Updated Abundance Indices for the Taiwanese Pacific Bluefin Tuna Longline Fishery Using GLMM and VAST Models

Shui-Kai Chang and Yu-Hsuan Tai

Sustainable Ocean Governance Center, National Sun Yat-sen University, Kaohsiung, Taiwan

March 2026

Working document submitted to the ISC Pacific bluefin tuna Working Group, International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC), from 24 to 27 March 2026, Sapporo, Japan.

Summary

The total catch of Pacific Bluefin Tuna (PBF) from Taiwanese coastal and offshore fisheries (mainly longline) reached a peak of 3,089 metric tons (mt) in 1999, followed by a continuous decline to a historic low of 214 mt in 2012. In recent years, the catch has shown a significant recovery, reaching 2,262 mt in 2024. The latest preliminary estimate for the 2025 catch is 2,339 mt, the second-highest record in the last two decades.

The average length of PBF was around 212–220 cm before 2008. Subsequently, the average length in the North region remained stable at 218–224 cm, while in the South region, it peaked at 235 cm in 2012 and then trended downwards, stabilizing at 206–210 cm between 2020 and 2025. The latest data from 2025 show that the average length in both the South and North regions is approximately 205–206 cm. Length frequency distributions indicate that the catch composition is dominated by a few cohorts, with its variation primarily driven by recruitment fluctuations.

Following the recommendations of the previous meeting, this study employed the delta-Generalized Linear Mixed Model (GLMM) and the Vector-Autoregressive Spatio-Temporal (VAST) model to standardize the CPUE. A key difference from previous analyses is the exclusion of Sea Surface Temperature (SST) as a covariate, as prior research demonstrated its negligible impact on standardized CPUE within the relatively small and seasonally concentrated Taiwanese fishing grounds. The results show a high degree of consistency between the models: all standardized CPUE series indicate a decline from 2003, reaching a nadir in 2011–2012, followed by a slow recovery and a rapid increase since 2020, suggesting a marked stock recovery.

Introduction

Pacific Bluefin Tuna (*Thunnus orientalis*) is a seasonally important target species for Taiwanese coastal and offshore fisheries. Its stock status declined steadily from 1996, reaching a historically low level in 2010. Reflecting this trend, the total catch of the Taiwanese fishery, which primarily harvests large adult fish, peaked at 3,089 mt in 1999 and subsequently declined to a low of 214 mt in 2012, less than 10% of the peak catch. With the implementation of conservation and management measures for small PBF since 2010, the stock began to recover, with the pace of recovery accelerating in recent years [1].

To continuously monitor the status of the PBF stock exploited by the Taiwanese longline fishery, this report provides updated historical catch and size information, as well as standardized relative abundance indices (CPUE). The analytical methods follow those adopted in previous Pacific Bluefin Tuna Working Group (PBFWG) meetings, primarily using the delta-GLMM, alongside a comparative analysis using the VAST model [2].

A large-scale port sampling program to collect PBF length data has been in place since 2010, with a measurement coverage rate exceeding 95%. This high-coverage Length Frequency (LF) data provides a reliable basis for understanding the catch-at-size structure. This analysis aims to integrate the latest fishery data to provide an updated assessment of PBF stock trends.

Materials and Methods

The catch and effort data (number of fish and fishing days per trip) used in this study cover the period from 2003 to 2025. The data reconstruction and compilation methods follow those documented in Chang et al. (2017) [3]. Two statistical models were used for CPUE standardization:

Traditional Delta-Generalized Linear Mixed Model (delta-GLMM)

The design of this model is identical to that used in previous studies (ISC/21/PBFWG-2/02). The CPUE standardization process is split into two parts: a zero-proportion model assuming a binomial error distribution to estimate the probability of a positive catch, and a positive-catch model assuming a lognormal error distribution to estimate the mean catch rate of positive catches. Covariates considered in the model include: Year (2003–2025), Month, Fishing Area (divided into North and South regions at 24.3°N latitude), and Vessel Size (CT1–CT4). While the fishing season typically spans April to July, this analysis utilized data from May to July to ensure stability in the standardization. However, in 2023–2025, the fishery closed early in June as the national quota was rapidly met due to high catch rates (Fig. 1); thus, data for these years cover only May and June.

For detailed model formulas and statistical derivations, readers are referred to the report by Yuan et al. (2024) [4], which provides a comprehensive description of the mathematical forms of the zero-proportion and positive-catch models. The calculation of the abundance index is also detailed therein.

Vector-Autoregressive Spatio-Temporal (VAST) Model

This model is capable of handling both spatial and temporal variations simultaneously. The model setup is similar to the 2024 study, incorporating spatiotemporal variations, month

effects, and vessel effects on catchability. Specifically, the model uses a logit-linked linear predictor to estimate the encounter probability and a log-linked linear predictor for the positive catch rate.

In the VAST model, spatiotemporal variation is modeled by combining a Gaussian random field for spatial variation with a first-order autoregressive process (AR1) for temporal variation. For detailed model equations and parameter estimation methods, readers are referred to the report by Yuan et al. (2024) [4], which contains the complete mathematical derivations and computational procedures.

This analysis did not include Sea Surface Temperature (SST) as a covariate. Previous analyses have confirmed that due to the small geographical range of Taiwan's PBF fishing grounds and the concentration of the fishing season in the summer months (May to July), water temperature variations are minimal, and thus the effect of SST on standardized CPUE is negligible. The study by Yuan et al. (2024) showed that the CPUE series produced with and without the SST covariate were nearly identical, especially in the South region [4]. This adjustment simplifies the model and avoids unnecessary parameter estimation.

Results and Discussion

Catch Trend and Size Structure

Taiwan's total PBF catch, after peaking at 3,089 mt in 1999, declined continuously to 214 mt in 2012. Since then, the catch has gradually recovered, reaching 1,154 mt in 2020, 2,262 mt in 2024, and a preliminary estimate of 2,339 mt in 2025, indicating a significant stock recovery in recent years (Fig. 1).

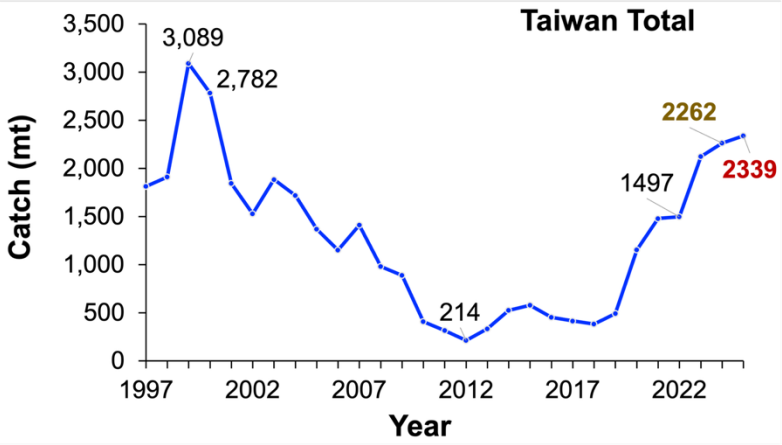

Fig. 1. Annual PBF catches by the Taiwanese offshore fishery.

Regarding average length, the mean size in the South region peaked at approximately 235 cm in 2012 before declining and stabilizing around 206–210 cm after 2020. The average length in the North region has been relatively stable. By 2025, the average lengths in both regions converged to approximately 205–206 cm (Fig. 2). This trend, consistent with observations from the length frequency distributions (Fig. 3), suggests that the catch composition is primarily influenced by fluctuations in recruitment rather than systematic changes in the fishing grounds.

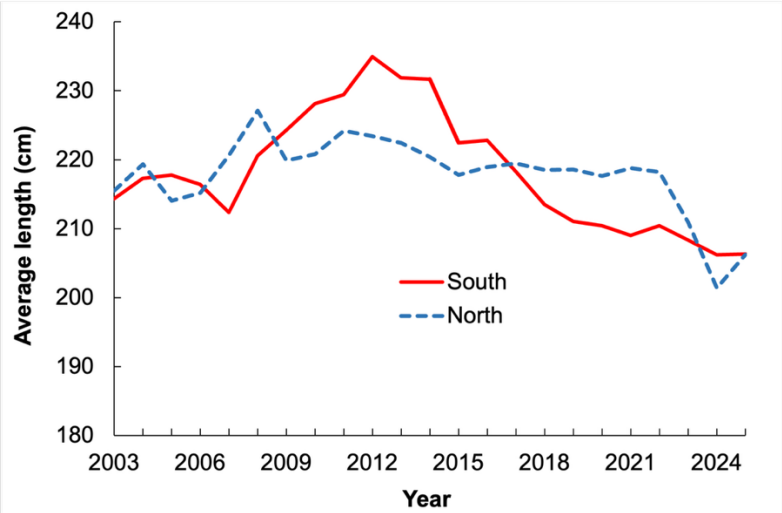

Fig. 2. Annual trend of average length of PBF from the Taiwanese longline fishery by region.

Biological Interpretation of Size Fluctuation

The sustained decrease in average length accompanied by an increase in catch volume is a critical biological signal. This phenomenon indicates that a large number of smaller individuals (new recruits) are entering the fishery, forming the main component of the current catch. This pattern is consistent with the typical characteristics of a stock in the early stages of recovery, where an influx of young individuals gradually replenishes a depleted stock. The concurrent facts of decreasing length and increasing catch further confirm that strong recruitment has been supporting the Taiwanese PBF fishery in recent years.

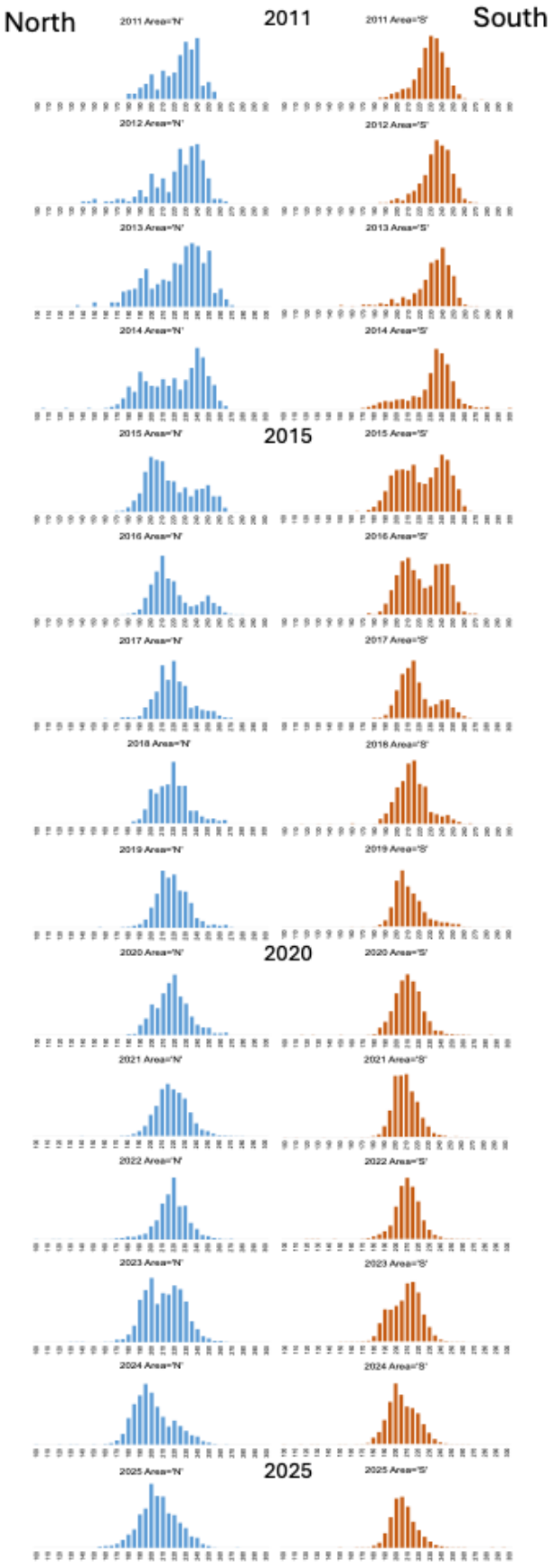

Fig. 3. Length frequencies of PBF from the Taiwanese longline fishery by region (2011–2025)

Distribution of Fishing Effort

The geographical distribution of fishing effort (Fig. 4) shows a stable fishing ground structure over the years, with the main operational area concentrated in the waters southwest of Taiwan (the South region). Although fishing effort increased in the outer southwestern waters after 2020, the catch rates there were relatively low. Overall, the distribution of fishing grounds in 2025 is consistent with the historical pattern.

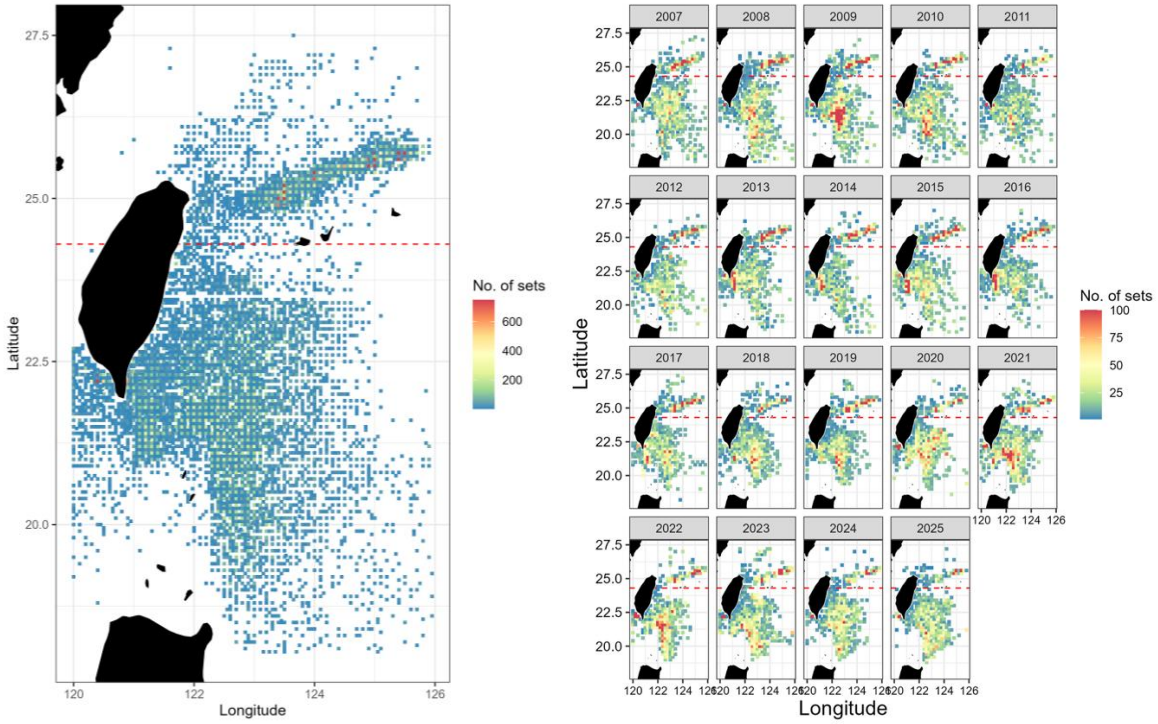

Fig. 4. Geographic distribution of fishing effort for the Taiwanese longline fishery (2007–2025).

Relative Abundance Index (CPUE) and Stock Status Assessment

This study updated the standardized CPUE series from the GLMM and VAST models to 2025 (Fig. 5). The results show a high degree of consistency between the trends produced by the two models, especially the growth trend after 2022, which is nearly identical. Compared to the previous year's assessment, the new series exhibits a similar pattern of variation, but the upward trend in CPUE has become steeper since 2020, reflecting an accelerated stock recovery.

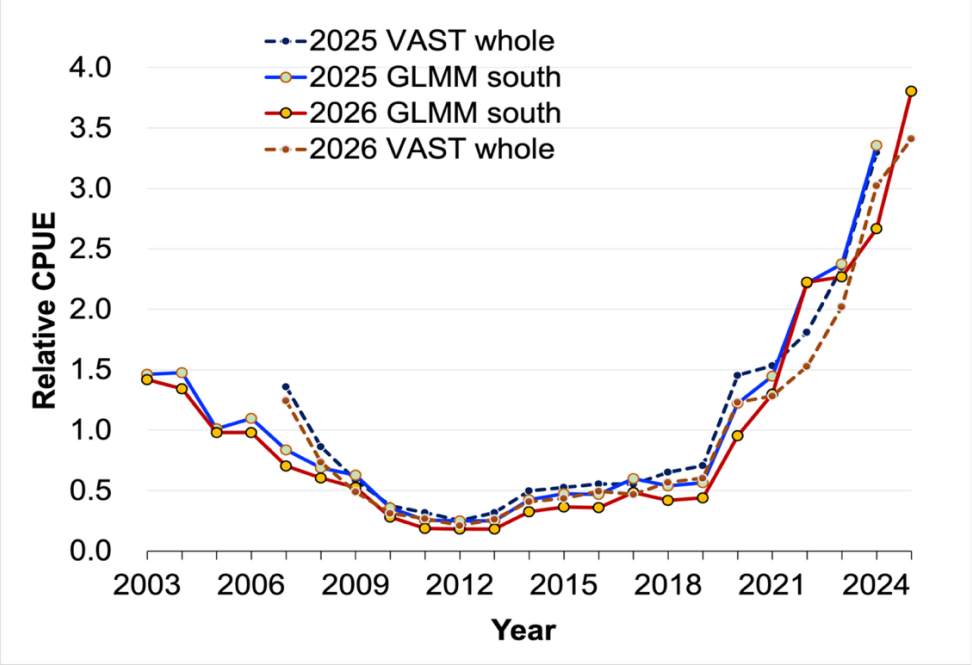

Fig. 5. Comparison of standardized relative CPUE indices for PBF from the Taiwanese longline fishery. "2025" and "2026" means the results obtained in 2025 study and in 2026 study, respectively.

Long-Term Trend

All standardized CPUE series indicate a consistent pattern of stock dynamics. From 2003 to 2011, the CPUE showed a continuous decline, reflecting stock depletion. During 2011–2012, the CPUE reached a historic low, marking the bottom of the stock status. Thereafter, the CPUE began a slow recovery, indicating gradual stock rebuilding.

Recent Growth and Stock Density

The most significant change occurred after 2020. The slope of the standardized CPUE became markedly steeper during this period, indicating rapid growth in stock density. According to the latest data from 2025, the relative CPUE from the VAST whole-area model has reached a historic high. In contrast to the CPUE at the beginning of the series in 2003, the current stock density has increased by more than 130% relative to the start of this data series. This rapid growth trajectory is fully consistent with the rising catch trend, further confirming the strong recovery of the stock.

Model Comparison and Consistency

The 2025 data included in this year's analysis shows that the GLMM and VAST models produce highly consistent results since 2009, demonstrating that both the traditional non-spatial model and the spatiotemporal model reach similar conclusions about the stock trend during the recent period. This consistency in the observed data period enhances the credibility of the analysis for assessing the current stock status and indicates that the stock recovery trend in recent years is robust and not dependent on a specific model choice.

Conclusion

Based on this updated information, the PBF stock exploited by the Taiwanese longline fishery shows strong signs of recovery. The synchronous increase in catch and standardized CPUE indices, coupled with a decrease in the average size of captured fish, confirms that the fishery has been supported by strong recruitment in recent years. This combination of biological characteristics (increased catch, decreased length, and rapidly rising CPUE) clearly indicates that the stock recovery is driven not only by management measures but, probably more importantly, by the entry of strong year-classes into the fishery.

From a technical standpoint, this year's analysis further validates the high consistency between the results of the GLMM and VAST standardization methods, especially in their growth trends after 2022. This consistency demonstrates that the 2025 stock recovery trend is robust and reliable, regardless of the statistical model employed.

Based on the above analysis, it is recommended that the PBFWG adopt this updated standardized CPUE index. Furthermore, given the advantages of the VAST model in handling spatiotemporal effects and its high consistency with the GLMM South-region index in recent trends, it is recommended that the PBFWG further evaluate whether the VAST whole-area analysis should gradually replace the traditional GLMM South-region index in the future. This would allow for the full utilization of available spatial information and might improve the precision of the stock assessment.

References

[1] ISC. 2023. Stock assessment of Pacific bluefin tuna. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean.

[2] Thorson, J.T., and Barnett, L.A.K. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and invertebrates. *ICES Journal of Marine Science*, 74(5): 1384-1402.

[3] Chang, S.-K., et al. 2017. Reconstruction of catch and effort data for the Taiwanese offshore longline fishery targeting Pacific bluefin tuna. ISC/17/PBFWG-1/06.

[4] Yuan, T.-L., S.-K. Chang, and H. Xu. 2024. Developing abundance indices for Taiwanese PBF longline fishery using GLMM and VAST, incorporating SST and size data. ISC/24/PBFWG-1/05.