SCIENTIFIC COMMITTEE
TWENTY-SECOND REGULAR SESSION
11-19 August 2026
Apia, Samoa (Hybrid)

UPDATES TO THE ESTIMATION METHOD FOR BIGEYE TUNA IN THE WCPO

WCPFC-SC22-2026-MI-WP02
24 July 2026

Submitted by M. Wickens[1], F. Scott, R. Scott

[1] Oceanic Fisheries Programme of the Pacific Community

Contents

Executive Summary

The WCPFC harvest strategy workplan schedules the adoption of the bigeye tuna management procedure (MP) by the end of 2026. This report describes the proposed estimation method (EM) for producing an estimate of stock status for input into the Harvest Control Rule (HCR).

In 2025, an earlier version of the proposed estimation method was provided to the Scientific Committee (SC). The SC "endorsed the general approach of using an [age-structured production model (ASPM)] for the EM but made a number of technical suggestions for consideration in future work to refine the EM" (WCPFC, 2025).

Several improvements, as recommended by SC21, were made to the EM including model settings for recruitment variation (σ_R), natural mortality, steepness and the catch-per-unit-effort (CPUE) indices. Further changes were also made to the selectivity patterns to reflect the shift from a spatial operating model (OM) to a single-region EM. These improvements aimed to increase the accuracy of the model, especially when the simulated stock status was low. In addition, the new model aimed to reduce the sensitivity to initial conditions and increase the convergence rate.

The updated estimation method was able to reliably and accurately estimate the 'true' stock status simulated across a wide range of fishery and biological uncertainties. Using the new OMs as described in Scott et al. (2026), the model had a very high convergence rate and a reduced bias when compared to the EM presented to SC21. Using the $SB/SB_{2012-2015}$ metric of stock status, the EM produced a robust and reliable estimate of the true simulated stock status.

SC22 is invited to:

- Consider the results of the proposed estimation method for the bigeye tuna management procedure, noting the improvements gained over the results presented to SC21, and
- Endorse the use of the proposed estimation method within the bigeye tuna management strategy evaluation design and testing.

1 Introduction

The purpose of this paper was to provide an update to the proposed estimation method (EM) for bigeye tuna within the harvest strategy framework. In 2025, an earlier version of the proposed estimation method was provided to the Scientific Committee (SC). The SC "endorsed the general approach of using an ASPM for the EM but made a number of technical suggestions for consideration in future work to refine the EM (e.g., model settings for sigma R, natural mortality, steepness, construction of CPUE indices) for further analysis, including re-evaluation of the EM under any expanded OM grid and taking into account the outcomes of agenda item 5.1.3.1." (WCPFC, 2025). The outcomes of agenda item 5.1.3.1 refer to the development of additional sources of uncertainty in the OMs.

Several improvements, as recommended by SC21, were made to the estimation method including model settings for recruitment variation (σ_R), natural mortality, steepness and the catch-per-unit-effort (CPUE) indices. Further changes were also made to the selectivity patterns to reflect the shift from a spatial OM to a single-region EM. These improvements aimed to increase the accuracy of the model, especially when the simulated stock status was low. In addition, the new model aimed to reduce the sensitivity to initial conditions and increase the convergence rate.

The OMs used for testing the estimation method were also updated. Since SC21, additional uncertainty in growth and natural mortality were included. The resulting simulations cover a wider range of population trajectories and depletion levels for evaluating the EM. To evaluate the performance of the EMs, two metrics of stock status were considered: the spawning biomass in the terminal year relative to the spawning biomass in the initial year (SB/SB_{Initial}), and the spawning biomass in the terminal year relative to the average spawning biomass in the reference period from 2012 to 2015 ($SB/SB_{\text{2012-2015}}$).

It is important to note that the EM serves a different purpose to the stock assessment. The EM is a single model that provides an estimate of current stock status to the HCR to define future fishing levels and it need not accurately estimate historical population changes. In contrast, the stock assessment is used for monitoring purposes under the harvest strategy approach and is typically an ensemble of models that aim to estimate historical and current stock statuses.

2 Methods

2.1 Simulation Data

Simulation data for the EM comes from the bigeye OMs and therefore represent outcomes for the WCPO only. Between SC21 and SC22, these OMs were updated to reflect greater uncertainty in growth and natural mortality. Further information about the design of the OMs can be found in Scott et al. (2026).

The projection period adds further uncertainty to the OMs, mostly in terms of potential effort creep and recruitment variability. Consistent with the work presented at SC21, half of the projections include effort creep for longline (1% per year) and purse seine fisheries (2% per year) (Hoyle, 2025). Recruitment deviation values were sampled from either the long term or short term historical values to add environmental and biological uncertainty in the projection period.

The EM was tested within the MSE framework for the scenario where the bigeye MP controlled all tropical longline fisheries operating between 20^{o}N and 10^{o}S, including the Hawaiian longline fleet. In order to test the EM under different depletion levels, the OMs were projected with catch and effort targets that achieved three contrasting median levels of depletion. The nuclear grid described in Scott (2026) was used to determine the catches for longline fisheries managed through the MP and the corresponding FAD closure period that achieved those depletion levels at the end of the 30-

year projection period. Fisheries not controlled directly by the bigeye MP were assumed to remain at fixed recent catch or effort levels for evaluation purposes. Simulated population trajectories from three example OMs are shown in Figure 1.

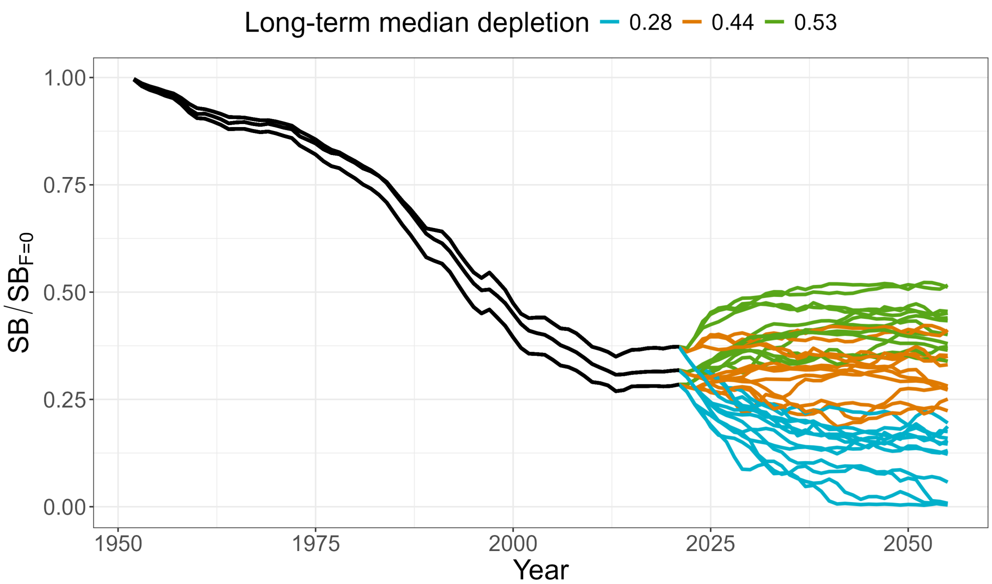

Figure 1: Simulated historical and projected bigeye tuna spawning biomass relative to unfished spawning biomass ($SB/SB_{F=0}$) of three example models from the OM set. Each projected trajectory is coloured by the long-term median depletion achieved across all OMs.

Input data to the EM were simulated by the OM through an observation process. The observation process generated annual catch by fishery and an annual whole-fishery catch rate index. In order to mimic the data collection and analysis involved in fishery management, observation error was added to catch by sampling from a normal distribution with a coefficient of variation equal to 0.2 and mean equal to the 'true' observation. Observation error was also added to catch rates by sampling from a normal distribution with a coefficient of variation equal to 0.1 and mean equal to the 'true' observation. The observation error was applied to the catch rate after the regional weighting and seasonal averaging. An illustrative example of the observed catch and CPUE from one iteration of the EM are shown in Figure 2 and 3.

2.2 Model Structure

The Stock Synthesis 3 (SS3) framework was retained in the updated EM due to the encouraging performance of the EM version presented to SC21. The model was run on an annual timestep without seasons and only one spatial region. To mimic the fishery structure of the OMs in Scott et al. (2026), the model used thirty-six extraction fisheries but only one index fishery. In fishery population models, structural parameters such as selectivity and growth are difficult to estimate without tagging and size composition data so selectivity and growth were fixed at plausible values estimated in previous stock assessments and OM-conditioning (see Section 2.2.4 and 2.2.5). Settings

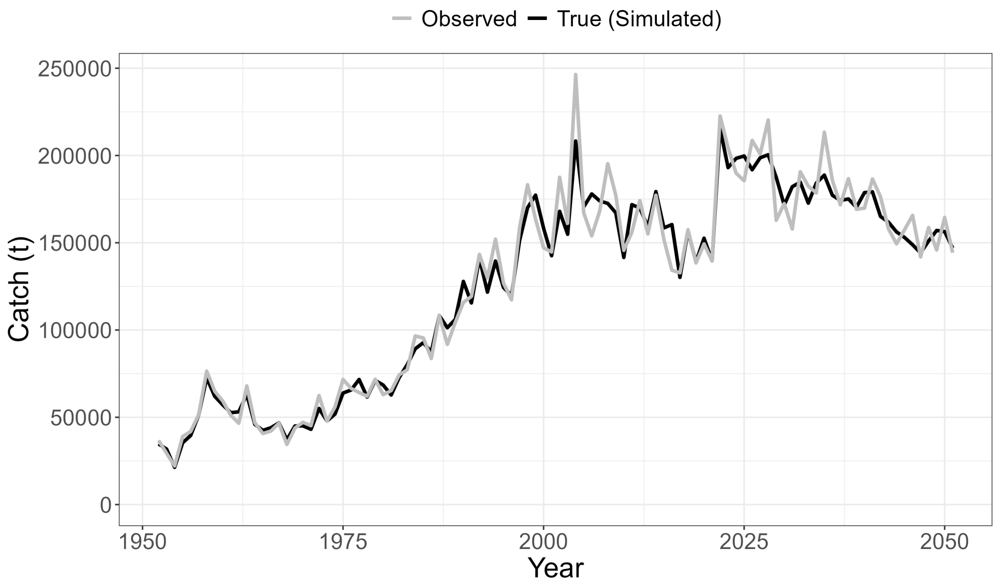

Figure 2: Illustrative example of true catch from the simulated population and observed catch provided to the EM.

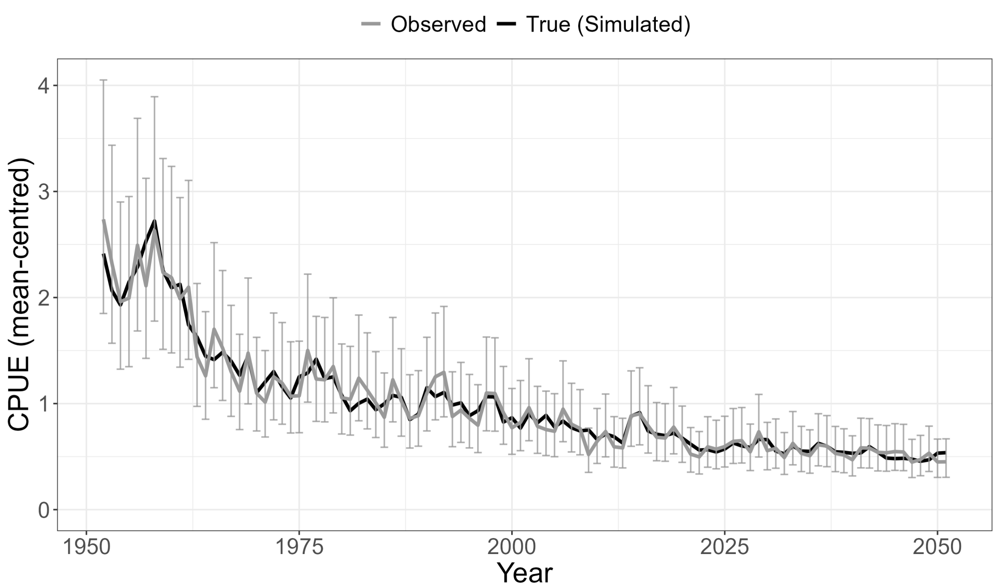

Figure 3: Illustrative example of true catch-per-unit-effort (CPUE) from the simulated population and observed catch-per-unit-effort provided to the EM. Error bars show the 95% confidence interval provided to the EM.

for movement and the distribution of recruits were obsolete without spatial structure so they are not considered in the tested SS3 EM.

2.2.1 Coefficient of Variation

The estimation method relies heavily on CPUE data to gain information on stock status so it was particularly important to explore different approaches for these data. In the EM presented at SC21, the CPUE indices from the 9 bigeye regions were summed to produce a WCPO-wide consensus index. This consensus method puts the onus on the scientist to justify the scaling between the indices instead of forcing the model to reconcile the differences between regions (Hoyle et al., 2024). The consensus index was developed as a weighted sum of CPUE indices with weighting equal to the area of each region. The area-weighted method approximates the suitable habitat area available in each region to transform an index of population density into an index of population abundance. This method, however, overlooks the variance or error of the resulting indices.

It was suggested at SC21, that SS3 may be sensitive to the coefficient of variation (CV) on the CPUE data so further investigations were completed to determine the appropriateness of the chosen CV value for the remaining data. The CPUE standardisation model, while a pre-defined process, is not part of the estimation method in the MSE processs due to the high computational cost to run this model. However, the real CPUE model (used for conditioning the OMs) was used to inform the CV values.

The real CPUE model was predicted at a regional level to produce nine longline index fisheries using the sdmTMB package. Due to the large amount of data in this model, the resulting CV was unreasonably small. So, when the CPUE data were used for conditioning, the CV was adjusted via MLE regression (see Section 5.5.1 of Magnusson et al. (2023)). The CPUE and corresponding CV are shown in Figure 4 with the label “Regional”. The MLE-adjusted CVs are also reasonably consistent through time.

The same CPUE model was also predicted and aggregated across all areas. Similar to the regional indices, the CV was unreasonably small (refer to “Single region” data in Figure 4). The suggested CV of 0.2 presented to SC21 sits between the CV produced from MLE regression and the CV produced by sdmTMB. Since the estimation method must be fast, efficient and consistent across the OM simulations, the CV of 0.2 was deemed suitable for the estimation method.

Therefore, the area-weighted CPUE was provided to SS3 with a CV of 0.2 for the entire timeseries (refer to “Area-weighted” data in Figure 4). The fit to the CPUE data was also influenced by the variance of recruitment deviations.

2.2.2 Recruitment Variation

Closely linked to the CPUE CV is the recruitment variation parameter, σ_R, which represents the variance of the recruitment deviations. When a fishery population model lacks size composition data, there is little to inform recruitment deviations other than the CPUE abundance indices. Therefore, σ_R plays a vital role in how ‘dramatic’ recruitment variation can be and how well the CPUE indices are fit. At SC21, members suggested testing sensitivity to the parameter σ_R.

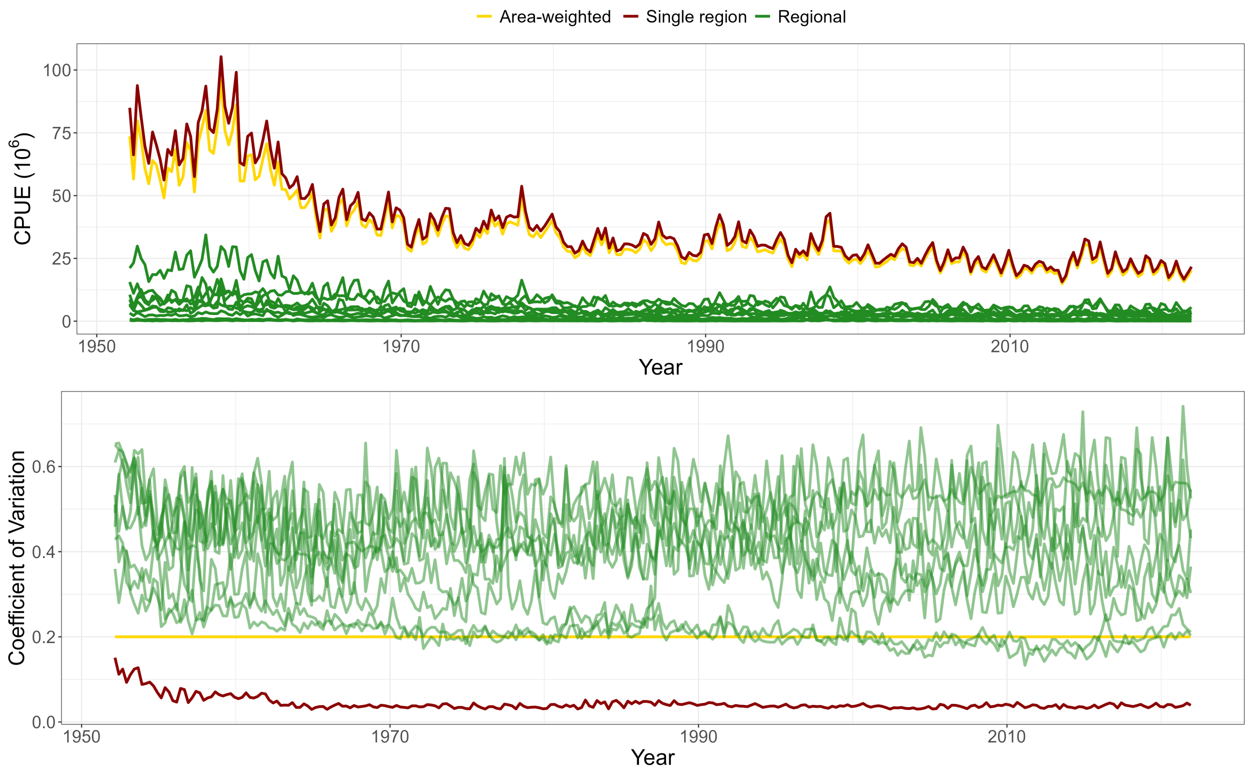

Figure 4: Coefficient of variation resulting from different CPUE methods. The area-weighted method aligns with the observations from the simulation. The single region method is the result from the sdmTMB model. The regional method produces indices for each model region from the sdmTMB model with CVs adjusted via MLE regression.

In the EM presented to SC21, σ_R was set to 0.2 to reduce large deviations from the stock-recruitment relationship in the context of limited data. Since then, larger values of σ_R were explored and for the recommended EM, the recruitment variation parameter was increased to 0.6. The CPUE fits were improved and the trend in recruitment deviations was very similar (see Figures 11 and 12).

2.2.3 Natural Mortality and Steepness

Natural mortality (M) and steepness (h) are notoriously difficult to estimate, both within and external to population models. In the proposed estimation method, priors were placed on M and h informed by the 2023 stock assessment. The priors constrain M and h within a biologically plausible range, whilst introducing flexibility during the optimisation process, allowing the model to better explore the parameter space of the population scaling parameter ($R0$) and recruitment deviations.

The Lorenzen form of natural mortality is implemented in the Stock Synthesis estimation method as well as the MFCL-conditioned OMs. This approach is supported by outcomes from the 2023 Tuna Stock Assessment Good Practices workshop hosted by the Center for the Advancement of Population Assessment Methodology (CAPAM), which endorsed the use of a Lorenzen functional form for estimating age-specific natural mortality in tuna. By contrast, the 2020 assessment relied on externally estimated and fixed M-at-age values, resulting in a quarterly M estimate of 0.1275. That approach raised concerns during the yellowfin independent review (Punt et al., 2023), particularly regarding the traceability of input data used in the external estimation. We note that the standard deviation of the prior on M used here was large enough to include the 2020 assessment value.

The steepness values considered in the 2023 stock assessment, and also included in the OMs, were: $0.65, 0.8$ and 0.95. The prior placed on steepness in the estimation method encapsulated these values using a normal distribution with mean of 0.8 and standard deviation of 0.1.

2.2.4 Selectivity

Selection patterns in spatial population models often reflect both the gear selectivity and the age-structure of the fish population in the fished area. Since the candidate EM is a single region model, more attention was given to the fixed selectivity curves originally informed from the 9-region 2023 stock assessment diagnostic model. Instead of using the estimated selectivities directly from the 2023 stock assessment, the model was re-run in MFCL as a single-region model and new selectivity curves were estimated. In the single-region MFCL model the fishery groupings for selectivities were removed since different catch compositions could no longer be attributed to spatial differences. For most fisheries, the single-region model estimated a higher asymptotic selectivity. The selectivities were also provided to Stock Synthesis for each length class, rather than age class, for finer resolution. The fixed selectivity curves for all fisheries are shown in Figure 5 in the Appendix.

2.2.5 Growth

Growth in the EM used the single-sex von Bertalanffy length-at-age growth model, with values based on the 2023 stock assessment as per the candidate EM presented at SC21. The parameters were set up as follows: the mean length of the first age class $L_1 = 24.06$ cm, the mean length of the oldest age class $L_2 = 151.28$ cm, the growth coefficient $\kappa = 0.12$, the minimum age $A_1 = 0.25$ and the maximum age was $A_2 = 10$. The coefficient of variation was set to 0.1 for both young and old ages. The weight-length relationship in SS3 was parameterised with $\alpha = 0.000031$ and $\beta = 2.93$ as per the diagnostic model of the 2023 stock assessment.

2.3 Stock Status Metric

To evaluate the performance of the EM, we compared the estimated value from the EM to the 'true' value from the OM projection. We investigated the performance of two different metrics of the SS3 estimated stock status:

- the spawning biomass in the terminal year relative to the spawning biomass in the initial year (SB/SB_{Initial}), and
- the spawning biomass in the terminal year relative to the average spawning biomass in the reference period from 2012 to 2015 ($SB/SB_{\text{2012-2015}}$).

The SB/SB_{Initial} metric provides a measure of spawning biomass relative to the start of the model period. On the other hand, $SB/SB_{\text{2012-2015}}$ produces a measure of spawning biomass relative to spawning biomass in the reference period for the bigeye tuna target reference point (2012 – 2015) (Pilling et al., 2024). The previous EM analysis presented at SC21 found that the measure of spawning biomass relative to the reference period was the most accurate metric to recover true stock status (Wickens et al., 2025).

3 Results

Following recommendations from SC21, updates were made to the data inputs and model configuration of the bigeye EM. Compared to the EM presented in 2025, the new EM demonstrated a higher convergence rate and little sensitivity to initial conditions. The estimation method was able to recover the stock status from the simulated data with improved accuracy across a wider range of terminal depletions. The estimates of stock status were also less biased. The main changes that led to these improvements were increasing the CV of the CPUE index, estimation of natural mortality and steepness with priors and a larger variance for the estimated recruitment deviations.

The results from the proposed EM are presented in Table 1 and Figures 6 to 10 in the Appendix. The $SB/SB_{2012-2015}$ metric performed equally well over projections with and without effort creep (Figure 8) and was not sensitive to the amount of simulated data in the model (Figure 9). The relative measure of stock status was also able to recover the true stock status across all natural mortality estimates used in the OMs (Figure 10).

When the estimation method takes the form of a population model, the model should reliably converge on plausible parameters when provided with data from different simulated populations. In particular, in MSE testing, the EM must converge without human intervention so that MPs can be tested across different conditions. Convergence was measured by the maximum gradient component of the parameters estimated through maximum likelihood estimation implemented in Stock Synthesis. A model was considered to be converged if the maximum gradient component was less than 0.001. Of the 25920 EM models run during MSE testing, no models failed to run and less than 0.1% of models finished with a maximum gradient component greater than 0.001. The non-converged models had maximum gradient components just slightly above the threshold of 0.001 and also produced accurate estimates so all models were included in plots and summaries. Arguably, the candidate EM resulted in a 100% convergence rate. This high convergence rate provides confidence that the EM can be implemented in the harvest strategy framework.

In addition to convergence, it was important that the estimation method could accurately estimate the true stock status from the simulation. The model was able to detect changes in biomass, even when the stock was at or below the limit reference point. The proposed EM metric ($SB/SB_{\text{2012-2015}}$) had a reasonable R^2 value of 0.76 from the linear model fit to the estimated and true stock status metric (see Table 1). Temporally-relative metrics (such as $SB/SB_{\text{2012-2015}}$) tend to outperform metrics that use the entire timeseries because the initial population size at the start of the fishery can be difficult to estimate.

Table 1: Results of fitting linear regression of the estimated stock status against the 'true' stock status for the EM.

Metric	Intercept	Slope	R^2
$SB/SB_{2012-2015}$	0.28	0.65	0.76
SB/SB_{Initial}	0.30	0.64	0.50

The improved performance of the EM cannot be directly attributed to any single change made to the model, but rather the combination of changes to settings for CPUE, natural mortality, steepness, recruitment variation and selectivity. Consistent with the well-known difficulty in estimating steepness and natural mortality, the estimates of steepness and natural mortality from the EM were not responsive to the true values in the simulated OMs. However, the priors were useful to constrain parameter estimates and likely gave the model the flexibility to convergence more consistently. The estimates of steepness and natural mortality are shown in Figures 13 and 14.

4 Future Considerations

The data inputs to run the EM were annual catch for the thirty-six extraction fisheries, and catch and effort data for longline fisheries to produce a whole-fishery longline CPUE index. The CPUE standardisation model also required environmental data in the form of the depth of the 15°C isotherm and the difference between the depth of the 12°C and 18°C isotherms. These data must be available up to 2025 in order to run the EM in 2027.

If the estimation method presented in this paper was adopted, the CPUE standardisation model will need to be run to update the model with new data. We note that new updates to the CPUE standardisation package (sdmTMB) enable a whole-fishery index to be produced which could replace the area-weighting methodology used in this testing. Of course, if that development was adopted in the future, the updated CPUE model should be compared with the model in 2023 to ensure there are no significant changes in results.

Acknowledgments

We gratefully acknowledge funding for this work from the New Zealand Ministry of Foreign Affairs and Trade (MFAT) funded project "Sustainable Pacific Fisheries".

Declaration of generative AI and AI-assisted technologies in the SC paper preparation process

No AI technologies were used in the preparation of this paper.

5 Appendix

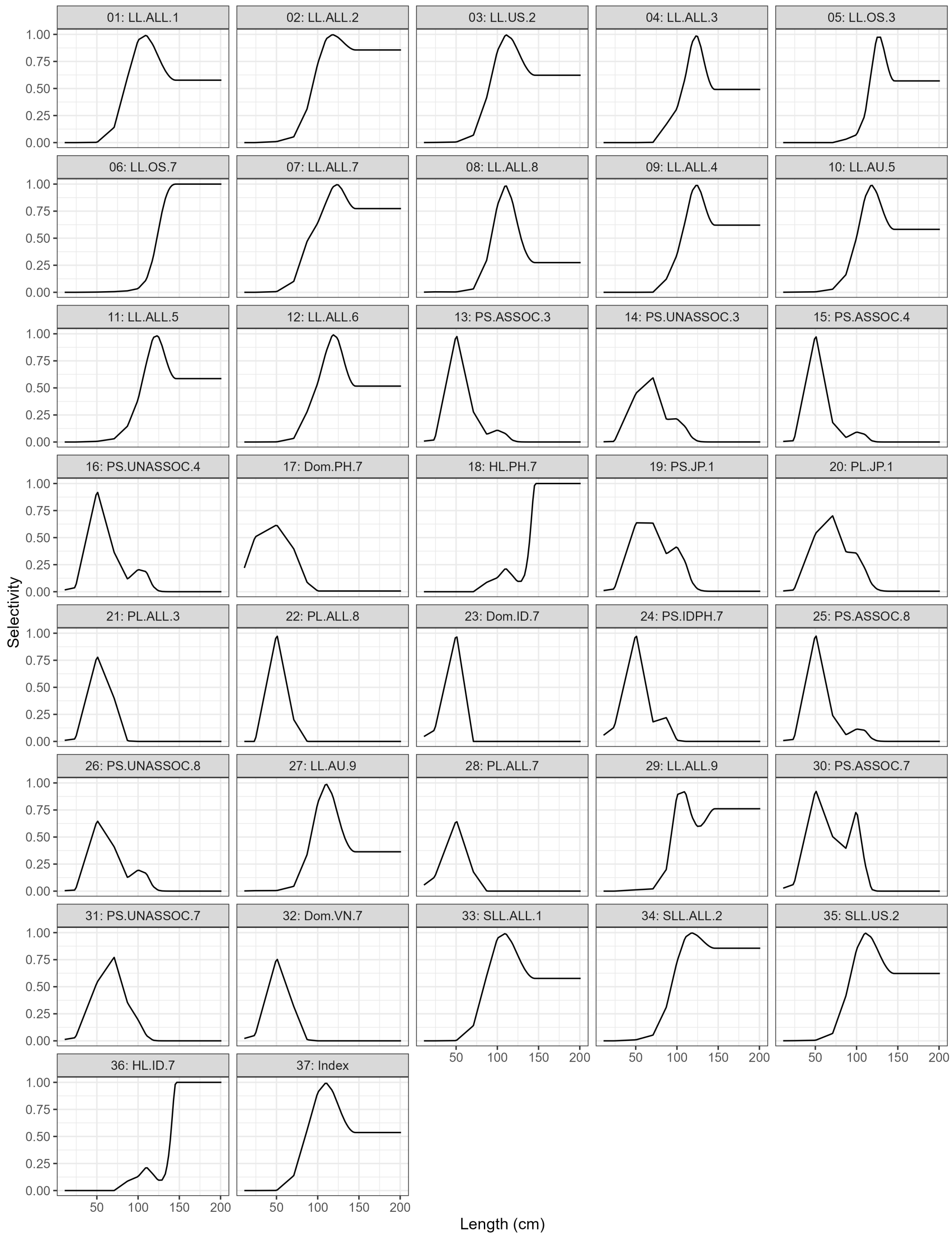

Figure 5: Fishery selectivities estimated with a single-region MFCL model and provided to the estimation method.

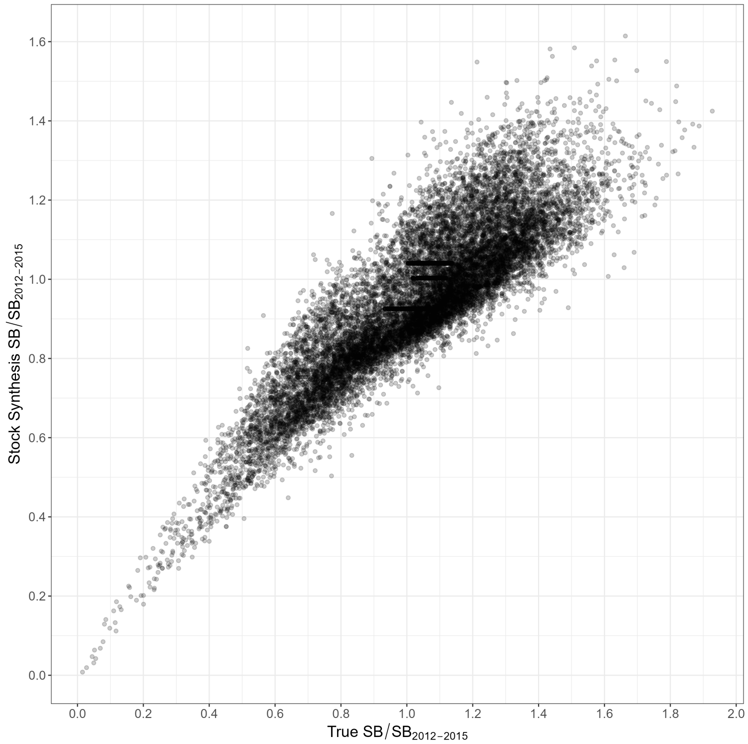

Figure 6: Comparison of 'true' OM stock status and estimate of stock status from SS3 using $SB/SB_{\text{2012-2015}}$.

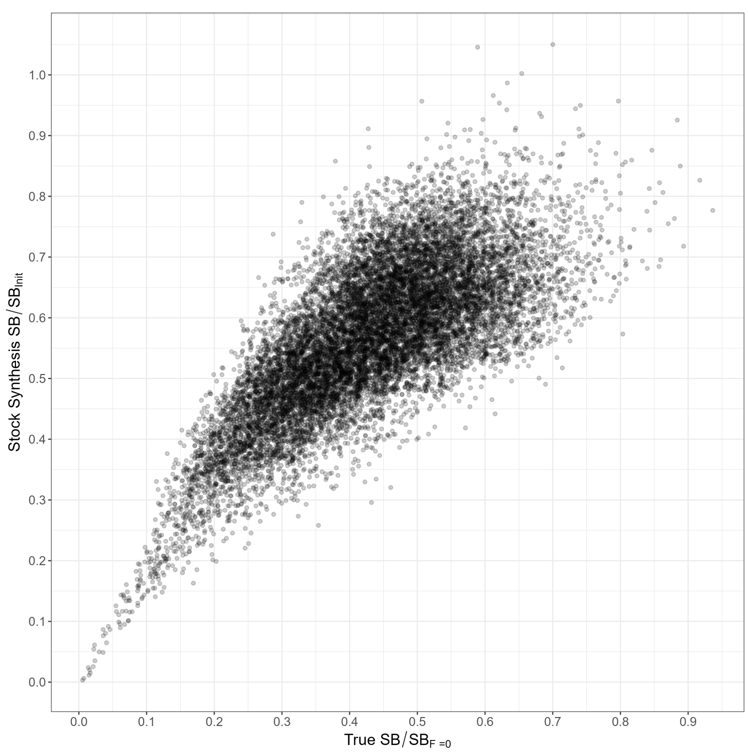

Figure 7: Comparison of 'true' OM stock status and estimate of stock status from SS3 using SB/SB_{Init}.

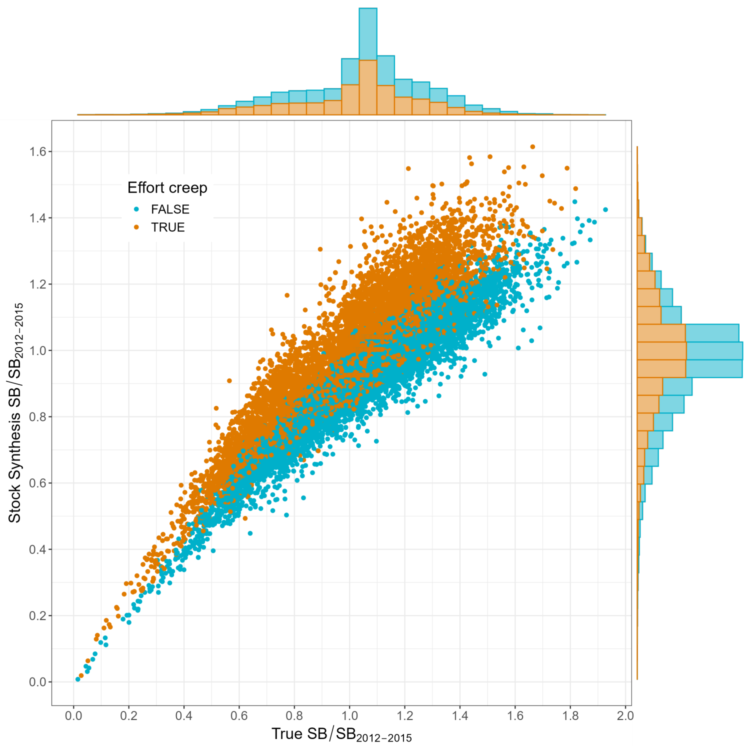

Figure 8: Comparison of 'true' OM stock status and estimate of stock status from SS3 using $SB/SB_{2012\text{-}2015}$ coloured by whether effort creep was included in the projection.

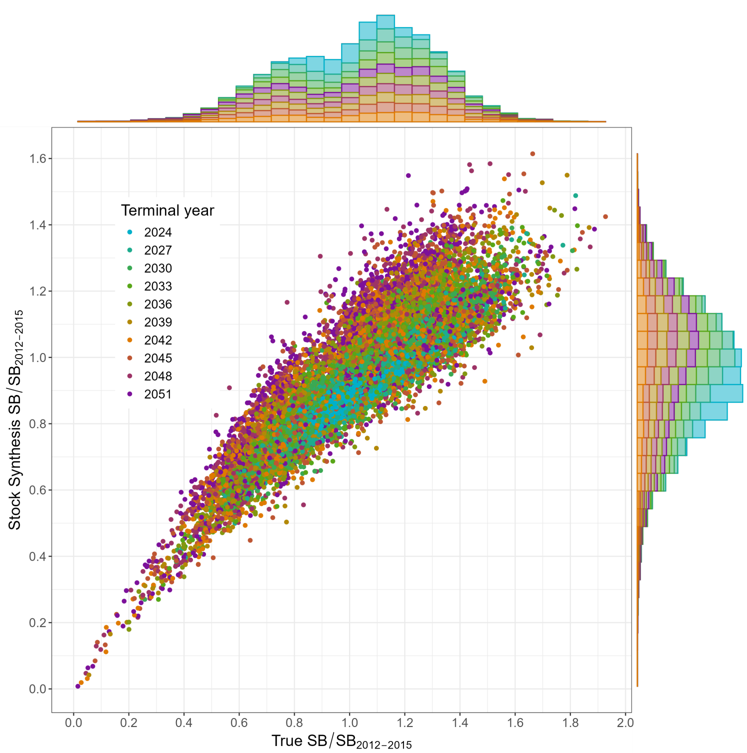

Figure 9: Comparison of 'true' OM stock status and estimate of stock status from SS3 using $SB/SB_{2012\text{-}2015}$ coloured by the last year of data supplied to the EM.

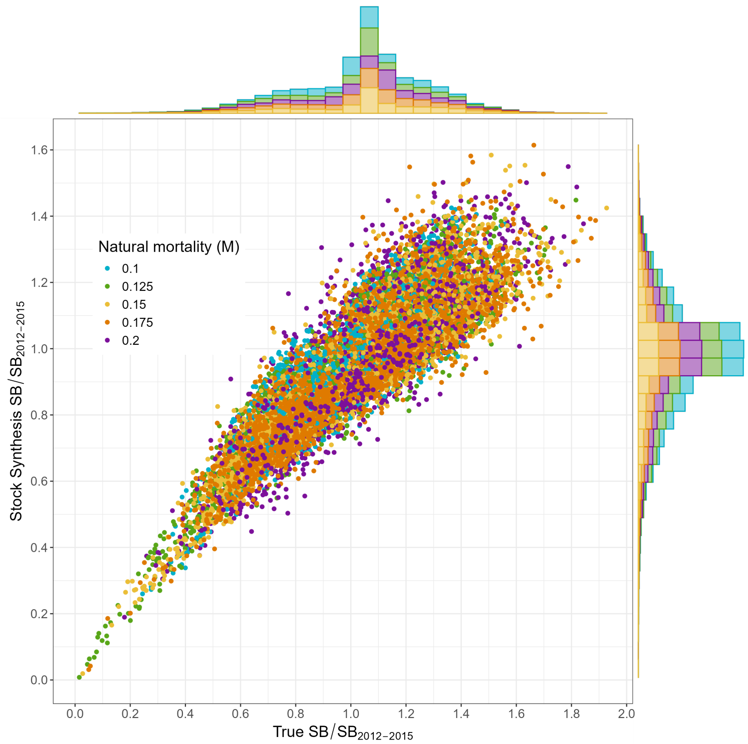

Figure 10: Comparison of 'true' OM stock status and estimate of stock status from SS3 using $SB/SB_{2012\text{-}2015}$ coloured by the true natural mortality of the OM.

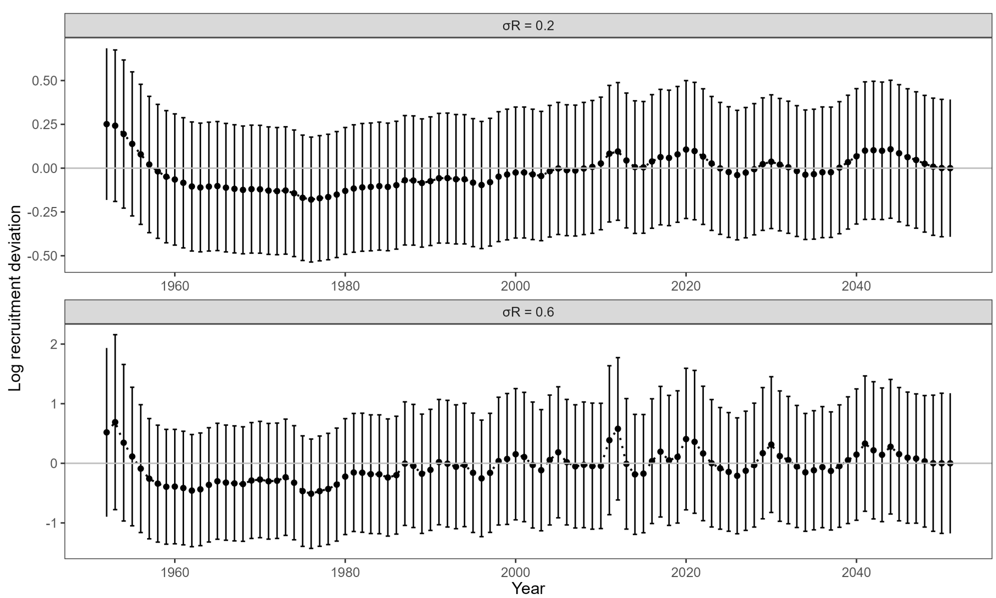

Figure 11: Illustrative estimates of recruitment deviation with different variation parameter σ_R.

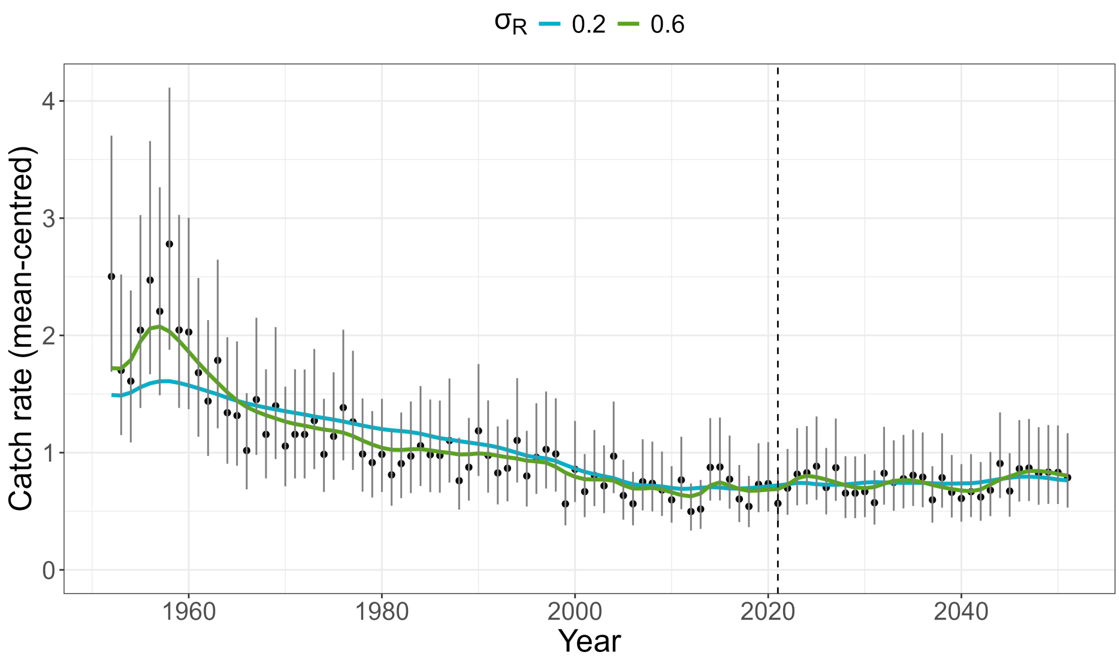

Figure 12: Illustrative fit to truncated CPUE data from EM with $\sigma_R = 0.2$ and $\sigma_R = 0.6$.

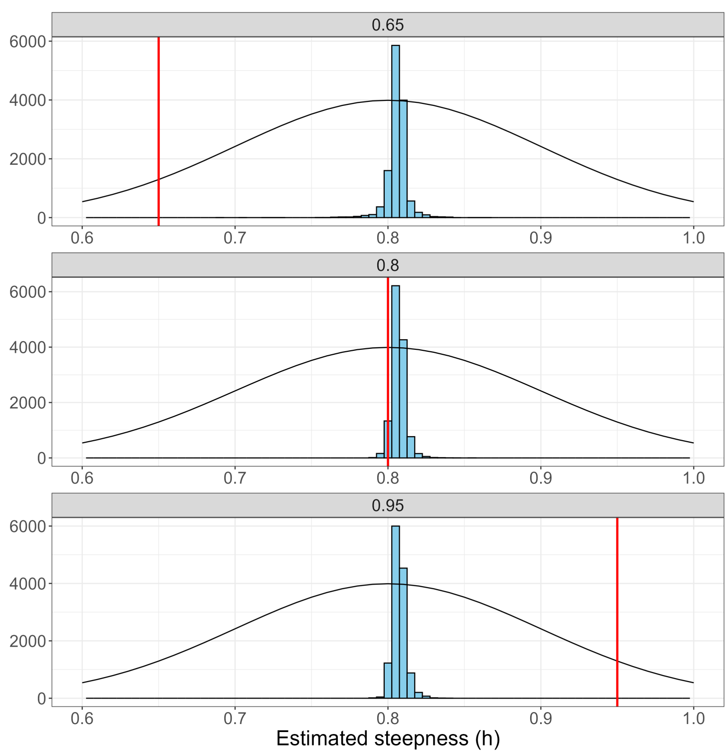

Figure 13: Estimated steepness (h) from all EM evaluations compared to the 'true' value (red line) and the prior (black curve).

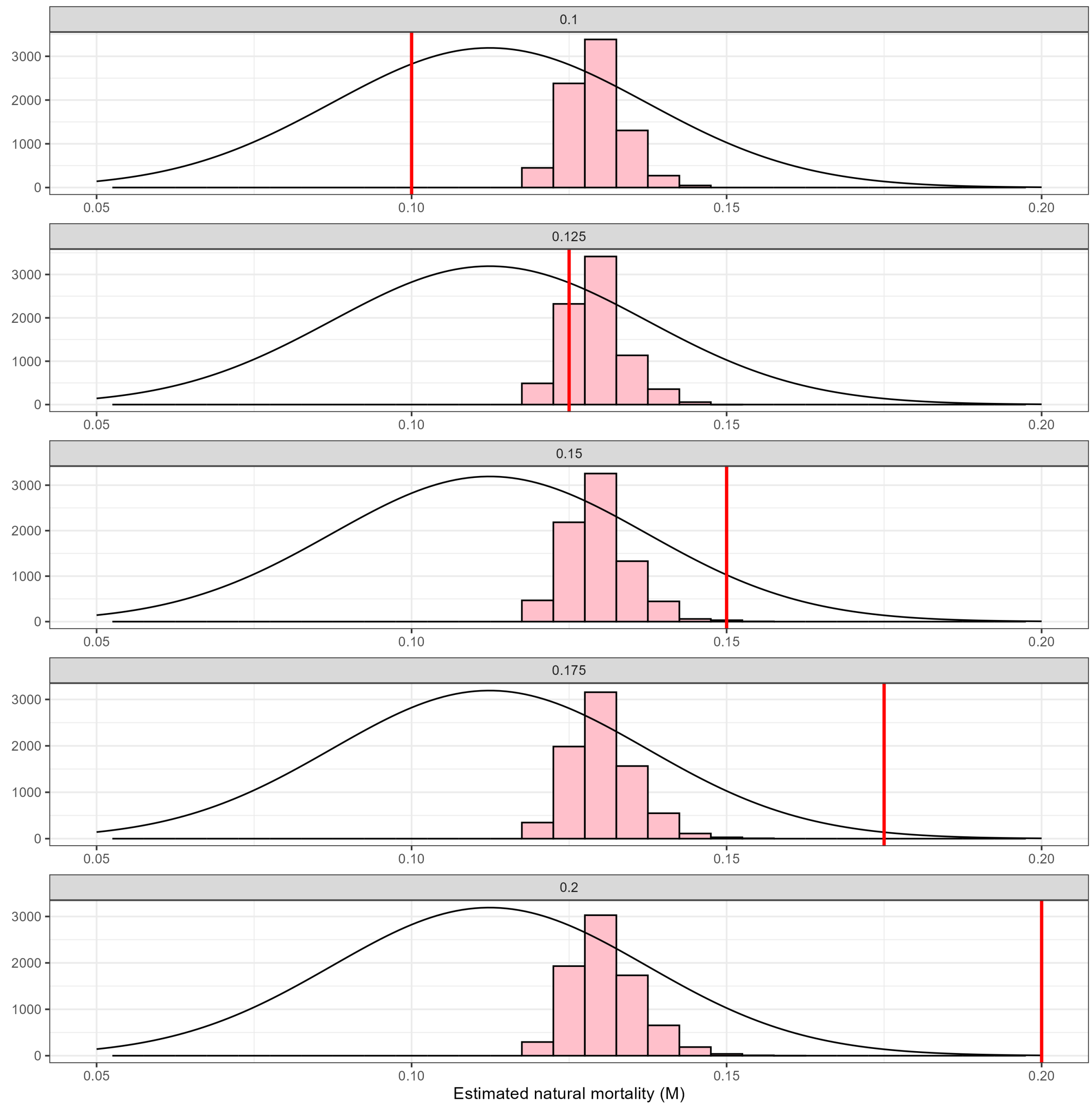

Figure 14: Estimated asymptotic natural mortality (M) from all EM evaluations compared to the ‘true’ value (red line) and the prior (black curve).

6 References

Hoyle, S. (2025). Effort creep in longline and purse seine CPUE and its application in tropical tuna assessments. WCPFC-SC20-2024/SA-IP-19, Manila, Philippines, 14–21 August 2014.

Hoyle, S. D., Campbell, R. A., Ducharme-Barth, N. D., Gruss, A., Moore, B. R., Thorson, J. T., Tremblay-Boyer, L., Winker, H., Zhou, S., and Maunder, M. N. (2024). Catch per unit effort modelling for stock assessment: A summary of good practices. *Fisheries Research*, 269:106860.

Magnusson, A., Day, J., Teears, T., Hampton, J., Davies, N., Castillo-Jordan, C., Peatman, T., Scott, R., Scutt Phillips, J., McKechnie, S., Scott, F., Yao, N., Natadra, R., Pilling, G., Williams, P., and Hamer, P. (2023). Stock assessment of yellowfin tuna in the western and central pacific ocean: 2023. WCPFC-SC19-2023/SA-WP-04 (Rev. 2), Koror, Palau.

Pilling, G., Scott, R., Hamer, P., and Scott, F. (2024). Analyses to inform discussions on candidate bigeye and yellowfin target reference points. WCPFC-SC20-2024/MI-WP-07, Manila, Philippines. 14 Aug - 21 Aug 2024.

Punt, A., Maunder, M., and Ianelli, J. (2023). Independent review of recent WCPO yellowfin tuna assessment. WCPFC-SC19-2023/SA-WP-01, Koror, Palau, 16-24 August 2023.

Scott, F. (2026). Bigeye tuna management procedure design and implementation considerations. WCPFC-SC22-2026/MI-WP-03, The Pacific Community, Apia, Samoa, 11–19 August 2026.

Scott, R., Wickens, M., Scott, F., and Yao, N. (2026). Updated bigeye operating models. WCPFC-SC22-2026/MI-WP-01, The Pacific Community, Apia, Samoa, 11–19 August 2026.

WCPFC (2025). Report of the Scientific Committee Twenty-First Regular Session. Summary report, Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean, Nuku'alofa, Tonga, 13–21 August 2025.

Wickens, M., Scott, F., Scott, R., and Yao, N. (2025). Bigeye tuna management procedure design considerations. WCPFC-SC21-2025/MI-WP-06, The Pacific Community, Nuku'alofa, Tonga, 13–21 August 2025.