How to improve a flexibility of the Stock Synthesis model for Pacific bluefin stock to the alternative assumptions with keeping its performance

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INTRODUCTION

The latest full stock assessment for the Pacific bluefin tuna (hereafter PBF) was conducted by the ISC PBF working group (PBFWG) in 2020, and fishery data up to 2018 fishing year were incorporated into the stock synthesis (SS; Methot & Wetzel, 2013) platform. One of the features of the PBF SS model is that the abundance in each year was surveyed at the beginning (recruitment) and very end (large adult) of their life history by the age-0 index and spawner indices (Nishikawa et al., 2020, Yuan et al., 2020, Tsukahara et al., 2020). Demographic changes after recruit were assumed based on the available scientific information about the growth and natural mortality, and the reasonably reliable observation data such as catch (incl. discard) and size composition data as fishery removals. Also, deviation of the recruitment from the assumed stock recruitment relationship was allowed but regulated to be within a certain range.

If those observation and population dynamics models were mis-specified critically, it should be appeared as contradictory signals in the model diagnostics. So far, the observed recruitment index, catch, and adult indices show a consistency under the fixed productivity assumptions of growth, natural mortality, and stock-recruit relationship (via ASPM and ASPM-R diagnostics). Also, size composition data were considered to provide appropriate information of catch-at-age without violating population scale estimation based on the indices and catch data (via a R0 profile). Those consistency among the data and model assumptions enabled robust assessments for recent three data-update or benchmark assessments since 2016 (ISC 2016, 2018, and 2020).

On the other hand, the WG also acknowledged several aspects as remaining issues, and one of those is the model convergence issue. Although the current base case does not show any evidence of further improvements on the model convergence, it showed inflexibility to the changes of recruitment assumption (e.g. lower steepness). The current base case allows for model convergence at slightly lower level of steepness only (h=0.99). The WG does not consider this an indication of a model structure issue, but the population is observed at a very low relative stock size, and the model is fine-tuned to explain data under the current assumption.

Whatever the reason is, this kind of inflexibility to the productivity assumptions makes the WG difficult to seek and account the model uncertainty for the productivity assumptions. This issue has been highlighted as, correctly or incorrectly, as an assessment uncertainty at the managers discussions as well as other scientific forum outside the ISC, and beside that, it will be a major issue when the WG considers the structural uncertainty grid for the MSE development. In this study, the author tried to develop an alternative PBF SS model, which maintains the well performed aspects while improves flexibility to the structural uncertainty.

MODELING

In this document, the base case developed in March 2020 by the ISC PBFWG was applied as the prototype of the new model. As a major premise, the input data are considered reasonably reliable and appropriately weighted. The parameters related to the population scale and the recruitment deviations were estimated consistently to all data sources in the prototype model. The goal of this new modeling is to develop a model which is more flexible to the alternative assumptions of the productivity while maintaining the advantages of the prototype model (population scale estimates etc…) as possible.

1.) How to estimate important parameters

Population scale

Estimating population scale is an essential component of stock assessments and in the case of PBF assessment, data contrasts in the catch and spawner indices were primal source of information to estimate the population scale (Fig. 1). In the early time series, we observed a high catch (about 30k tons) period (1954-1966) followed by a moderate catch (20k tons) period (1967-1980). After then, we observed a low catch (below 15k tons) period during 1983-1993 followed by a moderate to high catch at the recent period (1994-2008). The terminal period (2009-) could be defined as a low catch period due to the strict managements introduced by the WCPFC and IATTC. The terminal spawner indices also showed some contrasts and the ASPM diagnostics suggested that the contrast in catch were captured in spawner indices (ISC 2020).

It is valuable to note that there are some exceptions in above mentioned catch observations. For example, observed catch in the 1978, 1981 and 1982 were relatively high (<30k tons) within a moderate to low catch period (Fig. 1) even though the adult PBF stock and recruitment levels during this period are not high. Those observations were interpreted in the 2020 assessment model as very high fishing pressure. The author thinks that those unusual observations are important to know the fishing mortality and depletion rate in each year precisely. However, those unusual observation might make the model difficult to be flexible to the lower productivity assumptions.

The author also thinks that the population scale might be estimable based on the data contrast observed in the recent periods only, for example low~high~low catch periods after 1983 in conjunction with the corresponding recent spawner indices.

Recruitment deviations

Estimating recruitment variability is especially important for the PBF stock since the most of fish were caught at the age younger than 3. The primal source of the information for recruitment estimate is the Age-0 index from Japanese troll fishery and the ASPM-R diagnostics suggested this data source provided an appropriate and precise information about recruitment strength (Lee et al, unpublished study). This recruitment index is available since 1980, so it should be reminded that the recruitment estimates prior to 1980 are more uncertain.

Catch at Age

In the integrated model, catch at age is estimated inside the model informed by the size composition data under the assumptions about the fishery selectivity and biology (e.g. growth). In the case of the PBF, the number of countries and fisheries fishing for PBF combined with the spatial and seasonal disaggregation of the population age-groups has resulted in a proliferation of fleets in the model. The time varying selecting pattern is also assumed for many fleets to accommodate the variation of PBF migrations (spatio-temporal change in the availability of PBF at migratory ages) in a single-area model. This approach brought a certain advantage to the assessment but required many parameters to be estimated. The number of estimated parameters increased to 415 with a run time of more than 1 hour (including hessian matrix, not to use par file).

It should be noted that the size composition data for early assessment period are not available except Japanese longline and EPO commercial purse seine although some of the other fleets also had a significant amount of catch. Those lack of size data makes it difficult to estimate the population in early time series at a same degree of uncertainty with a recent period.

2.) Shortening of the assessment period

As described in above, the recruitment index and size composition data for many fleets are not available before 1980 and incomplete series of size composition data are continued until 1993. This indicates that the main portion of data are concentrated to after 1993 and the dynamics before 1980 are affected by data-rich period. In other word, information derived from data-poor period might not contribute to the final estimate of the dynamics very much. If we can estimate similar dynamics using only data rich period, the model can be simpler and reduce some parameters to be estimated. Also, a model that excludes unusually high catch at low biomass period in 1981 and 1982 might make the possible range of demographic parameters (recruitment and selectivity) wider. This may contribute to improve the flexibility of the model to the lower productivity assumptions.

3.) Example of the new model

The same fishery data (catch, discard, abundance index, size composition) during 1983-2018 fishing year were incorporated in the stock synthesis platform. Most of the model parameterizations were maintained from the 2020 assessment base case except recruitment part which are modified to be consistent to the data period. Namely, recruitments were estimated for 1983 to 2018 as the main assessment period, and 10 year classes before the assessment period were also estimated as early recruitments to calculate the age structure (Numbers at Age) at the beginning of the assessment. Also, in the 2020 assessment base case, the initial equilibrium fishing mortality (initial F) was estimated for two fleets (Japanese longline and Set-net fleets), however, to make the model simpler, only the initial F for Japanese set-net was estimated in this example model. In addition to those, some of the size selectivity parameters which were poorly estimated in the 2020 assessment and often hit to the parameter boundary were fixed at the MLE estimated values of the new model.

The results were compared with the 2020 assessment base case.

4.) Sensitivity analysis

A series of the sensitivity analysis (Table 1) were performed for a range of the steepness and natural mortality to evaluate the flexibility of the model to the alternative assumptions of productivity in terms of the model convergence. Since the length-age relationship (e.g. growth) of PBF are generally estimated well in average (Fukuda et al., 2015), the growth parameters are out of the scoop in this study.

RESULTS and DISCUSSIONS

In total, 351 parameters were estimated within the boundaries and the final gradient of the model hessian was positive-definite with a run time of about 45 minutes. The final gradient of the example model was slightly lower and 0.000309 and there is a possibility of further improvement. The example model fits to all of the input data generally well as the 2020 base case does (Fig. 3). The estimated SSB timeseries as well as the R0 are slightly lower in the example model than the 2020 base case but the recruitment time series are almost identical (Fig. 2). Those results show evidence that the population scale can be estimated from the production relationship in the example model as done by the 2020 base case model although the example model includes shorter time series of the data. The recruitment deviations are also estimable by the shorter time series model since those parameters were primarily informed by the recruitment index. Those results indicated possibility of the shorter time series model to perform as well as the current base case.

Even if the shortening of the assessment period still achieves consistent estimate of population scale and other parameters successfully, the WG should recognize there are some disadvantages such as smaller samples of the historical biomass in the output, missing opportunity to evaluate individual fishery impacts of historic fleet for example Japanese purse seine operating in the Pacific side (Fleet 5) or the U.S. commercial fishery (Fleet 13) when they had been dominant fishery. In addition, currently both commissions adopted a empirical-based rebuilding target as the initial rebuilding target (the median spawning stock biomass (SSB_{med}) from point estimates of the assessment between 1952 and 2014), so the shorter time series model literally has a shortage to estimate the reference point currently used. However, for the purpose of the operating model for MSE, shorter time series model might work satisfactory since the expected roll of the PBF MSE is evaluation of long-term management strategy after achieving the rebuilding targets.

In the 2020 assessment, the base-case model convergence was sensitive to changes in the assumed level of steepness. Small changes in the specified steepness level resulted in a non-positive definite hessian. The 2020 base case model does allow for model convergence only at 0.99 of assumed steepness or higher. The sensitivity of the example model showed that it is more flexible to the alternative assumptions for steepness than the 2020 base case (Table 1). The example model are also flexible to the different level of the natural mortality, indicating the model is flexible to both higher and lower productivity assumptions. Although the log R0 of the sensitivity runs varied from 9.41 to 10.088, the negative log likelihood of those model does not show much difference. This might indicate that the data in the model do not have enough information to estimate or validate the assumptions.

In conclusion, the short time series model brought some advantages such as higher flexibility to the alternative assumptions about steepness, shorter run time, and keeping its high model performance as shown by the 2020 base case. The author recommends to incorporate this kind of idea for the development and conditioning of the operating model. Also, the author does not recommend to use this model for the next assessment directory since the shorter time series model can not estimate the fishery impact and other demographic variables in the historic period.

Reference

ISC. 2020. Stock assessment of Bluefin tuna in the Pacific Ocean in 2020.

Fukuda, H., Yamasaki, I., Takeuchi, Y., Kitakado, T., Shimose, T., Ishihara, T., Ota, T., Watai, M., Lu, H.-B. and Shiao, J.-C. 2015b. Estimates of growth function from length-at-age data based on otolith annual rings and daily rings for Pacific Bluefin tuna. ISC/15/PBFWG-2/11.

Methot Jr., R.D. and Wetzel, C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142, 86-99.

Table 1 Gradient, Model Hessian, Negative loglikelihood and Log R0 by each model. Blank in the column of hessian indicates that hessian does not appeared to be positive at that model.

	Gradient	Hessian	NLL	Log R0
2020 base case	0.93×10^{-3}	366	1551.03	9.50784
Example model	0.31×10^{-3}	195	1336.68	9.47555
Ex w/ h = 0.99	0.23×10^{-2}	196	1336.72	9.53832
Ex w/ h = 0.98	0.21×10^{-3}	199	1336.7	9.61185
Ex w/ h = 0.97	0.57×10^{-5}	191	1336.94	9.68776
Ex w/ h = 0.96	0.15×10^{-2}	189	1337.47	9.76284
Ex w/ h = 0.95	0.20×10^{-1}	196	1337.84	9.82136
Ex w/ h = 0.94	0.49×10^{-4}	189	1339.15	9.89725
Ex w/ h = 0.93	0.16×10^{-3}	202	1340.26	9.94898
Ex w/ h = 0.92	0.18×10^{-1}	201	1341.42	9.99711
Ex w/ h = 0.91	0.154714	200	1342.6	10.0318
Ex w/ h = 0.90	0.77×10^{-5}	206	1343.12	10.0623
Ex w/ h = 0.89	0.98×10^{-2}	-	1344.01	10.0885
Ex w/ h = 0.88	0.35×10^{-2}	-	1345.46	10.1149
Ex w/ h = 0.87	0.20×10^{-2}	214	1346.82	10.1401
Ex w/ h = 0.86	0.91×10^{-2}	201	1347.69	10.1636
Ex w/ h = 0.85	0.99×10^{-3}	-	1349.14	10.1849
Ex w/ M2+ 10% high	0.76×10^{-4}	192	1337.58	9.50399
Ex w/ M2+ 20% high	0.20×10^{-4}	189	1336.85	9.53544
Ex w/ M2+ 30% high	0.46×10^{-4}	188	1338.29	9.57016
Ex w/ M2+ 40% high	0.50×10^{-5}	172	1340.53	9.60702
Ex w/ M2+ 10% Low	0.63×10^{-2}	197	1336.6	9.45203
Ex w/ M2+ 20% Low	0.36×10^{-2}	211	1337.21	9.43402
Ex w/ M2+ 30% Low	0.12×10^{-2}	223	1337.3	9.4211
Ex w/ M2+ 40% Low	0.23×10^{-2}	235	1337.33	9.41184

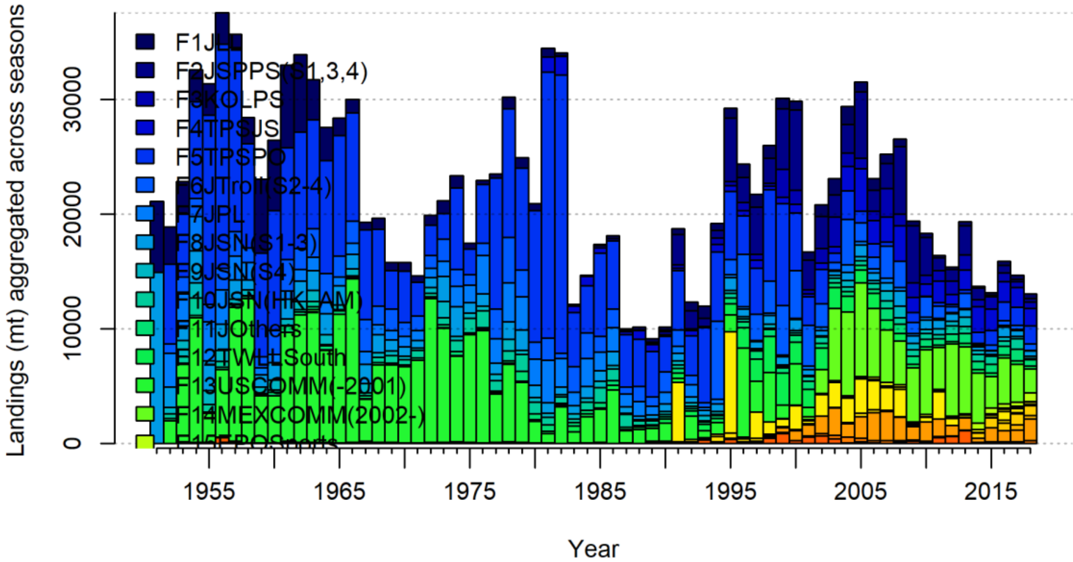

Fig. 1 Pacific bluefin tuna catch time series from 1952 to 2018 fishing year estimated by the 2020 stock assessment base case.

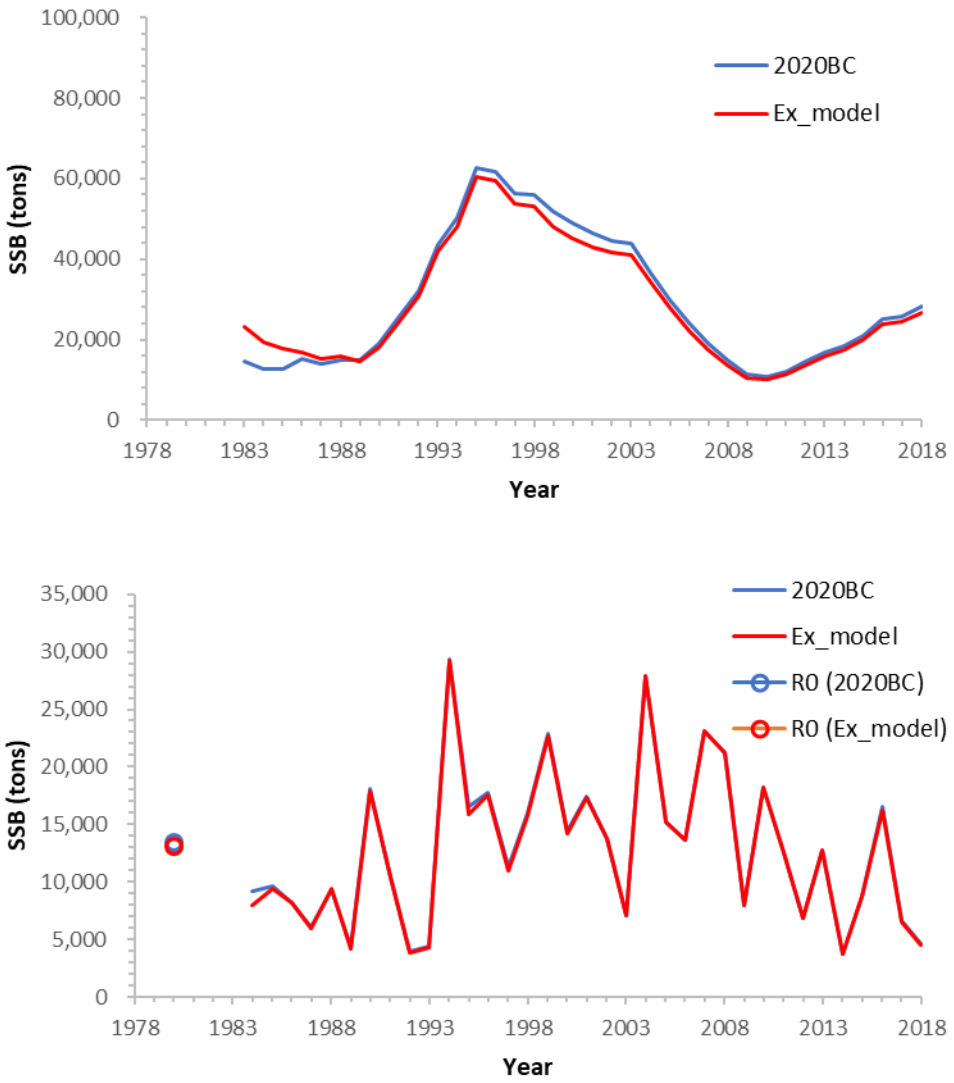

Figure 2 SSB and Recruitment, R0 estimated by the 2020 base case (2020BC) and the example model (Ex_model).

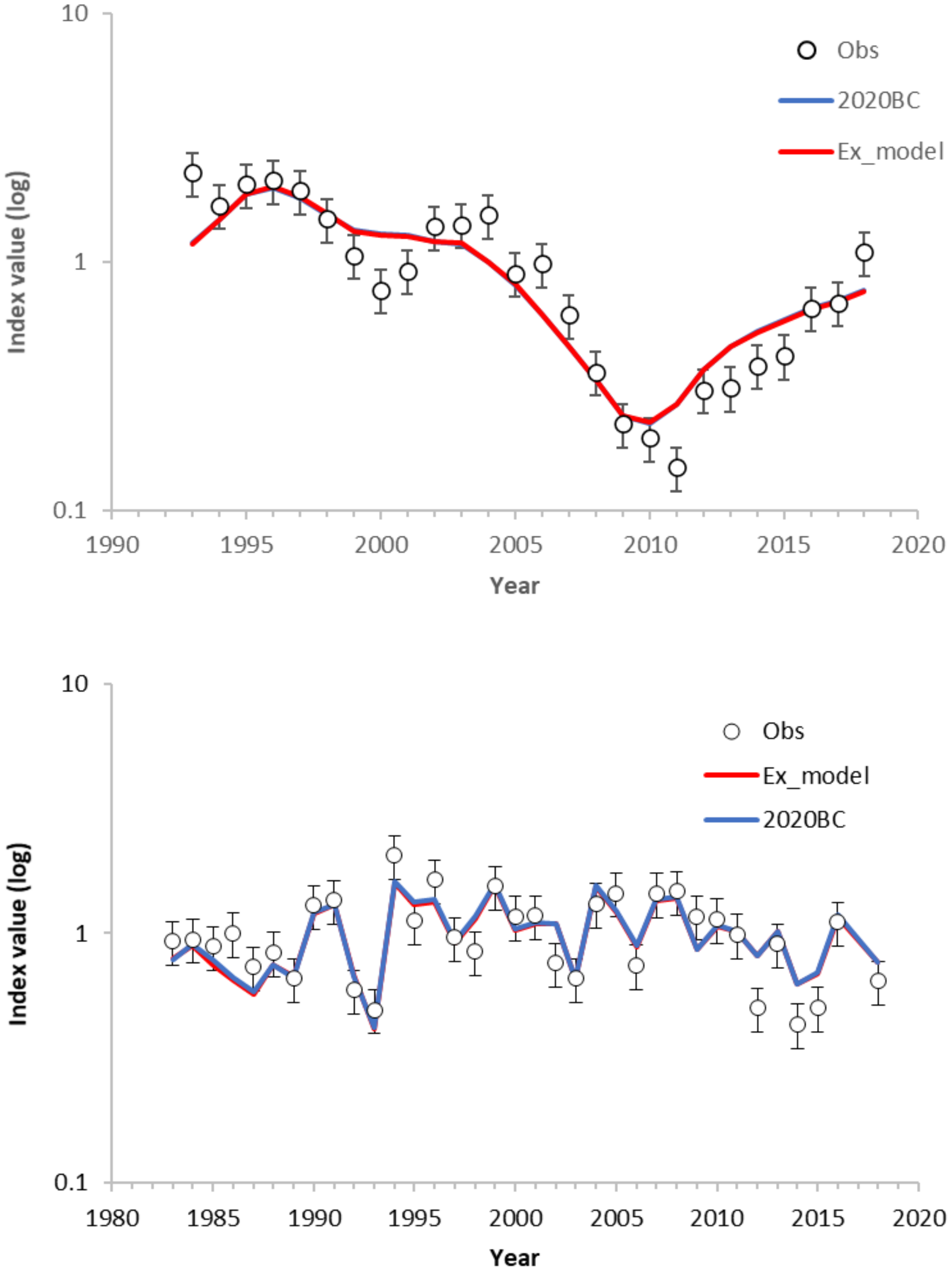

Figure 3 The model fits to the Japanese longline index (S1) and the Japanese troll index (S4) by the 2020 base case model and example model.