Comprehensive model diagnostics to investigate the cause of a systematic retrospective pattern of SSB in Pacific Bluefin tuna Stock Synthesis model used for the 2022 assessment.

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1 Introduction

The last full stock assessment for the Pacific bluefin tuna (hereafter PBF) was carried out in March 2020 (ISC PBFWG, 2020). The WG acknowledged that the assessment model was able to reconcile all key data sources sufficiently (catch, size composition, and abundance index) and a population scale were estimated based on the consistent information given by the data. However, the WG also noted that there was a small but persistent retrospective underestimation of terminal SSB in recent several years and this issue was carried to the updated assessment conducted in 2022 (ISC PBFWG, 2022). This issue was pointed out at the 18th meeting of the scientific committee of the Western and Central Pacific Fishery Commission (WCOFC SC18, 2022).

This error was likely indicated that the model could not anticipate the rapid recovery of the SSB when the observations are peeled back from the terminal year. The recovery of the SSB was basically informed by two consistent standardized abundance indices based on the catch per unit effort (CPUE) of longline fleets from two different fishing nations. And the recovery trend was also observed in the result using very simple stock assessment model (e.g. age structured production model (ASPM)) that fitted to the catch alone. In accordance with those other model diagnostics and observations, the WG concluded that the recovery of the SSB from the early 2010's was a robust estimation in the 2022 stock assessment.

Because this was not the case in the 2016 and 2018 stock assessment, the systematic retrospective error might occur due to the recently observed input data or time varying change in the fishery selectivity or biological traits of fish, which was overlooked in any way. The next assessment scheduled in 2024 is the benchmark assessment, and this could be an opportunity to confirm if the terminal SSB (2022 fishing year) has cleared the recovery target or not. In order to assess the terminal year SSB as reliable as possible, it is necessary to reduce a systematic retrospective error from the estimates. In this document, the cause of the retrospective error was highlighted through a series of the systematic model diagnostics.

2 Model and Data

The length-based age structured population dynamics model implemented to the Stock Synthesis version 3.3 (Methot and Wetzel, 2013) for the Pacific bluefin tuna stock assessment was the basis of this analysis. For the sake of the flexibility to the alternative assumptions, the short-term model starting from 1983 fishing year (Fukuda, 2021) was used for this analysis. The fishery data until 2020 fishing year were used and all of the model setting was basically consistent with the 2022 stock assessment. A modification was made for the selectivity of the Fleet 1 (Japanese longline fleet) to cancel the unnecessary time-block during 1993 to 2020. This model was treated as the short-term base case model in this document and the models with alternative model assumptions or data structure were also developed to investigate the cause of the systematic retrospective pattern.

3 Retrospective analysis on the short-term model

A diagnostic tool to confirm the potential stability of stock assessment model to the data updating is retrospective analysis (Mohn, 1999). This was performed on the short-term base case model by sequentially removing all of the terminal year data (i.e. peeling), refitting the model, and then comparing terminal year estimates of spawning stock biomass (SSB) to the full-data model. Mohn's rho was estimated as an indicator of the systematic retrospective error. This was also applied to other models, which have alternative model assumption or data structure, to compare the stability of the model.

In the short-term base case, a retrospective analysis showed a slight underestimation of terminal SSB for the past 5 years (Fig. 1). In particular, excluding 2019-2020 FY data made the 2016-2018 SSB much lower than the full data series model. The Mohn's rho for the terminal SSB was 0.27, which exceeded the general criteria of existence of retrospective bias (0.2). A systematic retrospective pattern was also shown in the recruitment year classes of 2011-2016, which corresponded to the 4-9 year old at the terminal year of the full-data model (Fig. 2). Among the age classes consisting the SSB, relatively young spawner (age 3 to 8) showed a clear retrospective pattern, where the biomass of older spawner (age 9 and older) showed a high stability of the estimated biomass (Fig. 3). Those results suggested that the data peeling affected to the recruitment estimates of recent (less than 10) years negatively and that lead the retrospective error of the SSB estimates. A robustly estimated SSB of age 9 and older as well as the recruitments in 2010 and previous years in the retrospective analysis suggested that the recruitment, removal, natural mortality and growth processes for those cohorts were consistent among the data peeling runs.

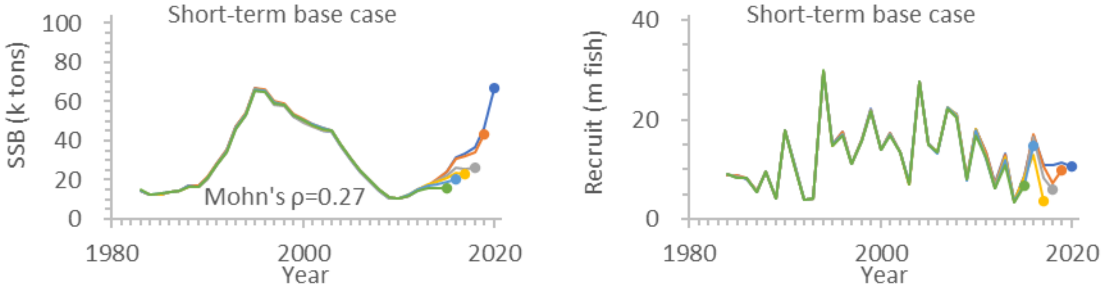

Figure 1 Five-year retrospective analysis on the PBF short-term base-case.

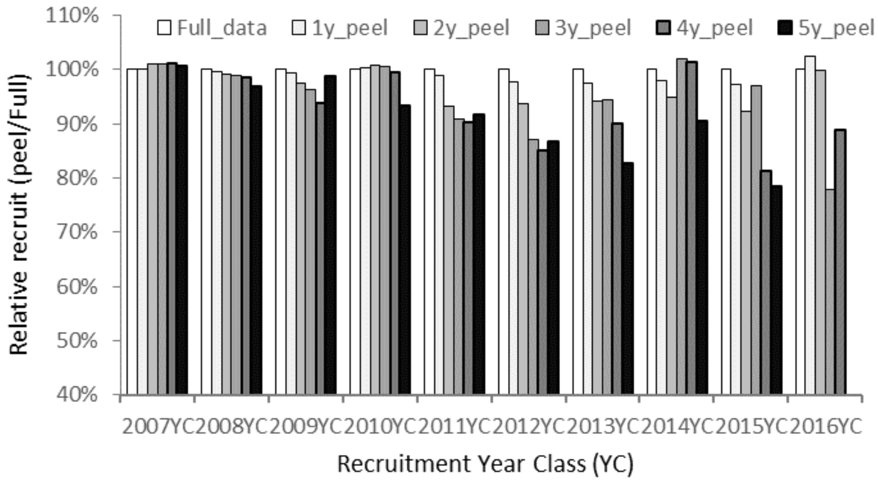

Figure 2 Comparisons of relative strength of recruitment for each recruitment year class over the 5-year peeling models.

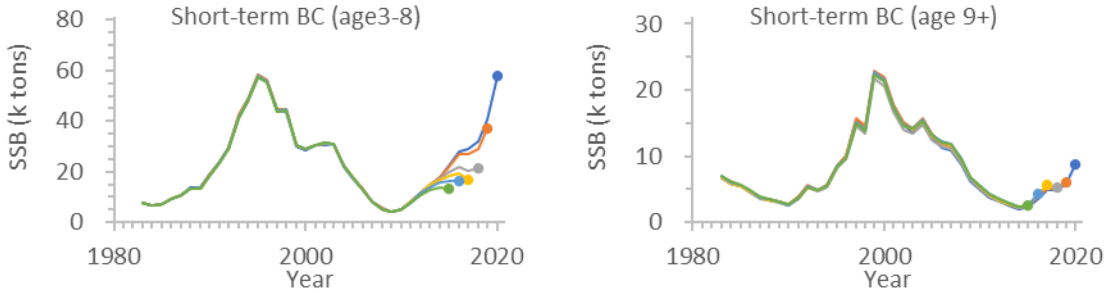

Figure 3 Five-year retrospective analysis of age specific SSB.

4 Alternative assumption regarding productivity

In general, the recruitment and natural mortality are major source of the uncertainty in the stock assessment since they are difficult to observe directory. To grasp the impact of those productivity assumptions, alternative models based on the 2 major assumptions of the recruitment and one from natural mortality were developed.

1.) Recruitment assumption

In the base case model of the PBF stock assessment, very high steepness value (0.999), which enable to create an average level of the recruitment at very low stock size, was assumed based on the independent estimates of steepness that incorporated biological and ecological characteristics of the species (Iwata 2012, Iwata et al. 2012b). To seek the possibility if this assumption caused the retrospective pattern in the recruitment, a run with alternative lower steepness (0.95) was prepared. Retrospective analysis for recent 5 years data were performed on the alternative steepness run.

A low steepness sensitivity run showed a similar trend of the SSB with slightly higher absolute SSB than the base case and it also showed clear retrospective pattern (Mohn's ρ =0.30) (Fig. 4a). A high steepness value in the base-case does not seem to be the reason of the systematic retrospective pattern.

2.) Constraints in the recruitment estimates

In the base case model of the PBF stock assessment, the recruitment was assumed as mean-unbiased so that the log recruitment deviations from the stock recruitment relationship was assumed to sum to zero over the estimated period. For this assumption, 0.6 of recruitment variability (sigma R) and a log-bias adjustment factor was applied. To seek the possibility that the constraints of recruitment estimates caused somehow pessimistic recent recruitments and consequently lead the systematic retrospective pattern in the SSB, a sensitivity run to estimate each recruitment deviation as a simple parameter without constraint was prepared. Retrospective analysis for recent 5 years data were performed on this alternative run.

A sensitivity run which assumed the recruitment deviation as a simple deviation parameter without constraint showed almost identical trend of the SSB with the base case and it also showed a clear retrospective pattern (Mohn's ρ =0.27) (Fig. 4b). A constraint to estimate the recruitment deviations in the base-case does not seem to be the reason of the systematic retrospective error.

3.) Natural mortality of the young adult

Since the retrospective analysis on the base case showed that the systematic negative pattern was occurred only for the biomass younger than age 8 when SSB was in recovery, this might be a sign of that the assumption of the natural mortality for those ages were mis-specified. For this assumption, an alternative assumption which specified 0.2 of the natural mortality for age 2 to age 9, which was 20% smaller value than the current assumption (0.25 for age 2+), was prepared and a retrospective analysis was applied.

A low natural mortality for young adult fish showed a similar SSB and it also showed clear retrospective pattern (Mohn's ρ =0.24) (Fig. 4c). The natural mortality values for young adult in the base-case does not seem to be the reason of the systematic retrospective pattern.

5 Effect of the Input Data on the systematic retrospective pattern

To elucidate the effect of input data on the retrospective pattern, we then prepared an age structured production model with estimating recruitment deviations (ASPM+R_{est}). The observed catch and abundance indices were included in the likelihood function of the model and the population scale, initial F, recruitment regime, and recruitment deviation were estimated. Basically, all of the selectivity parameters were fixed at the values estimated by the base case model. The exception is in a case the size composition data were added for its diagnostics and the selectivity parameters were estimated only for that fleet. The model settings were listed in Table 1.

1.) Size composition data

Retrospective analysis for recent 5 years data were performed on the ASPM+R_{est} to confirm whether the size composition data were related to the systematic retrospective pattern.

It was suggested that the ASPM+R_{est} still showed a systematically pessimistic pattern for the estimation of SSB at the terminal year, however, the symptoms were relieved from the one on the base case (Fig. 4d; Mohn's ρ =0.14). This might indicate that the recent size data (and misfits to those) somehow have information about the recruitments occurred in several years ago, and that peeling of the size data produced lower estimates of the recruitments during 2011-2015.

For further investigation of the influence of size composition on the retrospective pattern, we added each size composition of one-fishery-at-a-time to the ASPM+R_{est} (Table 1). Selectivity of fishery was estimated only for the fleet whose size composition was included in the likelihood function. A difference in the Mohn's rho value with the simple ASPM+R_{est} would be a contribution of the size composition data on the retrospective diagnostics. The results were shown in the Table 1. Although the ASPM+R_{est} showed a Mohn's rho smaller than 0.2, adding the size composition data of Fleet 5 (Japanese Tuna Purse Seine operating in the Pacific side) and Fleet 28 (Japanese longline Season 1 to 3, and the all seasons for 2017-) increased that to larger than 0.2.

For those fleets, a time invariant selectivity during 2015-2020 was assumed so that there would be some residuals around the mainly selected size range. Those residuals might affected to the recruitment estimates in the full-data model.

2.) Index of abundance

To know the potential effect of the abundance index to the retrospective pattern, one-off sensitivity runs were prepared using ASPM+R_{est} (Table 1). For the recruitment index, the entire time series was excluded from the model, while only recent 5 years data points were subject to removal for the Japanese and Taiwanese longline indices (S1 and S5, respectively). If the entire time series of LL index was removed, it could lead to the instability of the scale estimation, and consequently it might make us difficult to see the impact of the LL index on the retrospective pattern. This analysis showed that the exclusion of the recruitment index (S4) clearly resolving the pessimistic retrospective pattern of the terminal SSB (Table 1 and Fig. 4e). A flat or decreasing trend of the terminal SSB shown in 2 and more year peeling on the base case model would be caused by the information given by the recruitment index that informed a lower recruitment since 2011.

A retrospective analysis on the ASPM+R_{est} without recent 5 years of Japanese longline index (ASPM+R_{est}-S1_5y) showed a severer retrospective pattern than the simple ASPM+R_{est} (Fig. 4f). Since there was only a single longline index (S5; Taiwanese LL index) in this model for the terminal 5 years, this indicated that the peeling of the S5 index brought somehow instable estimates of the terminal SSB. In contrast, a retrospective analysis on the ASPM+R_{est} without recent 5 years of Taiwanese longline index (ASPM+R_{est}-S5_5y) showed a similar or relieved symptoms with the simple ASPM+R_{est} suggesting that the estimated terminal SSB based on the S1 index was more stable than that based on the S5 (Fig. 4g).

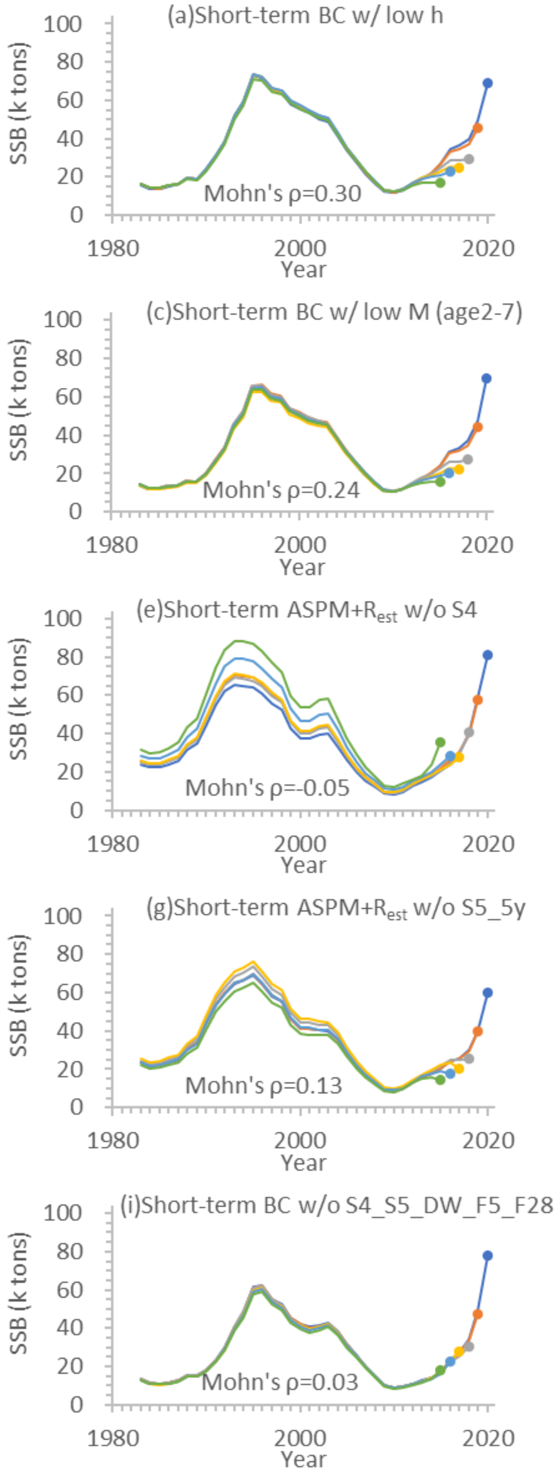

Figure 4 Five-year retrospective analysis on the PBF short-term models with an alternative assumption.

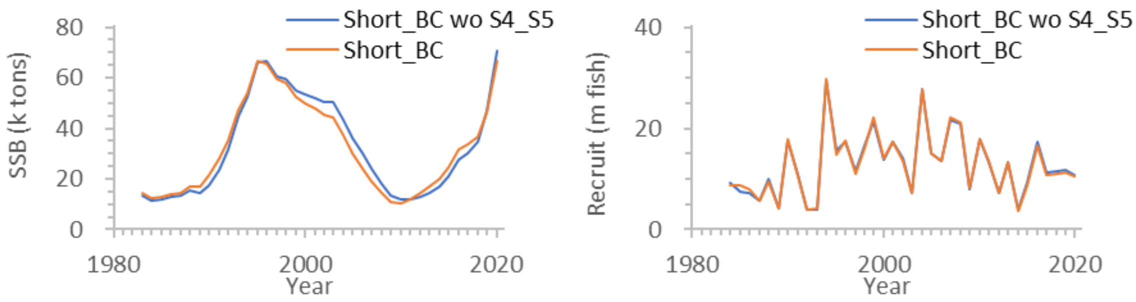

Figure 5 Comparison of the SSB and Recruitment between the short-term base case model and the short-term model without the recruitment index and Taiwanese Longline index.

6 Treatment to fix the retrospective pattern

To understand the behavior of the fully integrated model when it was stripped both of the recruitment index and Taiwanese longline index, the short-term base case model without S4 (recruitment index) and S5 (Taiwanese longline index) indices were prepared. It showed only a little difference in the SSB trend with the base case model; namely that was hitting the bottom at one year later timing and quicker recovery (Fig. 5). The systematic pattern was almost disappeared on the retrospective analysis of this single index model and the Mohn's rho was 0.08 (Fig. 4h). This suggested that the treatment to remove two indices also could work for the fully integrated model.

An additional down-weighting of the size composition data (lambda = 0.1) for Fleet 5 (Japanese Tuna PS operating in the Pacific) and Fleet 28 (Japanese LL season 1 to 3, and the all seasons for 2017-) on the above mentioned run further improved its retrospective pattern (Fig. 4i; Mohn's ρ =0.03).

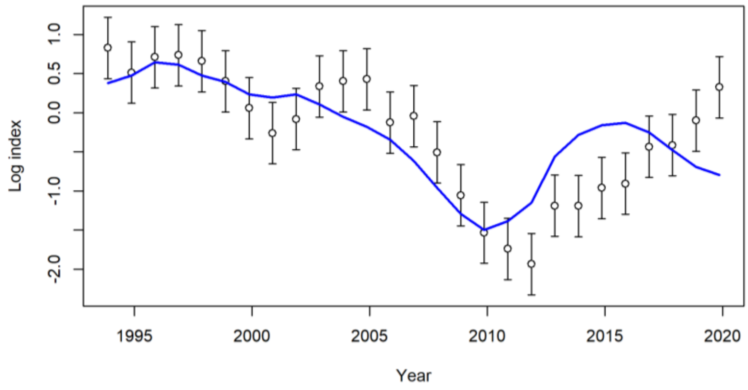

Figure 6 Observed Japanese longline index (S1) and the expected index by the ASPM+R_{est} without fitting any longline index.

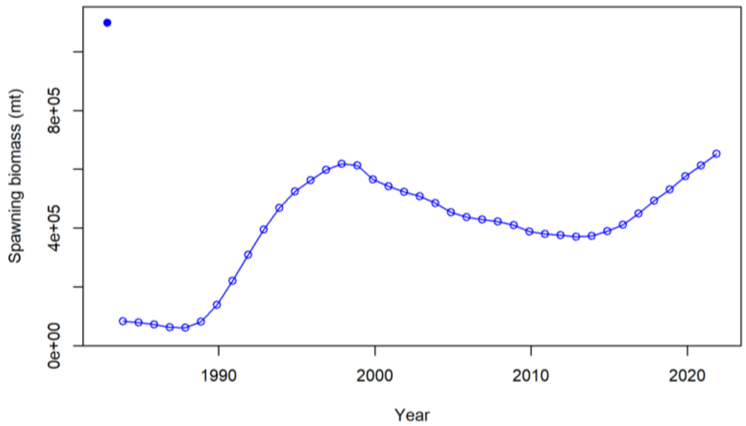

Figure 7 Spawning stock biomass of PBF estimated by the Age Structured Production Model fitted to the catch alone.

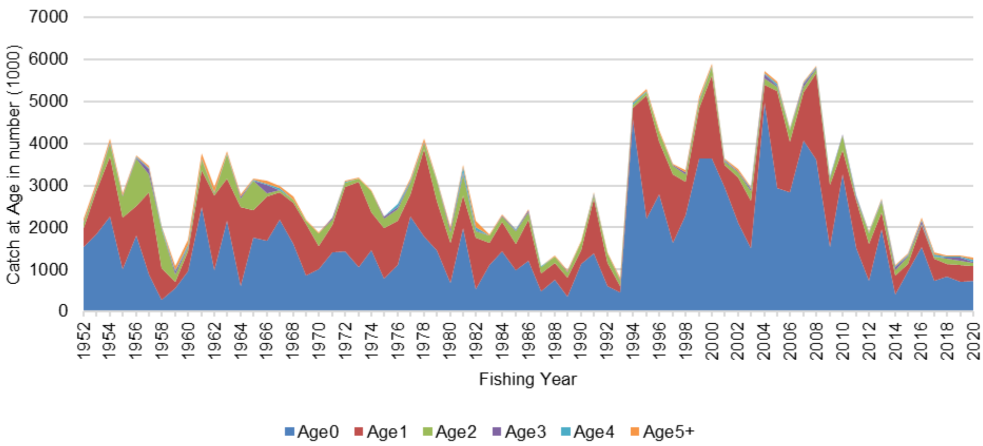

Figure 8 Estimated annual catch-at-age of PBF by the 2022 stock assessment.

7 Discussion

1.) Conflicted information about the recruitment and stock recovery

To understand the trend of SSB informed only by the recruitment index, an ASPM+R_{est} which fitted only to the catch and recruitment index was prepared (Fig. 6). Because the recruitment index was not the scaler of the SSB in its intension, the population scale ($logR_0$) was fixed at the same value of the ASPM+R_{est} only for this run. It basically followed the trend of both of the Japanese longline indices before 2016, even though the model did not fitted to this data (Fig. 6). However, the model expected decreasing trends after 2015. A similar thing was occurred in the predicted value of the Taiwanese logline index by this ASPM+R_{est}. Since the SSB trend in this model was basically estimated based on the information from the recruitment index, this result indicated a clear conflict of the information between the recruitment and longline indices. Although it is not easy to adjudge this conflict, a simpler Age-Structured Production Model (ASPM) which fitted to the catch and LL indices indicated the continuity of the stock recovery (Fig. 7). Since the PBF assessment rely on this relationship between the catch and the longline indices to estimate the biomass scale, any contradictory information against this relationship would not be welcomed.

Since early 2010's, new Conservation and Management Measures (CMM) to reduce the catch for age 0-2 PBF were introduced in the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) convention areas. The effect of those CMMs were clearly shown in the estimated catch at age for the small PBF, which was reduced since early 2010's (Fig. 8). Those CMMs might affected to the catchability of the Japanese Troll fleet, which should have been standardized statistically. Even if there is no recruitment index in the model, the model could estimate the past recruitment before 2010 (Fig. 5) based on the catch at age and the longline index (or indices), so that we could remove it from the assessment model. The weakness of the model, which does not have the recruitment index, is about the recent recruitments because the recruitments in recent years usually does not recruit to the longline fishery. The WG would want to discuss about the handling of the recruitment index in the next assessment. The choice could be;

A.) No recruitment index in the model;

B.) Keeping the recruitment index during 1983-2010 in the model, and no recruitment index after 2010;

C.) Keeping the recruitment index during 1983-2010 in the model, and a new recruitment index, if available, after 2010;

D.) No recruitment index during 1983-2010 in the model, and a new recruitment index, if available, after 2010.

This issue was also discussed in the other document submitted to the 2023 November PBFWG workshop (Fukuda et al., 2023).

2.) Conflicted information about the recent stock recovery

Since an ASPM+R_{est} without recent Japanese longline index showed a clear retrospective pattern, Taiwanese longline index currently used might have contradictory information within it. To highlight the effect of data update of the Taiwanese longline, an ASPM+R_{est} without the recruitment index and recent Japanese longline index was prepared. A retrospective runs on that model did not show the systematic pattern (Fig. 8a; Mohn's ρ =0.02), but it showed an instability of the SSB estimates, in particular on the two and more year's data peeling models. Observed Taiwanese longline index had somehow unexpectedly high values on their terminal two years (Chang et al., 2022). It also reported that the size composition from the southern fishing ground of the Taiwanese longliner was getting smaller (younger) composition during the terminal 4 or 5 years. It might be possible that the newly recruited PBF to Taiwanese longline fishery showed a high availability, and the fleet might concentrate on a specific fishing area to get those relatively new cohort. If this was the case, since the current CPUE standardization model implicitly assumed a random geographical distribution of the fish at each age as well as the fleet, the effect of the concentration of both the small fish and the fleet operation could not be standardized within the current procedure. Although this kind of unconsidered effect might make the index of abundance noisy, but the Taiwanese longline index still contained an important information about the large adult stock. It would be theoretically advantageous to use the Taiwanese longline index, which was standardized by the size structured Geo-statistical CPUE standardization model proposed by Yuan et al. (2023).

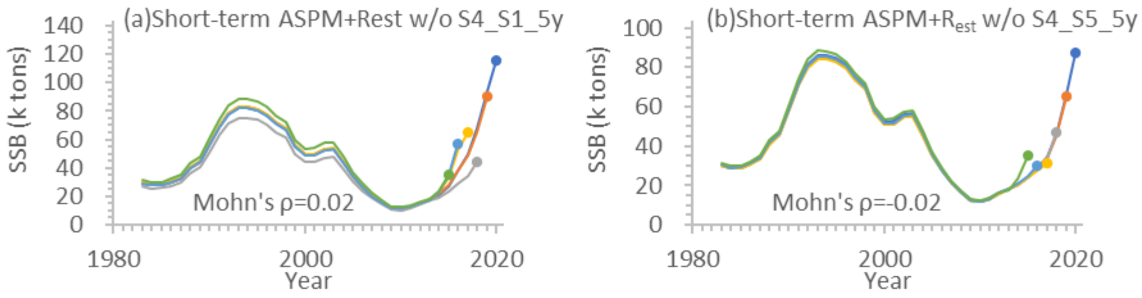

Figure 9 Five-year retrospective analysis on the PBF ASPM+R_{est} with an alternative data structure.

From 2020 FY, Japanese longline index has not been available due to the drastic changes in the fishery operation, and the Japanese scientists tried to develop an alternative index of abundance for large adult PBF although that work is really challenging. Given the situation, the Taiwanese longline index is the only abundance index of this stock currently available, so that the PBFWG needs to prepare properly to use this index in the 2024 stock assessment. This issue was also discussed in the other document submitted to the 2023 November PBFWG workshop.

3.) Effect of the size composition data on the systematic retrospective error

Some size composition data showed a negative impact on the retrospective analysis. Those fleets were assumed to have a time invariant selectivity for the recent period, which should lead some residuals in the assessment model. In this case, those residuals in the model made some recruitments (maybe 2010 and 2011 year classes) to be higher, consequently peeling those from the model would show a systematic retrospective pattern. It also should be noted that the improvement in the Mohn's rho was only 0.05, and the systematic retrospective pattern was almost fixed by removing two indices of the abundance from the model. The handling of the size composition data in the next assessment is one of the main topics during the PBFWG group meeting in November, the WG should consider that from several choices.

E.) Living with some residuals;
F.) Down-weighting;
G.) Adding further flexibility to those fleets (e.g. time-varying selectivity and/or wider age-based availability etc).

8 General Conclusion

This document provided the source of the systematic retrospective pattern shown in the 2022 PBF stock assessment model. Both of the productivity assumptions and the input data were tested one by one, and the thorough analysis suggested that the input data were possible contributing factors. A modified version of the 2022 model, which excludes the recruitment index and the Taiwanese longline index with down-weighted some composition data, showed very consistent SSB estimators on the retrospective analysis. However, excluding the Taiwanese longline index is not a realistic choice for the 2024 assessment given the current situation. Thanks to our Taiwanese colleagues, the WG has several choices for the Taiwanese longline index, so those should be chosen properly in the next assessment.

About the recruitment estimates, this document showed that the historical recruitments were basically estimable based on the information from the catch at age and the longline index. The primal advantage of the recruitment index for the stock assessment is the information about the recent recruitment. Although the currently used traditional troll index was one of the main causes of the systematic retrospective error, including a recent recruitment timeseries (i.e. only recent 10 years) in each assessment might be advantageous if it could correctly inform the relative strength of the recruitment.

Although the down-weighting of the size composition data improved the stability of the SSB estimates, down-weighting is not necessarily the best choice to reduce the residual of the composition data. Because the Fleet 5 and Fleet 28 were the fishery catching a large adult, it might be better to minimize the residuals to estimate fishing mortality on those ages correctly. Further discussion as well as the modeling work would be required for this part.

9 Literature cited

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Table 1 Data structure, model parameter setting, and Mohn's rho of the short-term model and alternative models.

	Data fitted in the model					Parameter estimated/fixed				
	Catch	Size	JLL index (S1)	TLL index (S5)	Age-0 index (S4)	Log R0	Initial F	Rdev	Selectivity	Mohn's rho
Fully integrated model (short term)	Yes	Yes	Yes	Yes	Yes	Estimated	Estimated	Estimated	Estimated	0.27
ASPM-R_{est}	Yes	No	Yes	Yes	Yes	Estimated	Estimated	Estimated	Fixed	0.14
ASPM-Rest + Size (F1)	Yes	Only F1	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F1 est.	0.12
ASPM-Rest + Size (F2&F20)	Yes	Only F2 and 20	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F2&20 est.	0.13
ASPM-Rest + Size (F3)	Yes	Only F3	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F3 est.	0.14
ASPM-Rest + Size (F4)	Yes	Only F4	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F4 est.	0.02
ASPM-Rest + Size (F5)	Yes	Only F5	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F5 est.	0.29
ASPM-Rest + Size (F6)	Yes	Only F6	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F6 est.	0.19
ASPM-Rest + Size (F8&F9)	Yes	Only F8 and 9	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F8&9 est.	0.10
ASPM-Rest + Size (F10)	Yes	Only F10	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F10 est.	0.12
ASPM-Rest + Size (F12)	Yes	Only F12	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F12 est.	0.17
ASPM-Rest + Size (F14)	Yes	Only F14	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F14 est.	0.09
ASPM-Rest + Size (F15)	Yes	Only F15	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F15 est.	0.15
ASPM-Rest + Size (F17)	Yes	Only F17	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F17 est.	0.17
ASPM-Rest + Size (F18)	Yes	Only F18	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F18 est.	0.15
ASPM-Rest + Size (F19)	Yes	Only F19	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F19 est.	0.14
ASPM-Rest + Size (F28)	Yes	Only F28	Yes	Yes	Yes	Estimated	Estimated	Estimated	Only F28 est.	0.21
ASPM-Rest - Index S1_5years	Yes	No	Yes (to 2015)	Yes	Yes	Estimated	Estimated	Estimated	Fixed	0.47
ASPM-Rest - Index S5_5years	Yes	No	Yes	Yes (to 2015)	Yes	Estimated	Estimated	Estimated	Fixed	0.13
ASPM-Rest - Index S4	Yes	No	Yes	Yes	No	Estimated	Estimated	Estimated	Fixed	-0.05
ASPM-Rest - Index S4&S1_5years	Yes	No	Yes (to 2015)	Yes	No	Estimated	Estimated	Estimated	Fixed	0.02
ASPM-Rest - Index S4&S5_5years	Yes	No	Yes	Yes (to 2015)	No	Estimated	Estimated	Estimated	Fixed	-0.02
Short-term model w/o index S4&S5	Yes	Yes	Yes	No	No	Estimated	Estimated	Estimated	Estimated	0.08
Short-term model w/o index S4&S5, Size F5&F28 down-weighted	Yes	Yes (F5&F8, λ =0.1)	Yes	No	No	Estimated	Estimated	Estimated	Estimated	0.03