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Update of SSfutur C++ ver. 2.0.4 for Future Projections of the North Pacific Albacore stock[1]

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Abstract

This paper describes updates to SSfutur C++ (ssfcpp) version 2.0.4, developed to support forward projections in the 2026 ISC North Pacific albacore stock assessment. The new version improves compatibility with Stock Synthesis 3 (SS3) by stabilizing single-sex models, expanding spawning-season options, and revising the catch equation used for total allowable catch (TAC) scenarios. Deterministic projections showed close agreement between ssfcpp and SS3 for spawning stock biomass, catch, and numbers-at-age. Stochastic simulations further demonstrated that ssfcpp can represent uncertainty in future stock trajectories. These results indicate that ssfcpp v2.0.4 meets current assessment needs, while also highlighting remaining issues related to initial-value generation and the treatment of uncertainty. Future work will focus on bootstrap-based initialization and additional functionality to support management strategy evaluation (MSE).

Introduction

The ISC Albacore Working Group (ALBWG) has long utilized SSfutur C++ (ssfcpp) for forward projections in North Pacific albacore stock assessments (Ijima et al., 2016). Through its seamless integration with Stock Synthesis 3 (SS3), ssfcpp facilitates the simulation of recruitment variability as well as interannual fluctuations in fishing mortality and selectivity. These dynamics are notably difficult to implement within the standard SS3 framework alone.

However, because ssfcpp was originally developed for the specific ecology and management requirements of North Pacific albacore, its applicability to other species assessed using SS3 remains limited. For example, the North Pacific albacore model assumes sex-specific growth and natural mortality, whereas many other assessments (e.g., Pacific bluefin tuna) do not explicitly differentiate by sex. To date, the compatibility of ssfcpp with single-sex SS3 configurations has not been fully evaluated.

Additionally, there are limitations relate to spawning seasonality. Although ssfcpp is currently optimized for a second-quarter spawning cycle, which is consistent with North Pacific albacore biology, it lacks the flexibility to accommodate stocks that spawn in different quarters or tropical tunas that spawn year-round. Additionally, because the ALBWG projections have primarily focused on constant fishing mortality scenarios, the software's support for constant catch (Total Allowable Catch; TAC) scenarios remains insufficient. This is particularly evident in the lack of consistency with recently updated TAC functionalities in SS3.

Furthermore, in the 2023 assessment, uncertainty was incorporated via a multivariate normal distribution (MVN). However, the extraction of necessary parameters and state variables from the MVN, including age-specific selectivity, harvest rates (hrate), and age-structured population abundance, has not been sufficiently organized to fully support this resampling approach.

This paper provides an overview of ssfcpp version 2.0.4, which has been enhanced to address these limitations by providing greater flexibility in sex specifications, expanded spawning season options, and improved support for TAC scenarios. Finally, we discuss the progress toward the official software release and identify remaining challenges for North Pacific albacore stock assessments.

Material and Methods

Updates Implemented in ssfcpp version 2.0.4

The primary updates from the version utilized in the 2023 stock assessment (version [Name/Number]) include the following:

Stabilization of the single-sex model: Preliminary analyses across multiple species demonstrated that the primary forward projection outputs under the single-sex model are now numerically consistent with those derived from SS3 (Ijima. 2025).

Expansion of spawning configurations: The updated version allows users to specify quarter-specific spawning seasons, spawning timing, and year-round spawning, thereby enhancing compatibility with SS3 settings. The single-sex, year-round spawning model was applied to the ICCAT bigeye tuna assessment, where it was confirmed that the model performed as expected (ref). It should be noted that the current version does not yet support multiple spawning events per year or year-round spawning within a two-sex population dynamics model.

Support for Constant Catch (TAC) scenarios: Previously, discrepancies existed between ssfcpp and SS3 in forward projection results under constant catch scenarios due to differences in their respective catch equations. This issue was resolved by revising the ssfcpp catch equation to align with the SS3 formulation.

Verification of Initial Value Generation

Initial values were generated using a multivariate normal distribution (MVN), consistent with the methodology used in the 2023 assessment. Random draws from the MVN were based on a variance–covariance matrix that included the 2024 numbers-at-age (representing the initial population state for the simulation) as well as the recruitment model parameters (B0 and R0).

Fishing mortality at age (FAA) was calculated as the product of the harvest rate (hrate) and age-specific selectivity. However, since the current version of SS3 does not output a comprehensive variance–covariance matrix for all combinations of these quantities, FAA was adjusted by applying an F-multiplier (fmult) as follows:

$$FAA = fmult \times hrate \times selectivity.$$

Using the 2024 numbers-at-age generated from the MVN, together with point estimates for catch-at-age and the hrate × selectivity product, the fmult value was estimated to accurately reproduced the observed catch-at-age.

Preliminary Analysis

To verify the operational integrity of ssfcpp, forward projection results—specifically spawning stock biomass (SSB), total catch, and numbers-at-age—were compared with those from SS3. This comparison utilized the preliminary model [Model/File Name] developed by the ISC Albacore Working Group. For this validation, 10-year deterministic forward projections were conducted with fishing mortality fixed at the 2020–2022 level.

Furthermore, preliminary simulations were conducted using management scenarios based on the actual stock assessment: "Historical F (2005–2022)" and "Constant F 2020–2022" (Table 1). In these runs, 10 sets of initial values were generated from the MVN, with 10 iterations performed per set to confirm model behavior. For the final full assessment, this approach will be scaled to 400 iterations for each of the 400 initial-value sets, resulting in a total of 160,000 simulations.

Result and discussion

Consistency between SS3 and ssfcpp

Preliminary projection results from SS3 and ssfcpp exhibited strong agreement. Under the constant fishing mortality scenario (F 2020–2022), the stock remained relatively stable with only minor temporal fluctuations, avoiding rapid collapse. Notably, the projected spawning stock biomass (SSB) and catch from both models were nearly identical

(Figures 1 and 2), confirming high numerical consistency. Throughout the projection period, SSB neither recovered substantially nor declined sharply, maintaining a constant level. Similarly, projected catch remained stable without significant volatility throughout the projection period.

Age-structured dynamics

Regarding numbers-at-age, while certain age classes exhibited temporary fluctuations, abundance tended to converge toward a stable equilibrium in the long term (Figures 3 and 4). Furthermore, both models yielded highly comparable results for both sexes, indicating that ssfcpp reproduces age composition patterns with a precision equivalent to that of SS3.

Uncertainty and stochastic projections

Stochastic projections using ssfcpp effectively captured SSB variability while accounting for uncertainty. A considerable spread in future SSB was observed under both the constant F (2020–2022) and resampled F (2005–2022) scenarios (Figures 5 and 6). These results suggest that while mean projections indicate a moderate stock level, recruitment variability and initial population uncertainty introduce non-negligible variance into future outcomes.

Requirements and remaining challenges

The current findings demonstrate that ssfcpp v2.0.4 satisfies the requirements for the ISC North Pacific albacore stock assessment while accommodating a broader range of biological assumptions than previous versions. However, challenges remain regarding the specification of initial values. Currently, extracting comprehensive variance–covariance matrices from SS3 is technically difficult; even when feasible, the extreme dimensionality of these matrices renders them impractical for routine use. Additionally, current FAA may not fully reflect uncertainty in selectivity and does not always align perfectly with the corresponding annual catch in numbers, which limits its precision as an initial condition.

Proposed solutions and future work

To address these limitations, we propose a bootstrap approach for generating initial values. This method facilitates the integration of uncertainty across all required parameters without relying on the assumption of multivariate normality. Unlike maximum likelihood estimation (MLE), which assumes approximately symmetric uncertainty, bootstrap methods can capture asymmetric uncertainty distributions in which the mean may deviate from the MLE. To ensure consistency between historical abundance estimates and future projections, evaluating uncertainty over the entire time series via bootstrapping is essential.

Future developments will focus on the following enhancements:

- Calculation of Spawning Potential Ratio (SPR) based on estimated selectivity.
- Generation of CPUE estimates for integrated monitoring.
- Integration of a Harvest Control Rule (HCR) module to automate management responses.

With these additional functionalities, ssfcpp will be fully applicable as an Operating Model (OM) for Management Strategy Evaluation (MSE) frameworks.

References

Ijima, H., Sakai, O., Akita, T. and Kiyofuji, H., 2016. New future projection program for North Pacific albacore tuna (Thunnus alalunga): considering two-sex age-structured popula-tion dynamics. ISC/16/ALBWG-02/06.

Ijima, H. 2025 Report on the development of ssfuture c++ (v2.0.2): a future projection software that seamlessly connects to stock synthesis 3. SCRS/2025/031

Table 1. Future projection scenarios in the 2026 North Pacific albacore stock assessment

Future Harvest Scenarios: 1)Historical F (2005-2022) 2)Constant $F_{2020\text{-}2022}$
Outputs: 1) Annual SSB 2) **Obj A:** Annual SSB with respect to new LRP (**14%$SSB_{current,F=0}$); Showing 60% and 95% CIs** 3) **Obj B:** Annual depletion (Age1+) relative to average **depletion** (Age1+) **in 2006-2015** 4) **Obj C:** Annual $F_{\%SPR}$ relative to **TRP ($F_{45\%}$)**

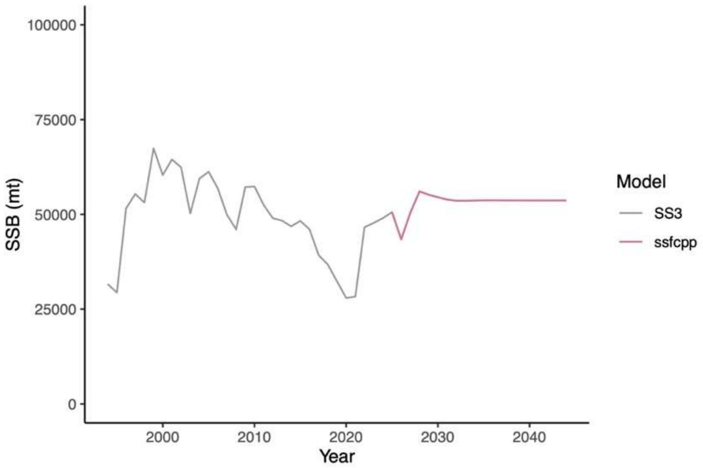

Figure 1. Comparison of deterministic spawning stock biomass (SSB) projections between SS3 and ssfcpp, assuming constant fishing mortality at the 2020–2022 level.

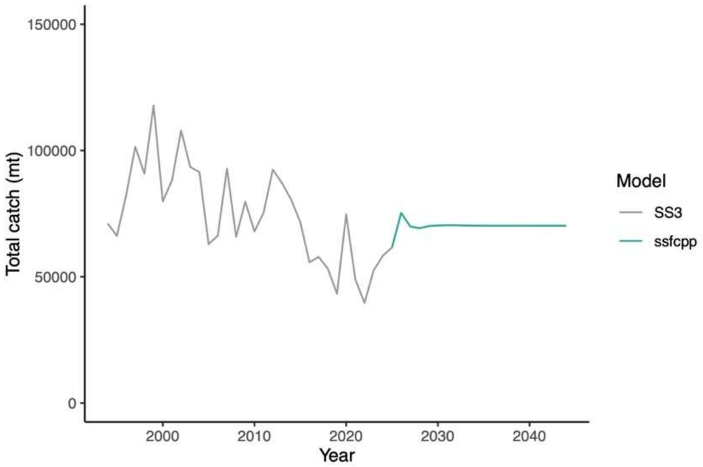

Figure 2. Comparison of deterministic total catch projections between SS3 and ssfcpp, assuming constant fishing mortality at the 2020–2022 level.

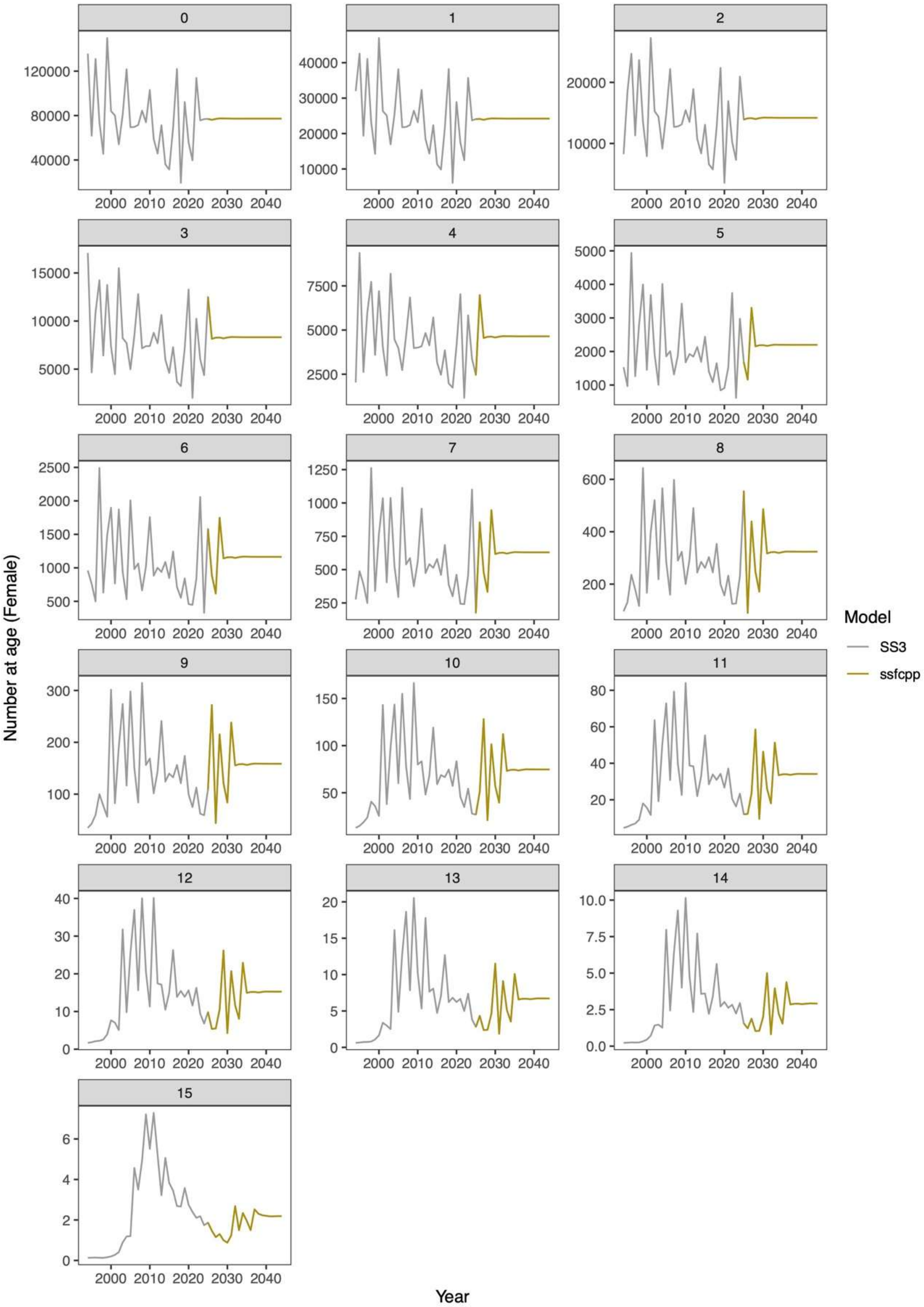

Figure 3. Deterministic projections of female abundance-at-age derived from SS3 and ssfcpp, assuming constant fishing mortality over the 2020–2022 period.

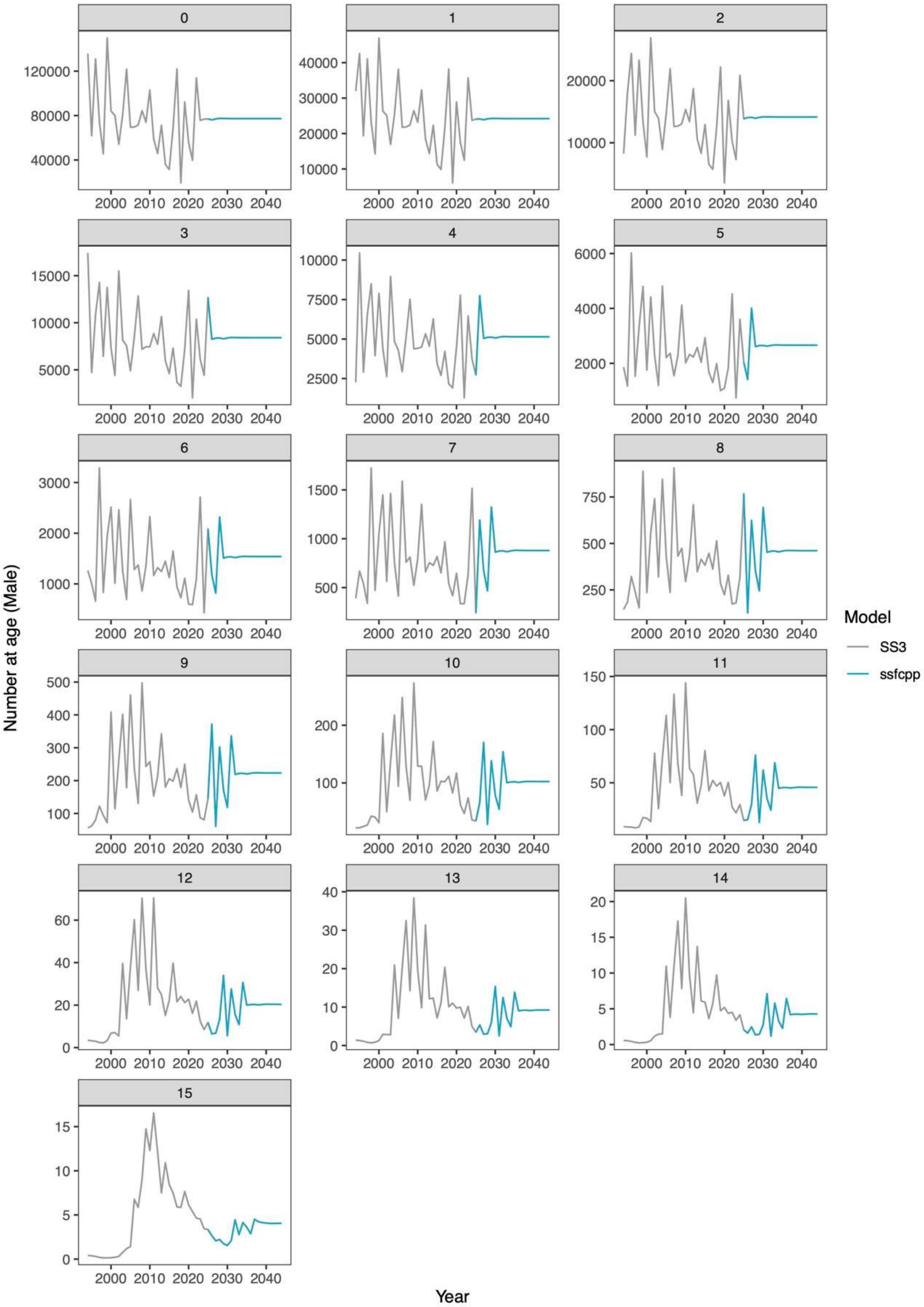

Figure 4. Deterministic projections of male abundance-at-age derived from SS3 and ssfcpp, assuming constant fishing mortality over the 2020–2022 period.

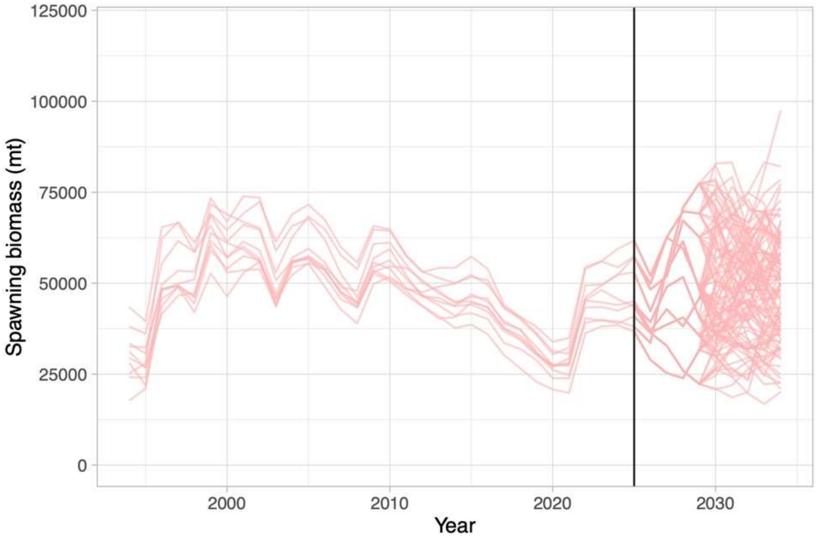

Figure 5. Stochastic projections of SSB generated by ssfcpp by constant fishing mortality scenario (2020–2022). Ten patterns of initial population size were generated using an MVN, and for each pattern, 10 iterative simulations were conducted with varying recruitment deviations.

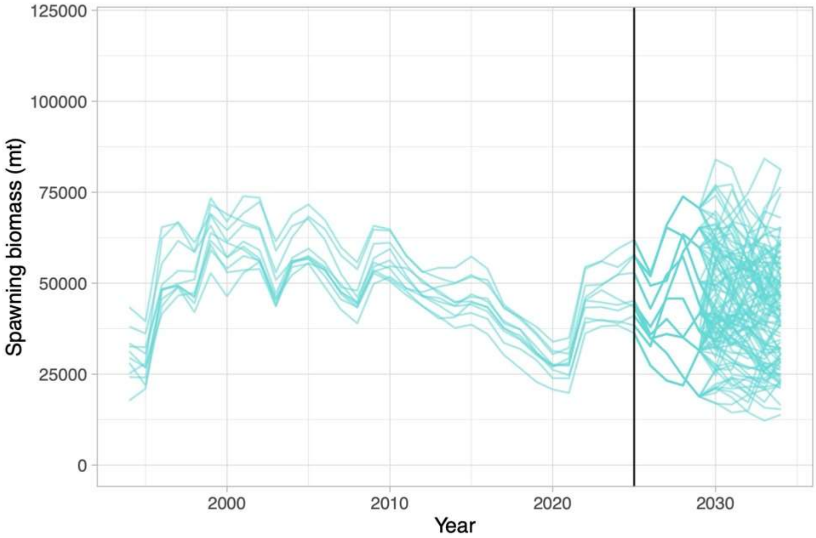

Figure 6. Stochastic projections of SSB generated by random resampling of fishing mortality scenario (2005–2022). Ten patterns of initial population size were generated using an MVN, and for each pattern, 10 iterative simulations were conducted with varying recruitment deviations.