On the latest updates of R package "*ssfuturePBF*" and the representation of the stock assessment results.

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Summary

Two updates were added to *ssfuturePBF*, the R package for future projections of Pacific bluefin tuna stock. These updates enabled to; (1) introduce arbitrary amount of recruitment; (2) introduce arbitrary age-specific fishing coefficient by the exploitation of a certain fleet. Furthermore, a standard representation format of the stock assessment and future projection results was proposed as follows; (1) the results of both past and future trajectory are shown by a single stock status plot (or, the Kobe plot); (2) the reference points are 20% of the spawning stock biomass without fishery ($SSB_{20\%}$) and the spawning potential ratio corresponding to $SSB_{20\%}$ ($SPR*_{20\%}$); (3) the initial rebuilding target, the median point estimate SSB for 1952–2014 (WCPFC, 2016) and corresponding SPR* is also shown.

Introduction

Pacific bluefin tuna (*Thunnus orientals*; PBF) is a large, highly migratory pelagic fish species that distributes mainly in the North Pacific. Because of its economic value, PBF stock is subject to the assessment and management by the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). The two commissions have adopted conservation and management measures based on the stock assessment and future projection under a number of scenarios on fishery and recruitment by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). Since 2008, the future projections have been calculated by using a software "*ssfuture*", distributed as a R-package (Ichinokawa 2012). *ssfuture* provides age-structured forward simulations based on the model used in the stock assessment of PBF (Stock Synthesis; Method and Wetzel 2013).

ssfuture underwent several updates since 2012, including the renaming to *ssfuturePBF*. Although Akita *et al*. (2015) reported details for the updates added by November 2015, no description is available so far for the subsequent updates. In this document, we explain details for the recent updates on the functions to specify the fishing pattern and recruitment. A standard format for the representation of the stock assessment and future projection results are also proposed.

NOTE: Following analysis uses the results from the 2016 PBF assessment. Therefore, after the stock assessment for PBF in 2018, the sample data sets and configurations of stock assessment software ("StockSynthesis", Methot & Wetzel 2013) used here for demonstrations should be out of date. The demonstrations shown in this document are not to infer any conclusions on the current stock status or future condition of PBF.

Details of the latest updates

Arbitrary amount of recruitment

ssfuturePBF so far determined the amount of recruitment by random sampling from the estimated recruitment during arbitrary selected years (Akita *et al.*, 2015), although there were other options (i.e., determining the amount of recruitment according to specific stock recruitment relationships, Akita *et al.*, 2016). For example, in the low recruitment scenario in the previous assessment, the amount of future recruitment is sampled from the estimated recruitments during 1980th, in which the level of recruitment was low (Akita *et al.*, 2017). The inconvenience of this method is that it cannot deal with unexperienced, extremely low or high recruitment. The new update enabled to set arbitrary amount of recruitment in future given years. As an application, we conducted future projections under the low recruitment scenario, with extremely low (half the historical minimum, 1,500,000 fish) and extremely high (double the historical maximum, 75,000,000 fish) recruitment in 2015 (Fig. 1).

Arbitrary fishing patterns for each fleet

ssfuturePBF so far determined the fishing coefficient at age at fleet by multiplying the actual exploitation pattern in any given year obtained from the stock assessment. For example, one scenario of future projection previously conducted multiplied the geometric mean fishing coefficient at age at fleet during 2002–2004 so as to fulfill the catch upper limit. However, in practice, the selectivity of each fleet might change, depending on the fishing activity and distribution of the stock. To simulate this situation, we have added an update that enables to set arbitrary fishing coefficient at age at fleet. As an illustration, we conducted future projections modifying the selectivity of a fleet that has exploited only small (age 0–2) fish so as to catch small and large (age 0–20+) fish (total catch was fixed, Fig. 2) The recruitment scenario was identical to the low recruitment scenario in the previous future projection (Akita *et al.*, 2017).

Representation of the stock status

Because the fishing selectivity differ substantially among the fleets, a regulation for a specific fleet corresponds to a relaxed fishing intensity for the target age classes and results in a specific stock recovery process. Therefore, in addition to whether the management target will be achieved under a certain fishing scenario, the process how the management will succeed/fail is also of our interest. Stock status plot (or Kobe plot), which shows indices of the spawning stock biomass (SSB) and fishing intensity in the horizontal and vertical axis, respectively, is a convenient tool to track the recovery process visually. We propose spawning potential ratio (SPR*) as an index of fishing intensity. SPR* is defined as the ratio of the equilibrium SSB under current fishing coefficient at age under virgin recruitment relative to the unfished SSB. SPR* is a reasonable index of fishing intensity as it contains the information of the selectivity that might change its annual pattern due to the capping rule. Note that the SSB per recruitment is also abbreviated as SPR in fishery science. For the avoidance of confusion, we use “SPR*” as spawning potential ratio and “SPR” as spawning biomass per recruitment in this document, according to Ijima (2007). SPR* is output from the stock assessment software Stock Synthesis, but *ssfuture*PBF does not calculate it. In what follows, we explain how to derive SPR* from the available output from *ssfuturePBF*.

From the definition, SPR* in year y (SPR^*_y) is expressed as the relative SPR in year y (SPR_y) to the SPR under absence of fishery (SPR_0):

$$SPR_y^* = \frac{SPR_y}{SPR_0}. \tag{1}$$

SPR_y is the sum of the spawning biomass at each age:

$$SPR_y = \sum_{a=0}^{20} SPR_{y,a}, \tag{2}$$

where a and $SPR_{y,a}$ denote the age (integer) and the SPR at age a in year y. $SPR_{y,a}$ are given by

$$SPR_{y,a} = \exp\left[-\frac{3}{4}(F_{y,a} + M_a)\right] W_{a,4} Q_a \qquad (a = 0) \tag{3}$$

$$\exp\left[-\frac{3}{4}(F_{y,a} + M_a) - \sum_{A=0}^{a-1}(F_{y,A} + M_A)\right] W_{a,4} Q_a \qquad (1 \le a \le 19) \tag{4}$$

$$\frac{1}{1-\exp[-(F_{y,a}+M_a)]}\exp\left[-\frac{3}{4}(F_{y,a}+M_a)-\sum_{A=0}^{a-1}(F_{y,A}+M_A)\right]W_{a,4}Q_a$$

$$(\mathrm{a}=20), \qquad (5)$$

where $F_{y,a}$, M_a, $W_{a,4}$, and Q_a denote the fishing coefficient at age a in year y, the natural mortality coefficient at age a, weight at age a at the 4th quarter, and the maturity at age a, respectively. Note that PBF is assumed to spawn in every 4th quarter in the stock assessment and future projection. The exponential terms in the right side of eq. (3) and (4) express the survival rate by age a, at the beginning of the 4th quarter. $SPR_{y,20}$ is given by the sum of the SPR at age over 20, because the age over 20 fish is aggregated into the age 20 group in the stock assessment and the future projection. M_a, $W_{a,4}$, and Q_a are assumed to be constant throughout the years. $F_{y,a}$ is sum of the fishing coefficient at age a for each quarter:

$$F_{y,a}=\sum_{q=1}^{4}F_{y,a,q}, \qquad (6)$$

where, $F_{y,a,q}$ denotes the fishing coefficient at age a, in year y, quarter q. $F_{y,a,q}$ is obtained by solving the following catch equation (Baranov, 1918) numerically:

$$C_{y,a,q}=\frac{F_{y,a,q}}{F_{y,a,q}+M_a/4}\left[1-\exp\left(-F_{y,a,q}-M_a/4\right)\right]n_{y,a,q}, \qquad (7)$$

where $C_{y,a,q}$, and $n_{y,a,q}$ denote the total number of age a fish caught in year y quarter q and the total number of age a fish at the beginning of year y quarter q, respectively. $n_{y,a,q}$ is available from the output of *ssfuturePBF*. The natural mortality is assumed to be constant throughout a year. $C_{y,a,q}$ is a summation of the number of exploited age a fish during year y quarter q, therefore given by

$$C_{y,a,q}=\sum_{f=1}^{19}C_{y,a,q,f}\,, \qquad (8)$$

where $C_{y,a,q,f}$ is the number of age a fish caught during year y quarter q by fleet f. $C_{y,a,q,f}$ is available from the output of *ssfuturePBF*, although needs to be converted from weight (tons) to number of fish. The denominator in eq. (1), SPR_0, is obtained in the same manner as eqs. (2)–(5), assuming $F_{y,a}=0$.

As an example, we showed stock status and projection plots using the results from the 2016 stock assessment (1952–2014) and future projection (2015–2034) under four scenarios:

Scenario 1. The harvesting scenario representing the WCPFC CMM and IATTC resolution under low recruitment scenario, carried out by the ISC (Akita *et al*., 2017).

Scenario 2. The scenario 1with an extremely low recruitment in 2015, conducted in the "*Arbitrary amount of recruitment*" section above.

Scenario 3. The scenario 1with an extremely high recruitment in 2015, conducted in the "*Arbitrary amount of recruitment*" section above.

Scenario 4. The scenario 1 with modification in fishing pattern, conducted in the "*Arbitrary fishing patterns for each fleet*" section above.

We showed the SSB relative to 20% of the unfished SSB on the horizontal axis. 20% of the unfished SSB was adopted as the secondary rebuilding target of PBF in WCPFC (WCPFC, 2017). The initial rebuilding target, the median point estimate SSB for 1952-2014 (WCPFC, 2016) was also shown. SPR* was shown on the vertical axis. We inverted the vertical axis because SPR* behaves inversely to the fishing intensity. Although there is no agreed target or limit reference points for PBF, we tentatively illustrated the SPR* and SSB (relative to 20% of the unfished SSB) corresponding initial and second rebuilding targets as the reference points.

Results and Discussion

The stock status plots (Fig. 3–6) clearly showed the process of the stock status change under each scenario. In the low recruitment scenario of the future projection (Scenario 1, Fig. 3), the total SSB from 2015 to 2034 showed gradual recovery, which decelerated as approaching the equilibrium. The SPR* increased with the recovery of the SSB. This increase of the SPR* was because of the recovering SSB and the catch limitation by the catch upper limit. The extremely low recruitment (Scenario 2, Fig. 4) resulted in a temporal decrease in the SSB and delay of its recovery. With the extremely high recruitment (Scenario 3, Fig. 5), the SSB rapidly and drastically recovered in the first 10 years and then decreased as the dominant year class depleted by the fishing and natural death. With the decreased and increased catch of small (age 0–2) and large (age 3–20+) fish, respectively, the SSB in 2034 was larger than that in Scenario 1. These results indicate the great impact of the amount of small fish on the stock recovery, highlighting the importance of small fish conservation, as is previously pointed out.

References

Akita, T., Tsuruoka, I., Fukuda, H., Oshima, K., and Takeuchi, Y. 2015. Update of R packages 'ssfuture' for stochastic projections in future. ISC/15/PBFWG-2/14rev.

Akita, T., Tsuruoka, I., & Fukuda, H. (2016). Update of a projection software to represent a stock-recruitment relationship using flexible assumptions. ISC/16/PBFWG-1/05: 13p.

Akita, T., Fukuda, H., & Nakatsuka, S. 2017. Preliminary analysis of additional future projections for Pacific bluefin tuna requested by WCPFC NC and IATTC. ISC/17/PBFWG-1/06.

Baranov, F. I. 1918. On the question of the biological basis of fisheries.

Ichinokawa, M. 2012. Operating manual and detailed algorithms for conducting stochastic future projections with R packages of 'ssfuture'. Nat. Res. Inst. Far Seas Fish., Shimizu, Shizuoka, Japan, Available at: http://cse.fra.affrc.go.jp/ichimomo/Tuna/projection_manual_v0.4.pdf

Ijima, H. 2017. Summary of reference point for North Pacific albacore tuna stock assessment. ISC/17/ALBWG/06.

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

WCPFC 2016. Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean, Northern Committee Twelfth Regular Session.

WCPFC 2017. Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean, Northern Committee Thirteenth Regular Session.

Table 1. List of mathematical symbols.

Symbol	Definition	Note
a	age of fish	a = 0, 1, 2, …, 20
y	fishing year	
q	quarter number	q = 1, 2, 3, 4
f	fleet number	f = 1, 2,…, 19
SPR^*_y	spawning potential ratio in year y	available only for the stock assessment results
SPR^*_0	virgin spawning potential ratio	
SPR_y	spawning biomass per recruitment in year y	
$SPR_{y,a}$	spawning biomass at age a per recruitment in year y	
$F_{y,a}$	Fishing coefficient of age a fish in year y	
$F_{y,a,q}$	Fishing coefficient of age a fish in year y, quarter q	
$C_{y,a,q}$	Catch (number) of age a fish in year y, quarter q	
$C_{y,a,q,f}$	Catch (number) of age a fish in year y, quarter q, by fleet f	output from *ssfuturePBF*
M_a	Natural mortality of age a fish	fixed value, assumed in the stock assessment in 2016
$n_{y,a,q}$	Number of age a fish in year y, at the beginning of quarter q	output from *ssfuturePBF*
$W_{a,4}$	Weight of age a fish in 4th quater	fixed value, assumed in the stock assessment in 2016
Q_a	Maturity of age a fish	fixed value, assumed in the stock assessment in 2016

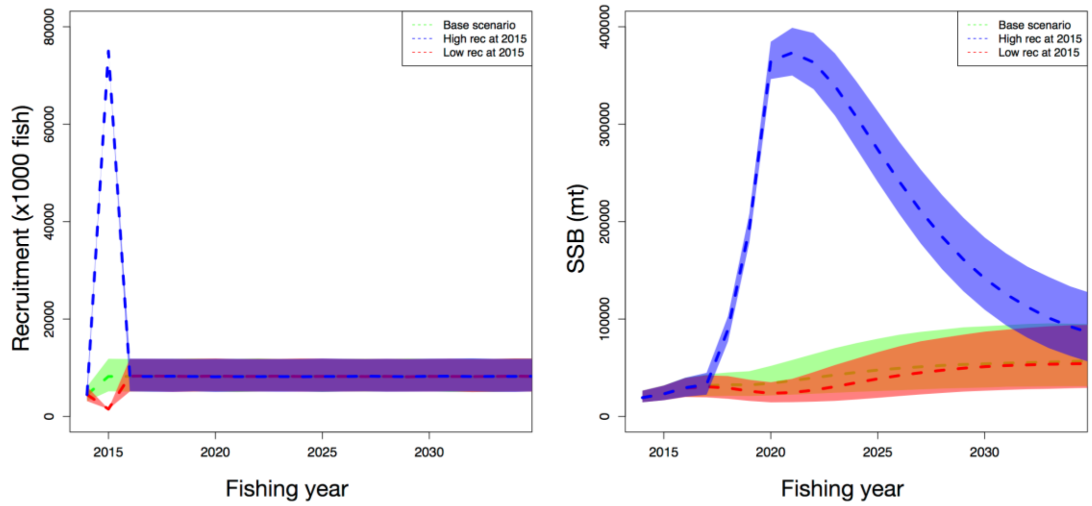

Figure 1. The modified recruitment scenarios (left) and the SSB time series obtained under the scenarios (right). The blue and red dashed lines indicate the median recruitment and SSB under scenarios with extremely high and low recruitment in 2015, respectively, whereas the green dashed line represents the ones under the original scenario. The 90 percentiles of the recruitment and SSB are shown by the shades around the dashed lines.

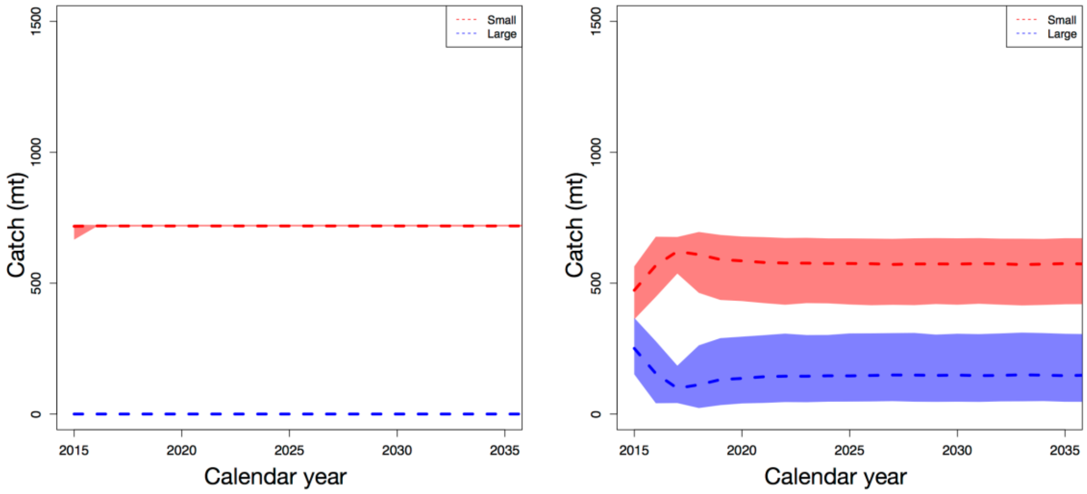

Figure 2. The catch of a fleet, whose selectivity has been modified. Before (left) and after (right) the modification. The red and blue dashed lines indicate the median annual catch of small (age 0–2) and large (age 3–20+) fish, respectively. The 90 percentiles of the catch are shown by the shades around the dashed lines.

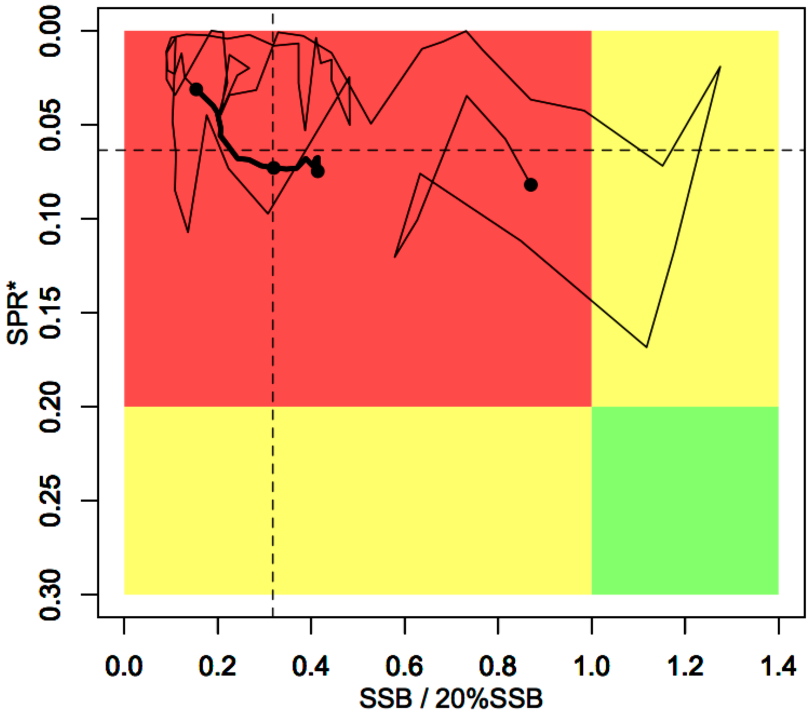

Figure 3. Stock status plot for the base case stock assessment (1952–2014, thin solid line) and base case future projection (average of 20 runs for 2015–2034, thick solid line) results. The solid circles indicate the stock status in 1952, 2015, 2024, and 2034. The vertical and horizontal borders of the colored areas indicate the rebuilding target (20% of the unfished SSB) and SPR* corresponding to the rebuilding target, respectively. The vertical and horizontal dashed lined indicate the initial rebuilding target, the median point estimate SSB for 1952-2014 (WCPFC, 2016) and SPR* corresponding to the initial rebuilding target, respectively.

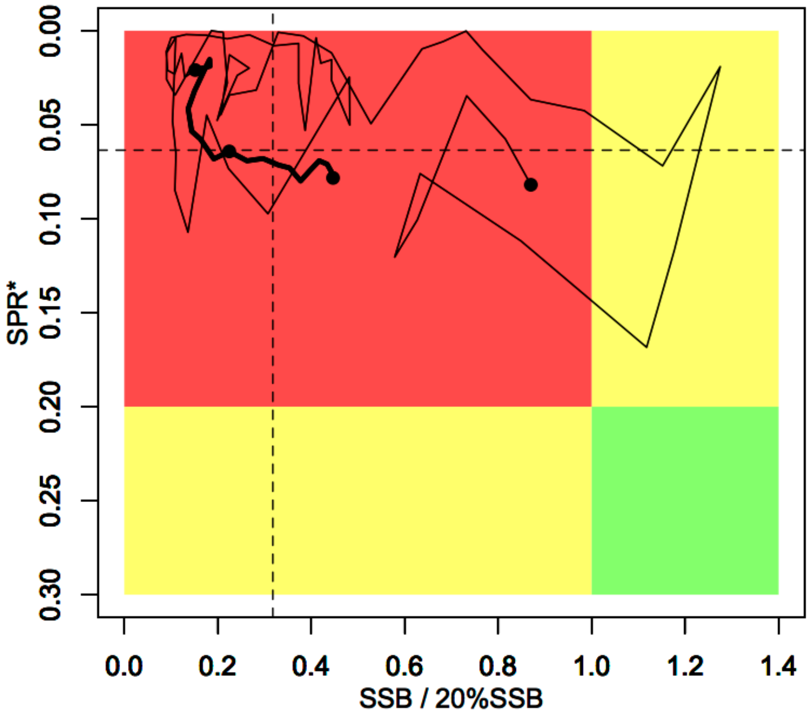

Figure. 4. Stock status plot for the base case stock assessment (1952–2014, thin solid line) and future projection with the extremely low recruitment in 2015 (average of 20 runs for 2015–2034, thick solid line) results. The solid circles indicate the stock status in 1952, 2015, 2024, and 2034. The vertical and horizontal borders of the colored areas indicate the rebuilding target (20% of the unfished SSB) and SPR* corresponding to the rebuilding target, respectively. The vertical and horizontal dashed lined indicate the initial rebuilding target, the median point estimate SSB for 1952-2014 (WCPFC, 2016) and SPR* corresponding to the initial rebuilding target, respectively.

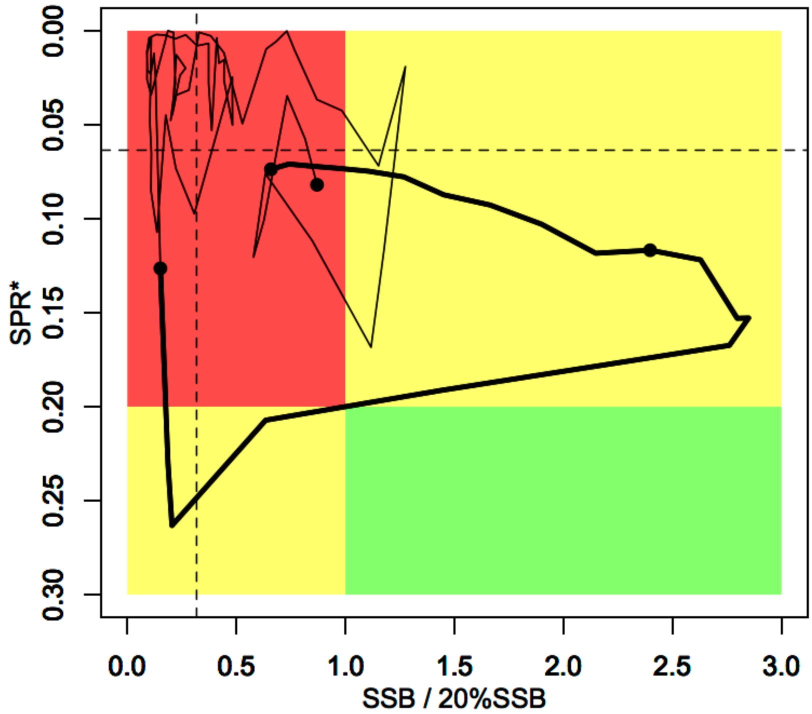

Figure. 5. Stock status plot for the base case stock assessment (1952–2014, thin solid line) and base case future projection with the extremely high recruitment in 2015 (average of 20 runs for 2015–2034, thick solid line) results. The solid circles indicate the stock status in 1952, 2015, 2024, and 2034. The vertical and horizontal borders of the colored areas indicate the rebuilding target (20% of the unfished SSB) and SPR* corresponding to the rebuilding target, respectively. The vertical and horizontal dashed lined indicate the initial rebuilding target, the median point estimate SSB for 1952-2014 (WCPFC, 2016) and SPR* corresponding to the initial rebuilding target, respectively. Note that the scales of the axes are not identical to Figure 3 and 4.

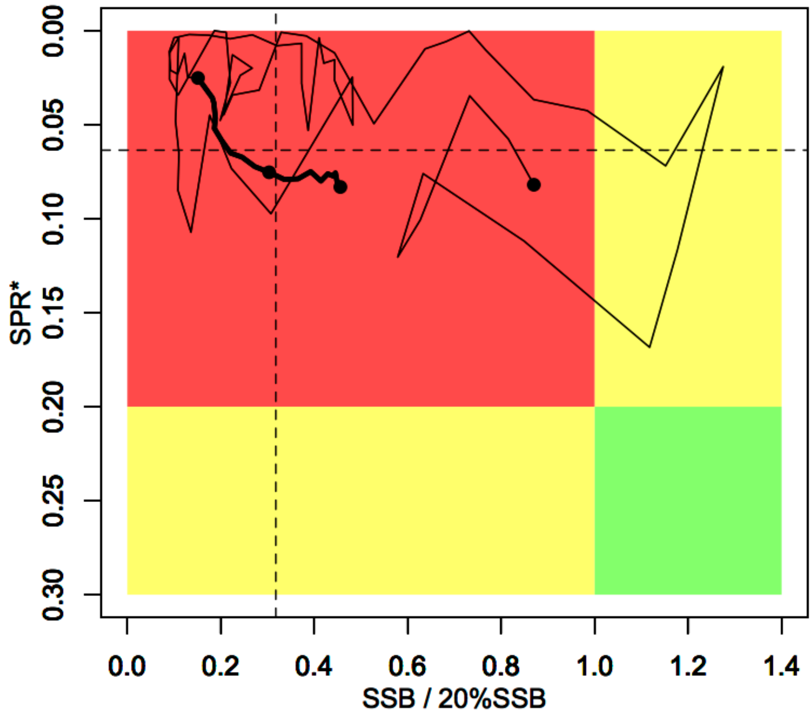

Figure 6. Stock status plot for the stock assessment (1952–2014, thin solid line) and future projection with the modified fishing pattern (average of 20 runs for 2015–2034, thick solid line) results. The solid circles indicate the stock status in 1952, 2015, 2024, and 2034. The vertical and horizontal borders of the colored areas indicate the rebuilding target (20% of the unfished SSB) and SPR* corresponding to the rebuilding target, respectively. The vertical and horizontal dashed lined indicate the initial rebuilding target, the median point estimate SSB for 1952-2014 (WCPFC, 2016) and SPR* corresponding to the initial rebuilding target, respectively.