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Skipjack Management Procedure Estimation Method Analysis: Japanese Pole-and-Line CPUE

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Contents

Executive Summary

The regional Japanese pole-and-line (JPPL) CPUE indices are key inputs to the estimation method used in the skipjack tuna management procedure (MP) adopted by the Western and Central Pacific Fisheries Commission (WCPFC) in 2022. Since then, several points have been raised during previous SC meetings and through the WCPFC skipjack tuna monitoring strategy report regarding these important indices within the MSE framework.

This paper investigates key issues that have been highlighted to ensure the robustness of the skipjack MP and its output:

- the origins of differences in the CPUE time series used within the 2022 dry run and the 2023 implemented MP run,
- the robustness of the MP to the potential technical transition from VAST to the sdmTMB platform, prompted by technical issues with VAST and as recommended by recent stock assessment analyses,
- the impact of any future degradation in tropical JPPL data availability on MP performance through simulation testing.

The analyses found:

- The index used within the 2022 dry run analysis contained inconsistencies in the penalty application within MFCL and did not implement the sea surface temperature (SST) spatial filter. Reapplying the SST filter and correcting the penalty calculations restored consistency with the tested MP.
- The use of sdmTMB for CPUE standardisation, resulted in CPUE time series and MP outputs comparable to those from the original VAST platform. The improved functionality of sdmTMB would be beneficial for future skipjack index development for the estimation method and produced results consistent with the MP testing.
- Simulations indicated that the MP remained robust under significant degradation of future JPPL data in equatorial regions, with estimation method outputs closely tracking the operating model (OM) across various fishing effort scenarios.

Therefore, we conclude:

- The current skipjack MP remains valid and is recommended for use in the 2026 management cycle.
- The transition to sdmTMB has minimal impact on MP outputs and is acceptable under current MP settings.
- The estimation method is robust to short-term loss of JPPL data, but long-term data degradation remains a risk and needs to be addressed.

We invite the SC21 to:

- Note the results of the investigation of the JPPL CPUE time series.
- Support the continued use of the adopted skipjack MP for the next implementation cycle.

- Note that settings used to develop standardised CPUE indices should be included within MP documentation for all relevant WCPFC management procedures.
- Provide guidance on alternative abundance indices or inputs for longer-term MP development.

1 Introduction

The Western and Central Pacific Fisheries Commission (WCPFC) adopted a management procedure (MP) for skipjack tuna (*Katsuwonus pelamis*) in 2022 CMM2022-01, following extensive testing within a management strategy evaluation (MSE) framework. The MP relies on an estimation method derived from the 2019 skipjack stock assessment (Vincent et al., 2019), which incorporates standardised catch-per-unit-effort (CPUE) indices from the Japanese pole-and-line (JPPL) fishery.

Following its implementation, the MP elements have been regularly evaluated by the Scientific Committee, guided by the WCPFC skipjack tuna monitoring strategy report framework. These discussions highlighted some key areas for further investigation to improve understanding of the development and performance of the management procedure and to improve its robustness to changes in the fishery. The current paper examines three different areas:

1. In 2022, prior to adoption of an MP by WCPFC19, the potential performance of the estimation method was examined through a 'dry run' of the MP using the available data, including the underlying standardisation of the pole and line CPUE data (Scott et al., 2022). In 2023, the MP adopted under CMM 2022-01 was run for the first time (Scott et al., 2023). SC19 noted that while both MP runs resulted in the same MP output (scalar = 1). The data used to determine the estimate in 2023 was not entirely consistent with that used for the dry run of the MP in the previous year, and that "SPC and Japanese colleagues [would work] together to identify the issue in last year's dry run" (SC19 summary report para 456). We therefore review and compare the workflows used to produce JPPL CPUE input for the 2022 dry run and the 2023 implemented MP and evaluate their consistency with the settings used when testing the MP under the MSE framework.

2. For the tested MP, CPUE standardisation for JPPL used a spatiotemporal delta-lognormal generalised linear mixed model (delta-GLMM), implemented in R via the VAST package (Thorson, 2019). This approach accounts for spatial and temporal autocorrelation and improves the precision of abundance indices. In principle, once a MP is adopted, the data analysis in the estimation method should remain consistent with that used during testing. However, technical constraints, such as software version compatibility and evolving dependencies, have increasingly hindered the reproducibility of earlier results using VAST. This issue was also noted in Teears et al. (2023). In response, SPC transitioned to the sdmTMB platform in 2023 to perform the geostatistical CPUE standardisation for recent stock assessments, including the current 2025 JPPL standardisation (Nishimoto et al., 2025). For future running of the skipjack MP, it seems appropriate to utilise the sdmTMB platform. We therefore re-run the implemented MP using the latest JPPL CPUE indices developed using sdmTMB and compare the results to those produced using VAST to assess the implications of a transition from the VAST to the sdmTMB platform.

3. The recent spatial contraction of the JPPL fishery, particularly in equatorial regions (Fig. 1), has been noted within the WCPFC skipjack tuna monitoring strategy report, raising questions about the representativeness of future JPPL CPUE data. This is particularly critical given that, as noted, the data collection and estimation method are fixed once the MP is adopted. A decline in data coverage or quality could therefore compromise the accuracy of stock status estimates and, in turn,

the robustness of MP performance over time. We therefore conduct simulation tests within the MSE framework to explore how assumptions about future JPPL data quality affect estimation method performance. We evaluate the robustness of MP performance where future JPPL CPUE indices from the equatorial region are removed completely (an extreme scenario), while preserving confidence in data from the consistently fished temperate regions, under different future fishing levels.

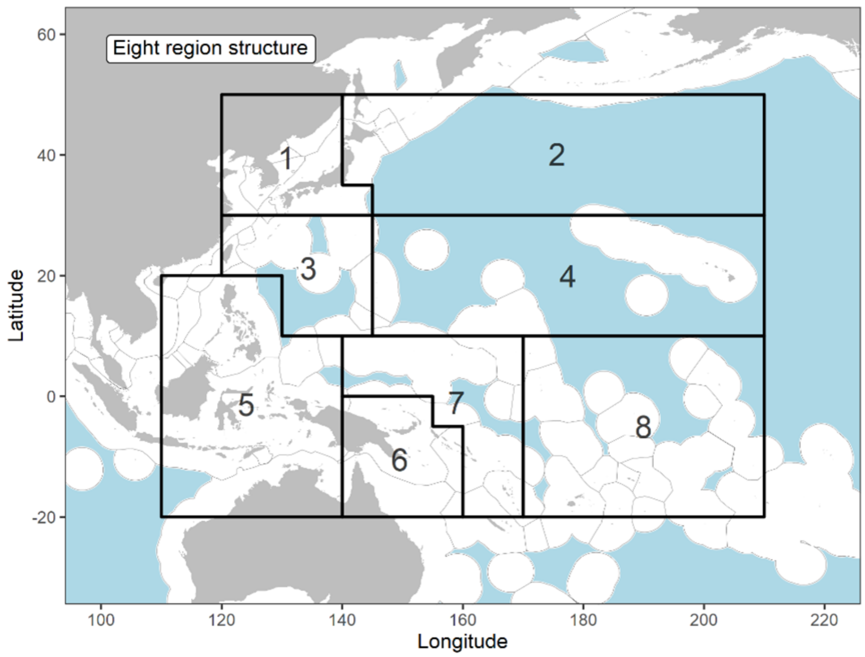


Figure 1: The geographical area covered by the stock assessment and the boundaries for the 8 region assessment models.

2 Difference in JPPL CPUE Between 2022 Dry Run and 2023 MP Implementation

Our investigation identified two key differences between the 2022 dry run and the 2023 MP run input CPUE indices: (i) differences in the penalty terms applied to the JPPL fishery; (ii) differences in the CPUE time series for model Regions 1 and 2.

2.1 Penalty Impact

The first difference concerns the penalty weights applied to the JPPL CPUE time series, which are derived from the time-varying coefficient of variation (CV) output of the geostatistical model. The penalty is calculated using the following equation:

$$\text{Penalty} = \frac{1}{2 \times CV^2} \tag{1}$$

This formula reflects an inverse relationship between the penalty and the CV: as uncertainty increases (i.e., higher CV), the penalty weight applied to the CPUE observation decreases. In other words, data points with higher uncertainty contribute less to the total likelihood calculation. Based on this theory, two key issues were identified with the penalty terms used in the 2022 dry run:

- **Temporal inconsistency in penalties:** The penalty values increased over time (i.e. CVs reduced), despite a contraction in JPPL fishing effort and reduced data availability in recent years. In theory, fewer data should result in higher uncertainty, thus higher CVs and lower penalties, yet we observed the opposite trend in the dry run.
- **High penalties on low CPUE values:** In the final years of the CPUE time series, penalties were high when CPUE values were low. This is problematic because low CPUE in this context could also reflect sparse or missing observations, not strong biological signals. Applying high penalties to such uncertain data gives them high influence in the model.

Further investigation revealed that, during the 2022 dry run, penalty terms were calculated by directly applying the standard error (SE) as the penalty, consistent with the approach used in the 2022 skipjack stock assessment (Castillo-Jordan et al., 2022). Once corrected (Fig. 2), the updated penalties showed a more expected pattern, with a gradual decline from earlier years to the present and no anomalous peak near the terminal year.

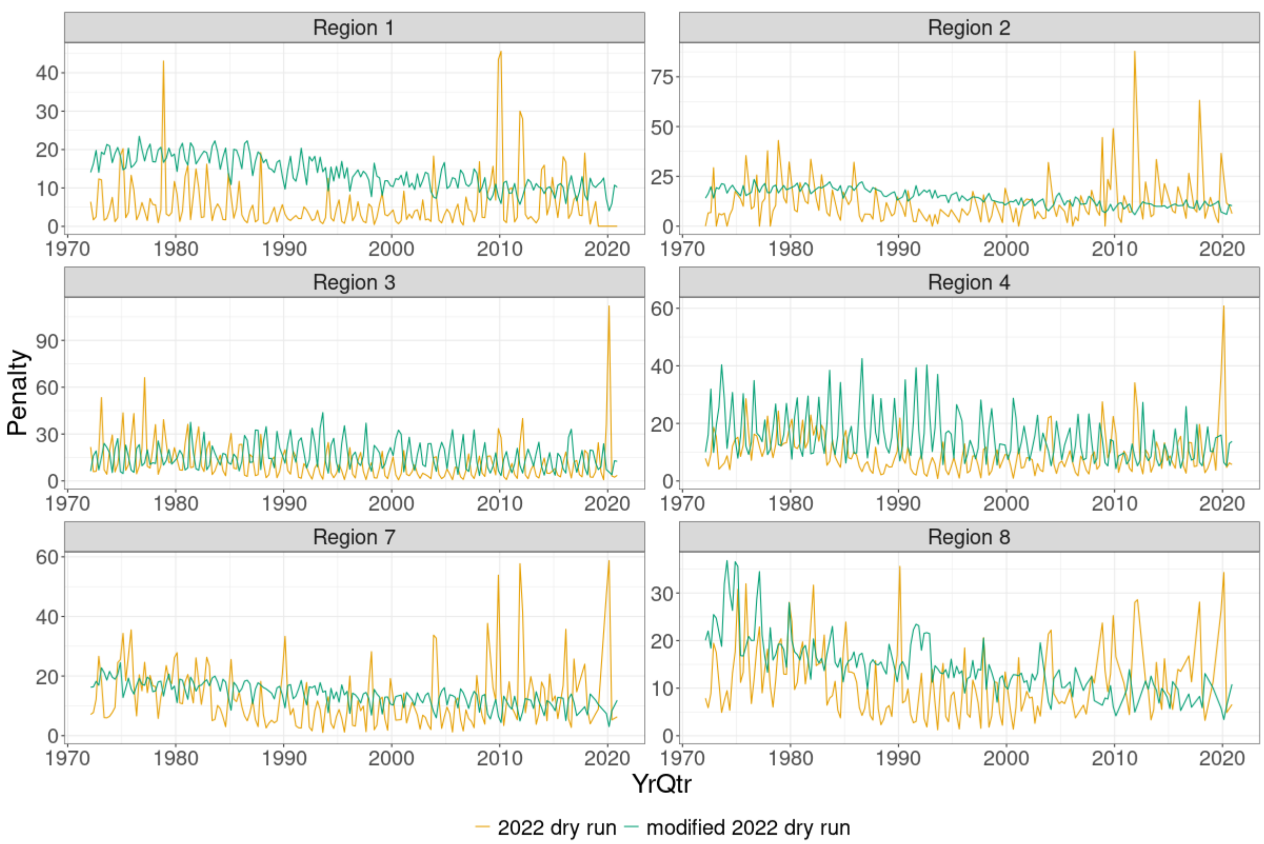


Figure 2: Comparison of the JPPL CPUE penalty terms from modified 2022 dry run and 2022 dry run.

This highlights the challenges of conducting a stock assessment and a MP run in the same year. Stock assessments are frequently updated with new methods, whereas the estimation method used in an MP should remain fixed. Conducting both processes concurrently increases the risk of method misspecification and inconsistencies, particularly when methodological updates in the stock assessment inadvertently influence the estimation method used for the MP.

2.2 Sea Surface Temperature Filter for CPUE Indices

Specifically for Regions 1 and 2 of the model, differences observed in the CPUE time series appear to be primarily driven by differences in the application of the sea surface temperature (SST) filter. SST is a key environmental covariate influencing the distribution of skipjack tuna, a tropical species with a lower thermal tolerance threshold of approximately 18°C, below which it is rarely encountered (Kiyofuji et al., 2019). Given its biological relevance, SST has been incorporated into geostatistical CPUE standardisation both as a covariate and as a spatial filter. In the tested MP, the 18°C threshold was used to exclude grid cells with environmentally unsuitable habitats from the CPUE standardisation.

However, in the 2022 dry run, SST was included only as a covariate and not applied as a spatial filter. Our investigation indicates that this omission contributed to inconsistencies in the CPUE time series, particularly in Regions 1 and 2. When the SST filter was reapplied, the resulting CPUE trends were more consistent with outputs from the tested MP (Fig. 3).

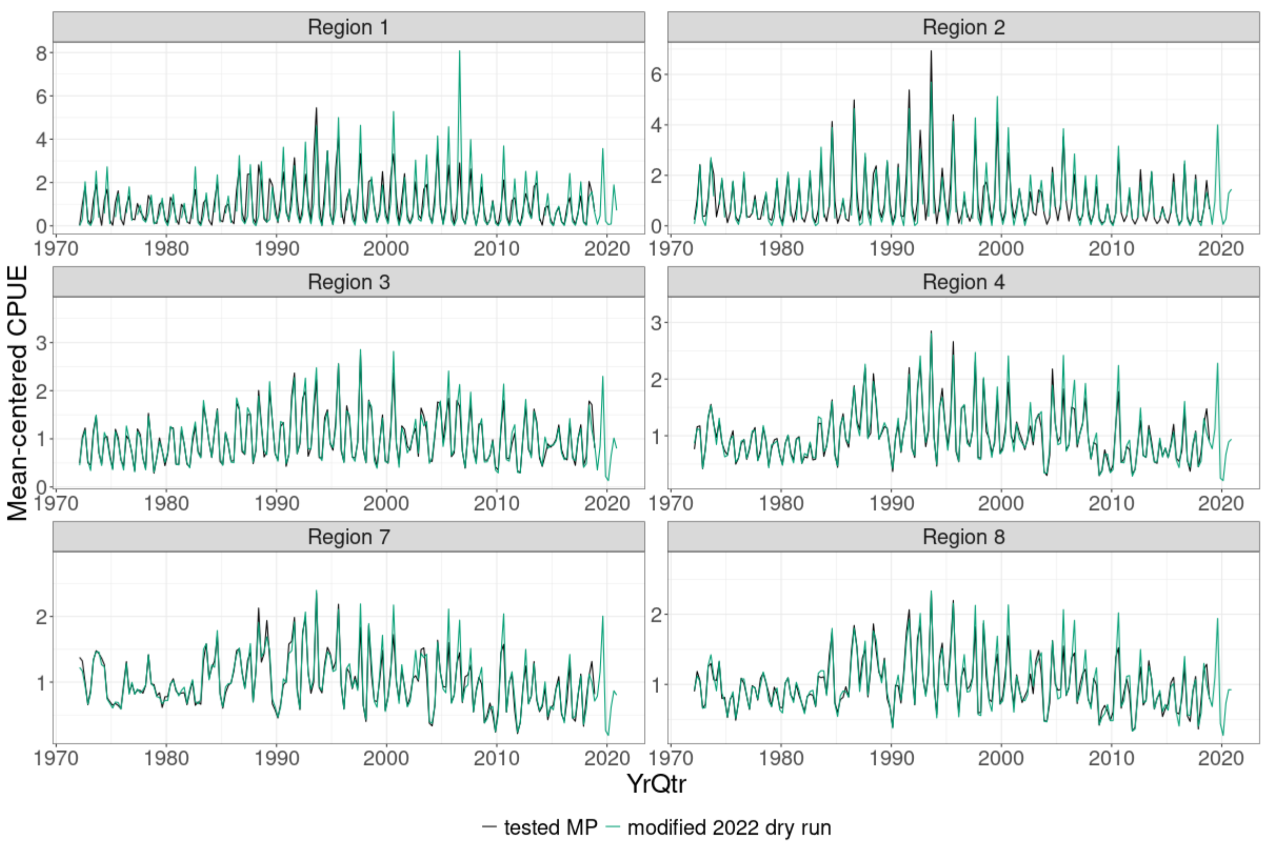


Figure 3: Comparison of the JPPL CPUE time series from the tested MP and modified 2022 dry run with the SST spatial filter applied to the CPUE.

To maintain consistency with the estimation method tested during the MSE process, the SST spatial filter should be implemented in future MP runs. This adjustment would improve the biological realism of the CPUE standardisation, particularly in the northern region.

In summary, Table 2 outlines the settings for CPUE standardisation and post-processing steps applied to the JPPL data in the tested skipjack estimation method. As a guiding principle, all future skipjack MP runs should adhere to these settings and procedures to maintain consistency with the tested estimation method. Any deviations should be clearly justified and subjected to thorough testing. Once the MP is adopted, the CPUE standardisation code should also be packaged using a containerisation platform (e.g., Docker) to preserve the original version and ensure reproduceibility.

3 sdmTMB Update

As noted, the skipjack MP evaluations are based on the 2019 stock assessment, which used a geostatistical model implemented via the VAST package in R (Thorson, 2019). However, due to the technical limitations associated with VAST, the geostatistical CPUE analysis for the stock assessment has been transitioned to the sdmTMB platform starting in 2023 (Teears et al., 2023). Accordingly, the 2025 JPPL CPUE standardisation for the skipjack stock assessment is conducted using the sdmTMB platform. This transition is documented in a comparison study by Nishimoto et al. (2025).

In principle, once a MP is adopted, the estimation method, including the CPUE analysis, should remain consistent with that used during the MP testing phase. However, given the transition in the stock assessment, we propose a parallel transition to the sdmTMB platform for future MP runs.

To assess the impact of this change, we reran the 2023 MP evaluation using the JPPL CPUE time series generated via sdmTMB (Nishimoto et al., 2025), which are intended for the 2025 stock assessment.

Table 1: Comparison of models applied in the tested MP and 2025 JPPL CPUE analysis.

	Tested MP	**2025 JPPL analysis**
Model Method	Spatiotemporal delta-lognormal generalized linear mixed model (delta-GLMM)	
Model Equations	$p_i \sim YearQtr + VesselID + \omega_1(x_i) + \phi_1(x_i, t_i) + Class + s(NumPoles) + s(grt) + \xi_1(x_i, t_i)$ $c_i \sim YearQtr + VesselID + \omega_2(x_i) + \phi_2(x_i, t_i) + Class + s(NumPoles) + s(grt) + \xi_2(x_i, t_i)$	$p_i \sim Year + month + VesselID + \omega_1(x_i) + \phi_1(x_i, t_i) + Class + NumPoles + grt + s(\xi_1)$ $c_i \sim Year + month + VesselID + \omega_2(x_i) + \phi_2(x_i, t_i) + Class + NumPoles + grt + s(\xi_2)$
Platform	VAST	sdmTMB
Last year of data	2018	2023

Figure 4: Stepwise comparison of the depletion $SB_{\text{latest}}/SB_{\text{F=0}}$ results from the 2023 MP run and MP run with the 2025 updated JPPL CPUE time series estimated from sdmTMB.

The estimation method using sdmTMB-standardised CPUE ran successfully and produced a depletion estimate ($SB_{\text{latest}}/SB_{F=0}$) of 0.43 in the terminal year, closely matching the result from the previous 2023 MP evaluation (0.42 $SB_{\text{latest}}/SB_{\text{f=0}}$ in the terminal year) (Scott et al., 2023). In both cases, the MP returned an effort scalar of 1.0.

4 Future Proofing the Skipjack Management Procedure Estimation Method

The tested skipjack MP uses the JPPL CPUE as the primary indicator of stock abundance (consistent with the 2019 stock assessment). However, the process of monitoring the adopted skipjack MP has highlighted the spatial contraction of the JPPL fishery, particularly in the equatorial region (model Regions 7 and 8), where a large portion of the skipjack biomass is estimated. The implications of a loss of the tropical pole and line CPUE data on the robustness of the MP were therefore examined.

4.1 Simulation Framework

To evaluate the impact of degraded JPPL CPUE in the equatorial region, we simulated scenarios under several key assumptions and settings: (i) historical JPPL CPUE data were assumed to be accurate; (ii) the time series of JPPL CPUE indices in equatorial Region 7 and 8 ended in 2019 and were not replaced by any alternative CPUE source in the future period, this was implemented in the model using effort = -1 and penalty = 0.01; and (iii) simulated future JPPL CPUE in more temperate Regions 1 to 4 continued and remained influential, using a penalty value of 12, consistent with the average historical penalty. The implications of the loss of the tropical CPUE series were tested under three fishing effort levels applied to all fisheries: (i) status quo (scalar = 1.0 × tested MP baseline effort), (ii) low effort (scalar = 0.5 × tested MP baseline effort), and (iii) high effort (scalar = 1.5 × tested MP baseline effort).

By simulating these extreme conditions, we aim to assess the sensitivity of the estimation method to the degradation of JPPL CPUE indices.

The full skipjack OM grid was used, with 20 iterations per model for three management cycles (a total of 9 years). In each iteration, the estimation method was run using outputs from the OMs under the scenarios described above. Estimation method runs were conducted with data updates at years 3, 6, and 9 after 2019, corresponding to 3, 6, and 9 years of missing CPUE from equatorial Regions 7 and 8. These results were then compared to outputs from the tested MP using the full time series, and to the true OM values.

4.2 Results

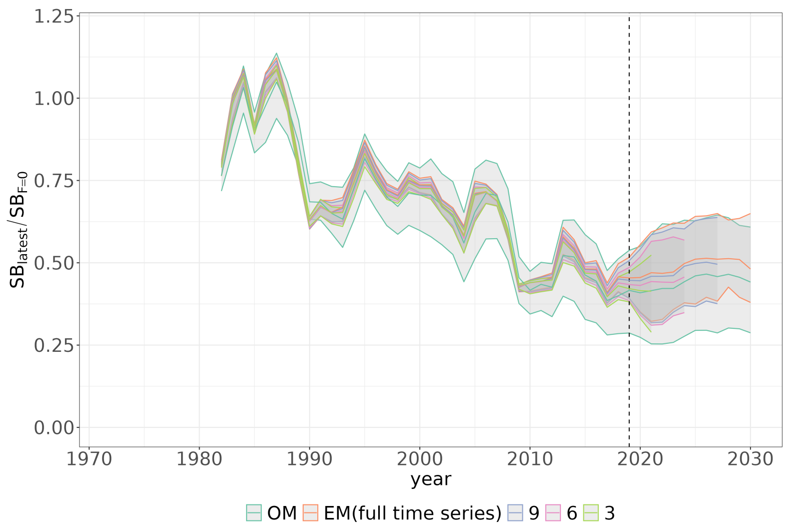
The simulation results indicate that the estimation method outputs under all three degraded JPPL scenarios (3, 6, and 9 years of missing CPUE in equatorial Regions 7 and 8) closely tracked the corresponding operating model (OM) trajectories across all fishing effort levels. Despite the removal of future JPPL CPUE indices, estimation method projections remained broadly aligned with OM trends, particularly in the early projection years. As expected, uncertainty in estimation method outputs increased with longer CPUE gaps, especially under high-effort conditions and in the equatorial region. Nevertheless, all estimation method outputs remained within the uncertainty range of the original tested estimation method, suggesting that short-term data loss from the JPPL fishery may have limited impact on overall stock status estimates that feed into the harvest control rule.

These findings suggest that although data degradation in the JPPL fishery introduces some uncertainty, the estimation framework retains robustness under the tested assumptions (up to 9 years loss of data). This supports the feasibility of maintaining the current MP in the short term, while acknowledging the importance of developing alternative indices for the equatorial region in the longer term.

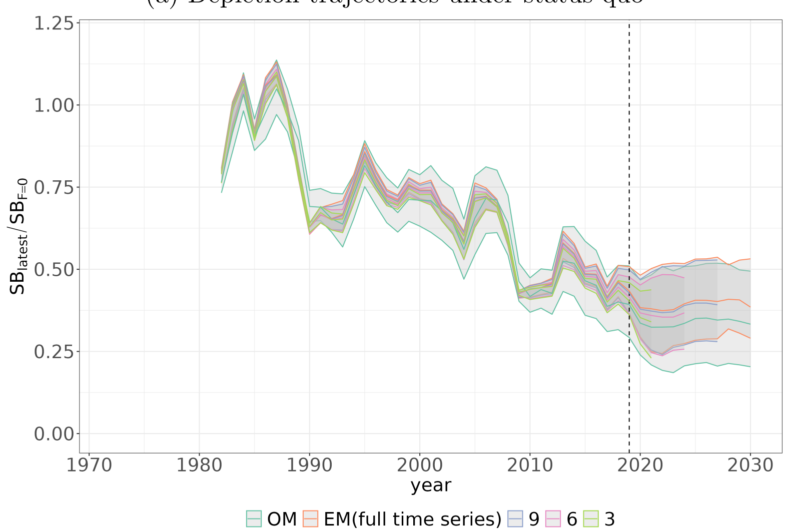
5 Discussion

5.1 Implications for JPPL CPUE time series

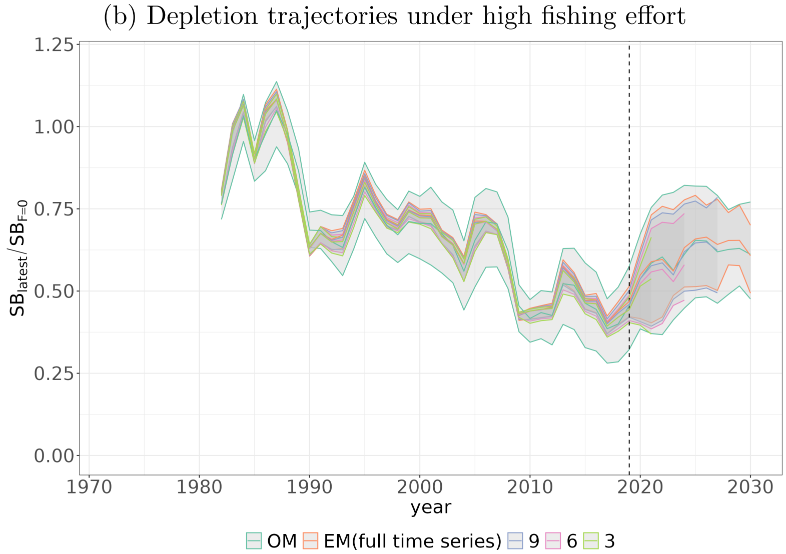
This analysis investigated several areas related to the continued use of JPPL CPUE within the skipjack tuna MP framework. First, discrepancies in penalty calculations and CPUE trends between the 2022 dry run and the tested MP underscore the importance of methodological consistency and documentation. The corrected penalty application and reinstatement of the SST filter improved the reliability and biological plausibility of the JPPL CPUE indices. These standards are recommended for continued use in future skipjack MP analyses, and the settings should be clearly documented in all relevant MP materials, including future MPs using standardised CPUE indices (Tab. 2).



(a) Depletion trajectories under status quo



(b) Depletion trajectories under high fishing effort



(c) Depletion trajectories under low fishing effort

Figure 5: Depletion trajectories ($SB_{\text{latest}}/SB_{F=0}$) from the operating model and estimation methods under varying JPPL data availability scenarios (3, 6, and 9 years of missing data) and future fishing scenarios. The solid line represents the median, and the shaded ribbon indicates the central 60% quantile range.

As candidate MPs were thoroughly tested through MSE, any post-adoption changes to the estimation method must be well justified and carefully evaluated. The transition from the VAST platform to sdmTMB for the JPPL CPUE standardisation was therefore closely examined. Nishimoto et al. (2025) showed that CPUE time series from sdmTMB were overall consistent with those from VAST, and re-evaluating the 2023 skipjack MP produced identical effort scalar estimates, resulting in the same management output. Given the computational and repeatability benefits of sdmTMB, this transition is considered appropriate.

Simulation testing further demonstrated that the estimation method remains robust under moderate degradation of JPPL CPUE coverage in the equatorial region. These results suggest that the current MP framework is capable of withstanding short-term data gaps without major degradation in performance. Accordingly, the continued use of JPPL CPUE is supported for the upcoming skipjack MP run, while acknowledging the need for longer-term strategies to future-proof the procedure.

5.2 Limitations and Future Work

Several limitations of this analysis should be acknowledged. First, the simulations assume that historical JPPL data are accurate and that only future observations are affected by fishery contraction. In reality, declining representativeness may already be influencing the reliability of recent data. Second, while the estimation method appears robust to JPPL data degradation under current assumptions, the potential impacts of broader factors, such as climate-driven shifts in fishery distribution, remain unknown.

To address concerns regarding the long-term availability and representativeness of JPPL data, options for future proofing the estimation method should be considered. One approach, recommended by SC20, is to replace JPPL with purse seine CPUE in the equatorial region (WCPFC, 2024). Purse seine fisheries are operationally stable, account for the majority of skipjack catch, and have already been incorporated into the recent stock assessment (Castillo-Jordan et al., 2022).

Other alternative approaches within the MP include incorporating spatiotemporal tag modelling (Mildenberger et al., 2024) or ecosystem-linked models such as SEAPODYM (Lehodey et al., 2008). These methods would require the inclusion of environmental variables not currently represented in the MSE framework, and assumptions on the patterns of those environmental variables into the future. In theory, integrating environmental drivers could improve MP resilience under climate-driven uncertainty.

However, introducing new data types or model structures into the current MP would require reconditioning the OMs and reevaluating the performance of candidate MPs, an effort that could span several years. Furthermore, any modifications to the MP would require formal adoption by the Commission. Therefore, such changes should be carefully considered by the WCPFC and the science provider, with a realistic multi-year timeline.

The next run of the skipjack MP is scheduled for 2026. Noting the corrections to model inputs and the results of analyses presented in this paper, we recommend maintaining the current MP in the short term. We note that a comprehensive review and evaluation of the performance of the MP is scheduled for its third implementation in 2029.

A key lesson from this work is the importance of aligning estimation method inputs with data that can be consistently collected and simulated within the MSE framework. Unlike stock assessments, data and statistical methods used in MPs must be fixed and thoroughly tested before adoption. Once adopted, data collection protocols should remain stable. Future MPs should therefore prioritise input data streams that are simple, sustainable, and operationally reliable over the long term.

6 Conclusion

This study examined the use of the JPPL CPUE time series and evaluated its suitability as an input to the estimation method within the skipjack MP. Based on the results, we conclude that the current MP remains fit for purpose and is recommended for use in the next management cycle. However, development of a future-proof skipjack MP should be initiated. In the meantime, ongoing monitoring of the JPPL fishery's spatial and temporal coverage is recommended to support informed management decisions.

We invite SC21 to:

- Note the results of the investigation of the JPPL CPUE time series.
- Support the continued use of the adopted skipjack MP for the next implementation cycle.
- Note that settings used to develop standardised CPUE indices should be included within MP documentation for all relevant WCPFC management procedures.
- Provide guidance on alternative abundance indices or inputs for longer-term MP development.

Acknowledgments

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Appendix

Table 2: Standardisation settings and post-processing steps for JPPL CPUE used in the skipjack estimation method.

Model Setting	**Description**
Model Type	Spatiotemporal delta-lognormal generalized linear mixed model (delta-GLMM)
Spatial Knot Configuration	A mesh with 285 knots.
Model Equations	$p_i \sim Year + month + VesselID + \omega_1(x_i) + \phi_1(x_i, t_i) + Class + NumPoles + grt + s(\xi_1)$ $c_i \sim Year + month + VesselID + \omega_2(x_i) + \phi_2(x_i, t_i) + Class + NumPoles + grt + s(\xi_2)$ where p_i is the encounter probability, c_i is the positive catch rate (CPUE defined as catch in kilograms per daily logsheet record), *Year* is a fixed effect, *Month* is a fixed effect, *VesselID* is a normally distributed random effect for vessel identification, $\omega_1(x_i)$ is the spatial random effect at knot x associated with logsheet record i, $\phi_1(x_i, t_i)$ is the spatiotemporal random effect at *Year* t and knot x, *Class* is a fixed effect denoting a vessel as either OS or DW, NumPoles is fixed effect, grt is fixed effect, and $s(\xi_1)$ is a polynomial spline of degree 5 for the sea surface temperature (SST).
Implementation Platform	sdmTMB version 0.6.0 (R packages)
Environmental Filtering	During the sdmTMB prediction phase, sea surface temperature (SST) filtering is applied on a quarterly basis, retaining only biomass from grid cells where SST exceeds the biologically realistic minimum threshold of 18°C for skipjack tuna. The SST dataset, specifically the objective analyses incorporating XBT corrections (Gouretski and Reseghetti, 2010) and MBT corrections (Gouretski and Cheng, 2020), is downloaded from the https://www.metoffice.gov.uk/hadobs/en4/download-en4-2-2.html.
Normalisation Method	CPUE values are mean-centered based on absolute values.
CV Rescaling Method	The mean coefficient of variation (CV) over the full time series is set to 0.2. All CV values are rescaled relative to this reference level.
Penalty Term Calculation	Penalty terms applied as $\frac{1}{2 \times CV^2}$