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Implementation and evaluation of the mixture model approach for North Pacific albacore stock assessment[1]

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Abstract
The conventional area-as-fleet approach in the North Pacific albacore assessment is undermined by spatial variation. It produces unrealistic CPUE fluctuations and increases structural uncertainty. To address this issue, we applied a mixture-model approach to Japanese longline fishery data. We then evaluated Stock Synthesis 3 (SS3) runs configured with alternative fleet definitions (F1–F10) within this framework. Compared with existing models, our approach reduced uncertainty in estimates of spawning stock biomass (SSB), yielding the narrowest 95% confidence interval. It also dampened the magnitude of interannual recruitment fluctuations, indicating a potential improvement in model fit. Changes in fleet definition had little effect on the spawner-per-recruit (SPR) estimates. Overall, the mixture-model approach helps resolve data conflicts and improves model fit for the North Pacific albacore assessment, offering a practical alternative to the previous area-based method.

Introduction
The International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) Albacore Working Group (ALBWG) has long applied an area-as-fleet approach to the stock assessment of North Pacific albacore (ISC 2023). This approach provides a practical means of incorporating spatially dependent size selectivity and migratory patterns into integrated assessment models that do not explicitly include spatial structure. However, the area-as-fleet approach has a fundamental limitation. Its reliance on fixed geographic strata makes it vulnerable to seasonal and annual variation in the spatial distribution of fish sizes. In the 2023 assessment, for example, an expansion of the juvenile distribution into adult fishing grounds created a notable problem (Matsubara et al. 2025). Under conventional fishery definitions, the Catch per Unit Effort (CPUE) then exhibited unrealistic sharp increases. In addition, the choice of areas can materially influence assessment outcomes and complicate fleet definitions, thereby increasing structural uncertainty in the assessment model.

In contrast, a mixture-model framework has been shown to classify Japanese longline logbook records statistically based on visually estimated mean fish weight, without predefined spatial boundaries (Ijima et al. 2023). Although this approach was tentatively applied to a subset of longline areas in the 2023 assessment, its concrete effects on assessment results were not fully evaluated (ref).

The objective of this study is to implement the mixture-model approach in Stock Synthesis 3 (SS3) for the complete Japanese longline logbook dataset. We used new size-class-based fleets defined by the mixture model study (ref). Specifically, we compile CPUE and length-composition data for each new fleet definition to construct SS3 input file. Results from SS3 using these inputs are compared with those from the 2023 assessment and a simple update that retained the area-as-fleet approach. The comparison focuses on key stock status indicators, including spawning stock biomass (SSB), recruitment, depletion rate, and fishing intensity (the Spawner-per-Recruit, SPR, proxy for fishing mortality). Through these comparisons, we evaluate the impact and effectiveness of the mixture-model approach on North Pacific albacore stock assessment results.

Material and methods
Defining fleets using the mixture-model approach
Fleet classification by the mixture model followed the results of a different study (Ijima and Tsuda. 2025). That analysis classified visually estimated mean fish weight per set in the longline logbook data by spatiotemporal stratum (year, month, and 5° × 5° grid). Based on this classification, the Japanese longline fishery was partitioned into 10 new fleets, F1 through F10 (Table 1).

Handling unreported logbook catch
We first obtained the catch weight reported in the longline logbook and the corresponding weight in the ISC Yearbook. We then estimated the unreported catch as the difference between these two figures. Using annual and seasonal catch ratios derived from the logbook, these quantities were aggregated into unreported catch for the first–second quarters (F11) and the third–fourth quarters (F12). Because F11 and F12 lack size data, their SS3 inputs were configured to mirror fleets with available size composition data. Specifically, we applied the size composition of F2 (Japanese longline, Q1, primarily sub-adults) to F11, and the catch selectivity of F8

(Japanese longline, Q3, primarily adults) to F12. These new definitions reduced the existing 20 Japanese longline classifications to 12.

CPUE preparation and processing

CPUE was standardized for three body-size groups: juvenile, sub-adult, and adult. However, spatial estimation uncertainties led to the exclusion of the indices for the juvenile and sub-adult groups from this analysis. Consequently, the only CPUE fitted in SS3 was the standardized CPUE for the adult group (F3). We adjusted the coefficient of variation (CV) for CPUE using the standard deviation (SD) of the standardized CPUE such that the mean CV was 0.2.

Construction of length-composition data

Length-composition data for SS2 were generated from the logbook under the new fleet definitions (F1–F10). We performed resampling, conditional on the number of fish caught, using a length–weight relationship that propagated parameter uncertainty, because the logbook records mean fish weight. This procedure yielded effective sample sizes for the length composition data. The effective sample values entered SS3 were scaled to the average effective sample size used for the Japanese longline fishery in the update analysis.

Other fleet definitions and SS3 execution

Definitions for the remaining fleets (F13 through S29), excluding the newly defined fleets (F1–F12), were kept identical to those in the 2023 stock assessment. For these fleets, the most recent updates to catch and length composition data were the same as in the 2023 update analysis. Using these fleet definitions and data from 1994 to 2024, we executed Stock Synthesis version 3.30.24.1 (SS3). The comparative assessment focused on key indicators such as spawning stock biomass (SSB), recruitment, depletion rate, and fishing intensity. The depletion rate was calculated using the $SSB_{Fcurrent = 0}$ reference, defined as the average SSB over the latest year (year t–1) and the three preceding years (years t–2 to t–4) for each model. Spawner per recruit (SPR) was used as the index of fishing pressure.

Results and Discussion

Spawning Stock Biomass

The SS3 model with the modified alternative fleet definitions converged appropriately. Comparison of the estimated SSB showed that both the time series trend and the terminal-year average were like those in the simple update model and the 2023 stock assessment model (Fig. 1). However, the 95% confidence interval (CI) in this study was the narrowest of the three models, and its range lay entirely within the CIs of the simple update and the 2023 assessment. This pattern indicates that the SSB estimates from the three models are broadly consistent, as the CIs largely overlap. It also suggests that the mixture-model approach reduced uncertainty in SSB estimation compared with models that use conventional fleet definitions.

Recruitment

Regarding estimated recruitment, the time series pattern of inter-annual fluctuation was generally similar between the simple update and the 2023 assessment models. In this study, the extreme spikes were mitigated, and the annual range of variation was smaller (Fig. 2). Across the three models, the 95% CIs for recruitment showed little overlap. Unlike the SSB results, this pattern suggests a statistically meaningful difference in recruitment among the models. Recruitment tends to fluctuation because it absorbs internal conflicts between CPUE and length composition within stock assessment models. The smaller variation observed here suggests that introducing the mixture model in the fleet definition may have reduced data conflict and improved model fit. However, further diagnostics are needed to confirm that this reduction is not an over-smoothing that ignores biological processes, since recruitment is strongly influenced by environmental drivers. A large spike in 2022 recruitment was observed in all models. This was likely because length data from pole-and-line fisheries, which primarily catch small fish, had not been fully reported. As a result, the model may not have reflected the most recent caught fish size.

Depletion Rate and Fishing intensity

The depletion rate estimated in this study showed the largest interannual fluctuation among the three models (Fig. 3). All models indicated a recent increase in stock level, but the estimated initial relative stock level in 1994, the model start year, differed markedly among models. This difference may arise from how the models estimated initial fishing mortality (F0) or initial recruitment (R0) at the start of the time series. Detailed internal diagnostics are therefore needed, including an R0 profile and an age-structured production model (ASPM) analysis, to determine whether the difference reflects structural factors such as the change in fleet definition or conflicts in the data. In contrast, SPR estimates were broadly consistent across the three models (Fig. 4). This suggests that the change in fleet definition did not materially affect SPR despite variation in initial stock condition.

Conclusion

- The introduction of the mixture model approach to the entire Japanese longline fishery data successfully reduced the number of fleet definitions by eight.
- The implementation of this approach demonstrated a tendency for reduced uncertainty in SSB estimation and stabilized inter-annual recruitment fluctuation, suggesting a potential improvement in the stock assessment model.
- While differences were observed in the initial estimates of the depletion rate, the change had no significant impact on the key management index, Spawner Per Recruit (SPR).
- Ultimately, this approach contributes to reducing structural uncertainty in the North Pacific albacore stock assessment. However, further model diagnostics are necessary to fully verify the biological plausibility of these results.

References

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Table 1: Fleet definition of SS3 model ued in this study. The data columns indicate the types of available data, which are, respectively, C: Catch data, S: Size data, I: CPUE index, A: Age data, and W: Weight data.

SSID	FleetID	Shortname	Description	Data
1	F1	F1_JPLL_Q1_J_num	Japan LL, Q1, Juveniles only, catch in 1000s of fish	CSI
2	F2	F2_JPLL_Q1_SA_num	Japan LL, Q1, Sub-adult only, catch in 1000s of fish	CSIA
3	F3	F3_JPLL_Q1_A_num	Japan LL, Q1, Adult only, catch in 1000s of fish	CSI
4	F4	F4_JPLL_Q2_J_num	Japan LL, Q2, Juveniles only, catch in 1000s of fish	CS
5	F5	F5_JPLL_Q2_SA_num	Japan LL, Q2, Sub-adult only, catch in 1000s of fish	CS
6	F6	F6_JPLL_Q2_A_num	Japan LL, Q2, Adult only, catch in 1000s of fish	CS
7	F7	F7_JPLL_Q3_SA_num	Japan LL, Q3, Sub-adult only, catch in 1000s of fish	CS
8	F8	F8_JPLL_Q3_A_num	Japan LL, Q3, Adult only, catch in 1000s of fish	CS
9	F9	F9_JPLL_Q4_SA_num	Japan LL, Q4, Sub-adult only, catch in 1000s of fish	CS
10	F10	F10_JPLL_Q4_A_num	Japan LL, Q4, Adult only, catch in 1000s of fish	CS
11	F11	F11_JPLL_Q1Q2_wt	Japan LL, Q 1 & 2, catch in mt	C
12	F12	F12_JPLL_Q3Q4_wt	Japan LL, Q 3& 4, catch in mt	C
13	F13	F13_JPPL_A35_Q1	Japan PL, Area 3 & 5 (>=30N), Q1, catch in mt	CS
14	F14	F14_JPPL_A35_Q2_9421	Japan PL, Area 3 & 5 (>=30N), Q2, catch in mt	CSI
15	F15	F15_JPPL_A35_Q3	Japan PL, Area 3 & 5 (>=30N), Q3, catch in mt	CSA
16	F16	F16_JPPL_A35_Q4	Japan PL, Area 3 & 5 (>=30N), Q4, catch in mt	CSA
17	F17	F17_JPPL_A24	Japan PL, Area 2 & 4 (<30N), Qtr All, catch in mt	CS
18	F18	F18_USLL_A35	US LL, Area 3 & 5 (North), Qtr All, catch in mt	CS
19	F19	F19_USLL_A24	US LL, Area 2 & 4 (South), Qtr All, catch in mt	CSA
20	F20	F20_TWLL_A35	Taiwan LL, Area 3 & 5 (25-45N), Qtr All, catch in mt	CSWA
21	F21	F21_TWLL_A24	Taiwan LL, Area 2 & 4 (0-25N), Qtr All, catch in mt	CWA
22	F22	F22_KRLL	Korea LL, Area All, Qtr All, catch in mt	C
23	F23	F23_CNLL_A35	China LL, Area 3 & 5, Qtr All, catch in mt	CS
24	F24	F24_CNLL_A24	China LL, Area 2 & 4, Qtr All, catch in mt	CS
25	F25	F25_VUOTHLL	Vanuatu & Others LL, Area All, Qtr All, catch in mt	CS
26	F26	F26_EPOSF_9921	EPO Surface, Qtr All, catch in mt	CSIA
27	F27	F27_JPTWKR_DNMisc	JP, TW & KR Drift Net and Misc, Area All, Qtr All, catch in mt	C
28	S28	S28_JPLL_RTV_A2	Japan LL Research & Training Vessels, Area 2	S
29	S29	S29_JPLL_RTV_A4	Japan LL Research & Training Vessels, Area 4	S

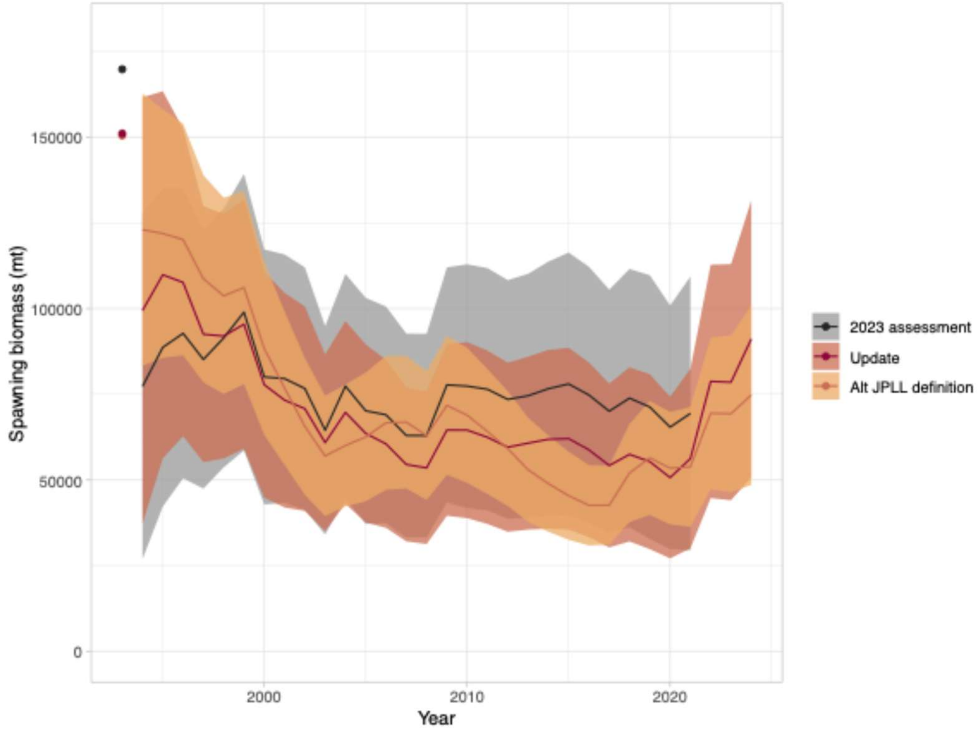

Figure 1: Comparison of the time-series changes in spawning stock biomass (SSB) from Three Stock Synthesis 3 (SS3) models.

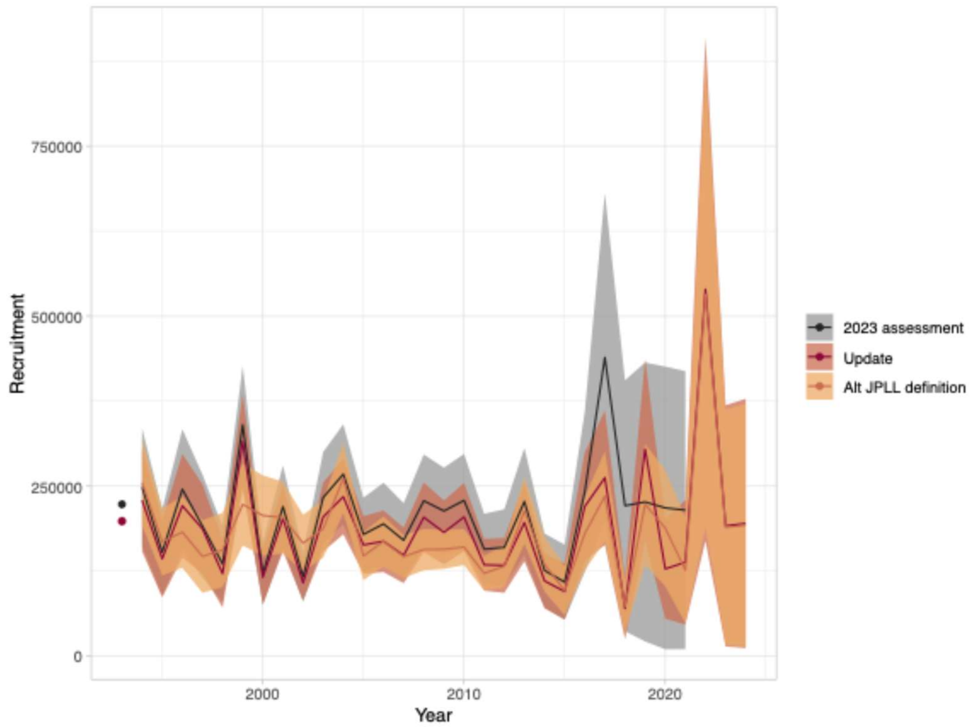

Figure 2: Comparison of the time-series changes in recruitment from Three Stock Synthesis 3 (SS3) models.

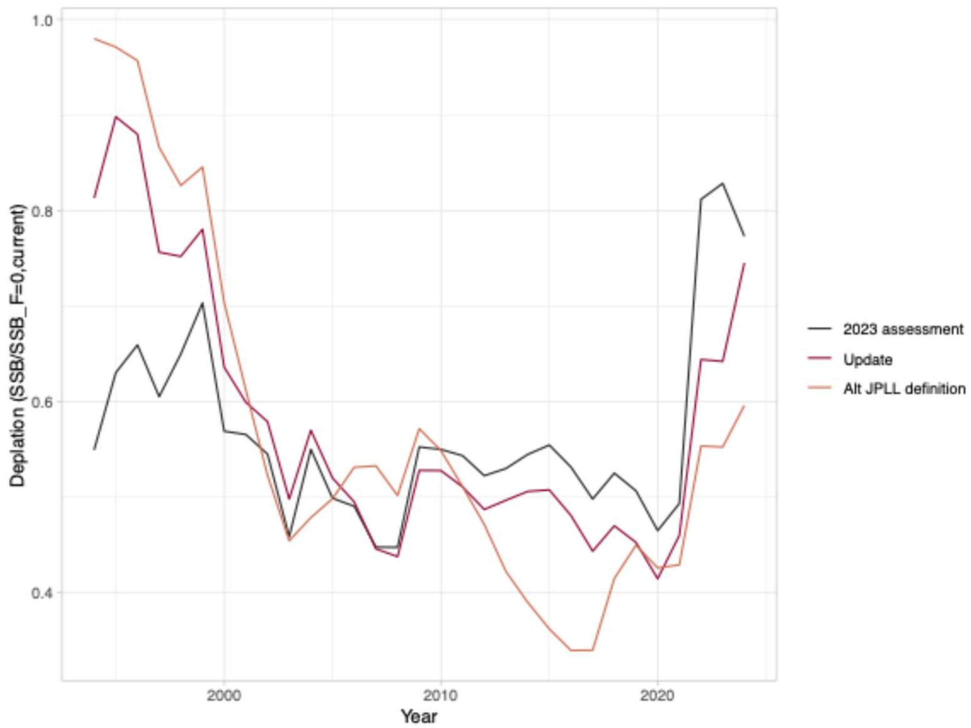

Figure 3: Comparison of the time-series changes in depletion rate from Three Stock Synthesis 3 (SS3) models.

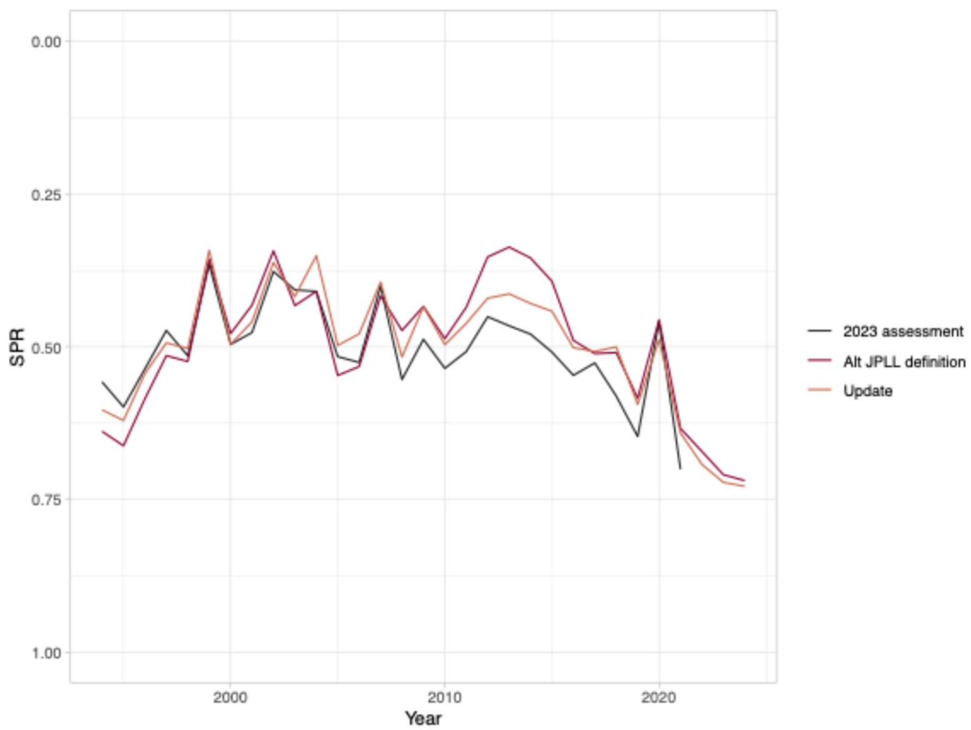

Figure 4: Comparison of the time-series changes in span pre recruitment (SPR) from Three Stock Synthesis 3 (SS3) models.