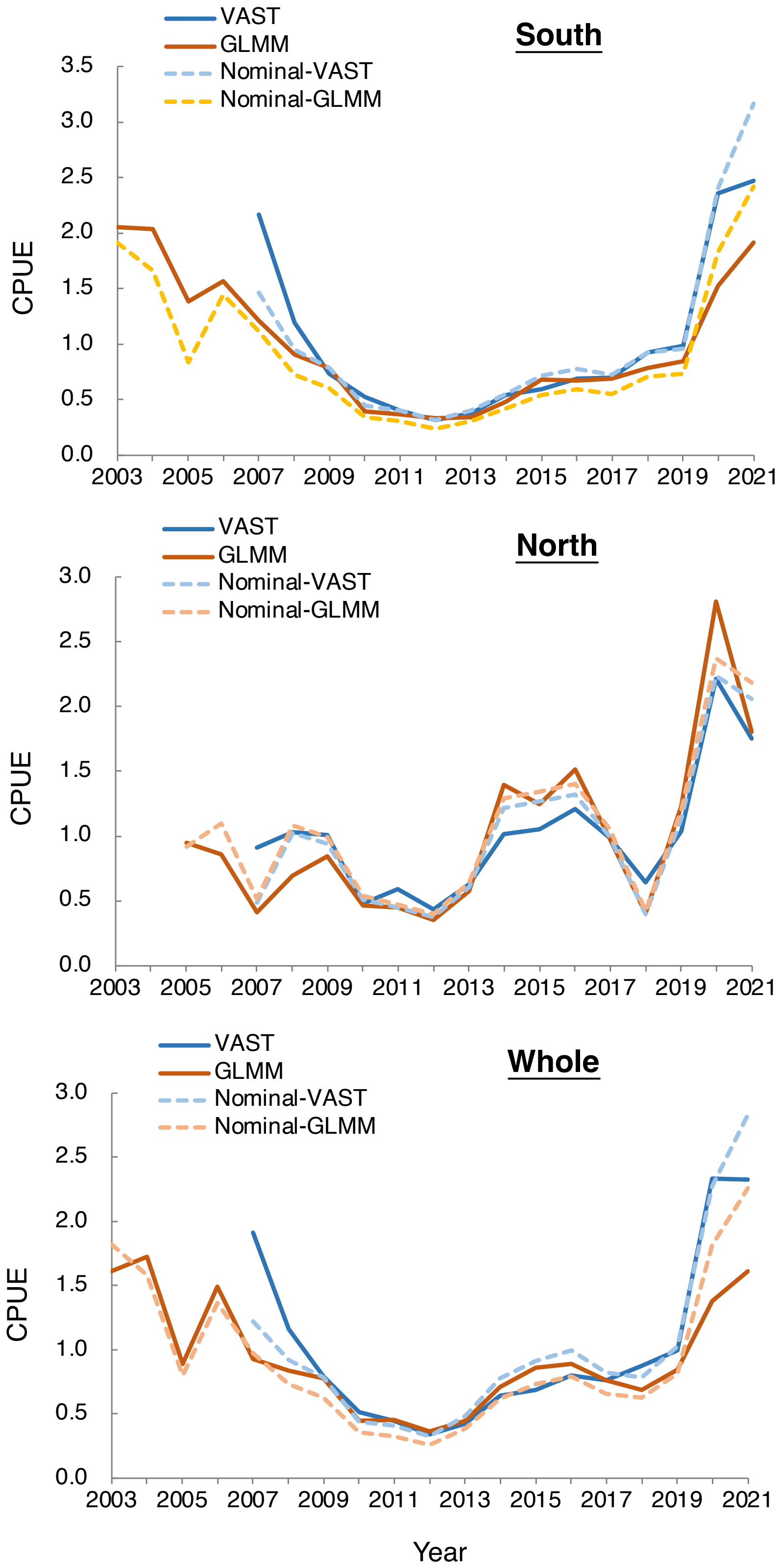

Fig. 5. Nominal CPUE and standardized CPUE series based on delta-GLMM on the whole dataset and on VAST analyses on the core area data, by region.

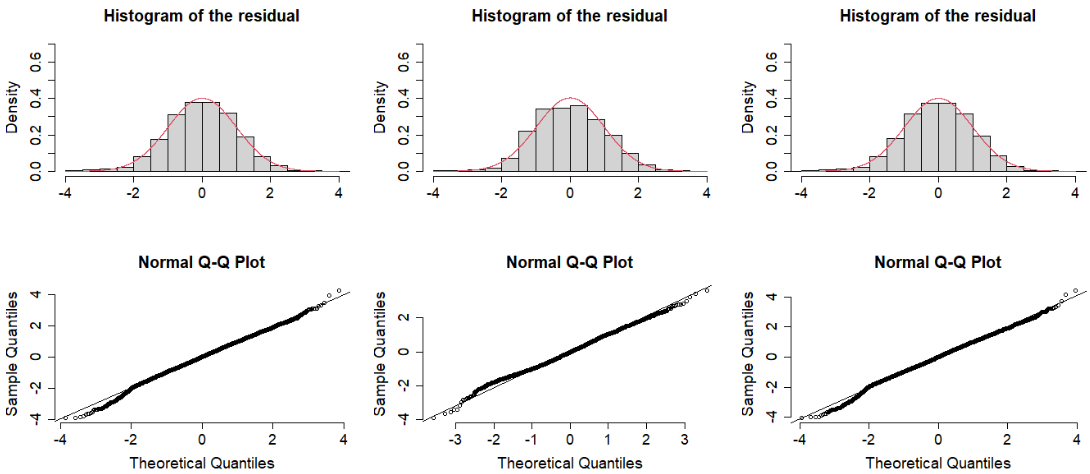

Fig. 6. Diagnostic residual plots (the posterior-predictive residual histogram and qq plot comparing the observed and predicted quantiles of CPUE given encounter) for the traditional delta-GLMM analyses. Panels from left to right are for the southern, northern and whole fishing grounds.

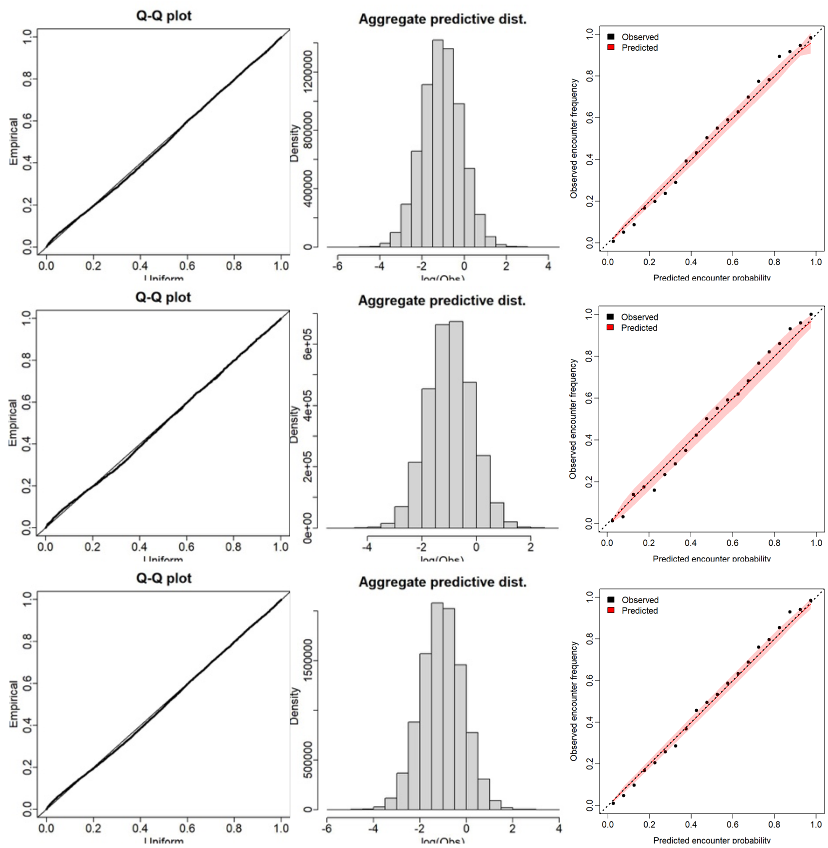

Fig. 7. Diagnostic residual plots for VAST analyses on, from top to bottom, the southern region, the northern region, and the whole region). The graphs from left to right: the qq plot, the posterior-predictive residual histogram, and encounter probability.

(A) (B)

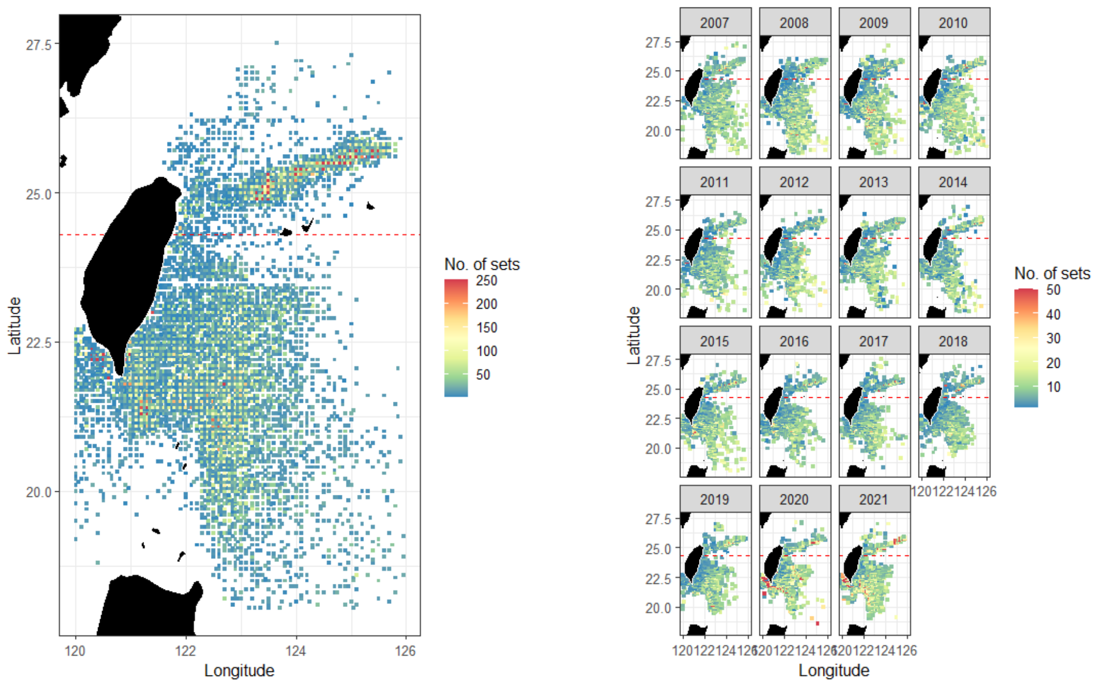

Fig. 8. Geographic distribution of fishing days per 0.1°×0.1° grid cell during 2007–2021: (A) whole period; (B) by year.

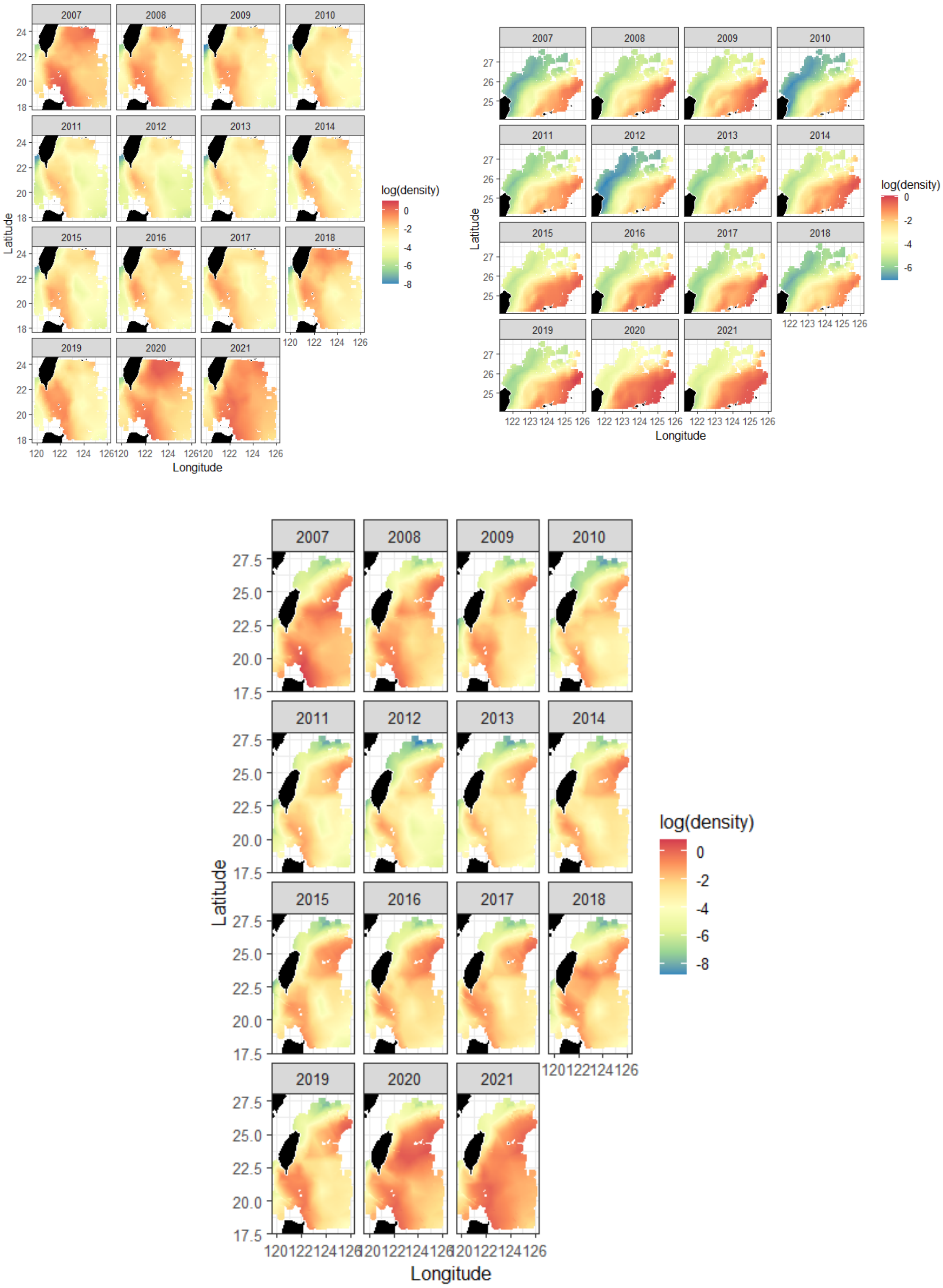

Fig. 9. Spatiotemporal distribution of predicted log density of PBF during 2007–2021 from VAST analyses (upper left – South, upper right – North, bottom: South and North combined).