Review of biological reference points with specific recommendations for Pacific Bluefin tuna

Hiromu Fukuda[1] and Shuya Nakatsuka[1]

[1.] National Research Institute of Far Seas Fisheries, 5-7-1, Shimizu-orido, Shizuoka 424-8633, JAPAN

Corresponding author: fukudahiromu@fra.affrc.go.jp

March 2019

Working document submitted to the ISC Pacific bluefin tuna Working Group, International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC), from 18-22 March 2019, Jeju, Korea.

1 Background

Biological reference points (BRPs) are metrics of the population size and fishing intensity. They can tell the managers and stakeholders if a stock is in a desirable state (above Target RPs), undesirable state (below Limit RPs), or between them.

In the 18th International Scientific Committee for tuna and tuna-like species in the North Pacific Ocean (ISC) plenary, held in Yeosu, Korea from 11-16 July 2018, the ISC chair tasked each species working group (WG) with updating the information in ISC/10/PLENARY/04, which listed potential BRPs with specific notation of the pros and cons of using each BRP for the ISC related species.

Since 2010 when the ISC had provided the review paper about potential BRPs to the Northern Committee (NC) of the Western and Central Pacific Fisheries Commission (WCPFC), the situation regarding the BRPs for Pacific bluefin tuna (PBF) has not changed substantially; no limit or target reference points are formally adopted in the auspices of WCPFC and Inter-American Tropical Tuna Commission (IATTC). Because of a very low stock size in both of historical and relative (to the unfished level) senses at around 2010, the discussion about the recovery plan might have been prioritized over the discussion about the BRPs in those Regional Fisheries Management Organizations (RFMOs). As a result of the large efforts by the management bodies, so far, the initial and second rebuilding targets as well as a Harvest Control Rule (HCR) for the proper recovery to those rebuilding targets in step-by-step manner within a certain time period has been introduced for PBF (WCPFC CMM 2018-02, WCPFC HS 2017-02, IATTC C-16-08).

However, because the recovery plan of PBF was developed independently from the discussion about BRPs, the PBFWG needs to once again provide concept and definition of various candidate BRPs to help and enhance the discussion on the BRPs in the NC, WCPFC and IATTC. For above mentioned purposes, the authors reviewed and updated the list of potential reference points for PBF based on the result of 2018 stock assessment.

2 Candidate Reference points

2.1 Fishing mortality based Reference points

Fishing mortality based (F-based) reference points are used as a metric to evaluate if stocks are subject to overfishing at certain reference year(s). F-based reference points can be divided several categories depending on their concept such as the Maximum Sustainable Yield (MSY) concept (F_{msy}), Yield Per Recruitment (YPR) concept such as F_{max} and $F_{0.1}$, Spawning Potential Ratio (SPR) concept ($F_{\%SPR}$), and empirical Recruitment Per Spawner (RPS) concept such as F_{med}.

Given the uncertainty in the steepness of the stock recruitment relationship, PBFWG has not provided estimates for F_{MSY}, although the WG has never consider this BRP as unusable. Note that, given the assumption of the stock assessment about steepness (h=0.999) for PBF, the estimates of F_{msy} would be theoretically almost identical with F_{max}.

In circumstances where F_{MSY} is poorly estimated, a range of proxies can be used. F_{max} and $F_{0.1}$ can be a proxy of F_{MSY} although $F_{0.1}$ is more conservative RP than F_{max}. They do not require knowledge about stock recruitment relationship nor stock-recruitment estimates. F_{max} is sometimes inestimable if the yield per recruitment curve over the F multiplier is asymptotically flat-topped, however, this is not the case for PBF until now (Fig. 1). It should be noted that those BRPs are unable to consider recruitment overfishing due to its nature although they can take into account growth overfishing under the given selectivity.

Another candidate could be $F_{\%SPR}$, which is defined as fishing intensity that produces a given percentage of the unfished spawning potential (biomass) in an equilibrium condition. Estimates of this RPs only requires life history parameters such as mortality rates (both natural and fishing), weight, and maturity at age. Since $F_{\%SPR}$ includes concepts of growth and reproduction, it can theoretically take into account of recruitment overfishing. However, the choice of percentage is always difficult. Currently, 20% of SSB_0 was adopted as the second rebuilding target for PBF in the RFMOs, so that $F_{20\%SPR}$ is a fishing intensity that will produces spawning stock biomass corresponding to the second rebuilding target on average. Note that because this reference point does not include concepts of yield, this cannot work to avoid growth overfishing.

F_{med} is a fishing mortality corresponding to a median of the empirical spawning biomass/recruitment slopes. It is expected that the stock (recruitment) would distributed around median of the observed distribution under this fishing intensity. This is one of the empirical recruitment based RPs and works to avoid recruitment overfishing. However, as same as $F_{\%SPR}$, this RP does not include a concept of yield, so that this would not work to avoid growth overfishing. It also needs to be careful that estimates of recruitment were observed under probably insufficient range of the SSB estimates for PBF stock (Fig. 2).

2.2 Biomass based Reference points

Biomass based (B-based) reference points are often used as a metric to evaluate if stocks are in overfished status. Although different biomass definitions are estimable as a B-based RPs (e.g. total stock, spawning stock or vulnerable stock biomass), spawning stock biomass (SSB) including both sexes has been conventionally used for PBF.

B-based RPs also can be divided several categories depending on their concept such as the MSY concept (SSB_{msy}), unfished spawning biomass based (Depletion ratio; xx%SSB_0), recruitment based ($SSB_{50\%R}$) and empirical observation based RPs (SSB_{med}).

Currently the RFMOs adopted SSB_{med} (median of estimated historical SSB) during 1952-2014 and 20%SSB_0 as the initial and second rebuilding targets, respectively. SSB_{med} in a general sense would naturally fluctuate as more data points are added as year passes. Although currently SSB_{med} is fixed as its term to use as a rebuilding target, this calculation method should be reevaluated to consider whether it is better be fixed or should fluctuate reflecting all historical trend, if it is to be used for limit or target reference point in future.

From the perspective to avoid negative impacts on recruitment due to low level of stock biomass, some RPs associated with recruitment more explicitly have been developed and used. $SSB_{50\%R0}$ is defined as the biomass level that produces 50% of unfished recruitment in average under an assumed stock-recruitment relationship, and this RP was adopted as the interim limit reference point in the IATTC for Bigeye tuna and Yellowfin tuna with assumption of conservative steepness value (h=0.75) for precautionarity. Although the choice of the steepness value is difficult and depends on the biological traits of each species, 0.75 was chosen for this RP in the IATTC where they assume 1.0 for the stock assessment of the same species (Maunder and Deriso, 2014; Maunder et al., 2015).

There also be an empirical method to determine a species-specific limit reference point from the observed recruitment and stock biomass to formally identify the biomass level that would prevent recruitment overfishing (Nakatsuka et al, 2017).

Depletion level is a simple B-based reference point and often used as the limit and/or target RPs in the tuna-RFMOs such as the WCPFC and CCSBT. Currently 20%SSB_0 was adopted as the second rebuilding target for PBF in the RFMOs. In this approach, RPs would fluctuate if the reference SSB_0 is estimated in a dynamic approach while it would not if the SSB_0 is estimated in an equilibrium approach.

3 Preliminary calculation

Preliminary calculations were performed for most of the BRPs mentioned above following the method of Akita and Ijima (2016) with the results of the 2018 PBF stock assessment (ISC, 2018). In addition to those, BRPs were also calculated with the results from sensitivity runs to adult M at age above 2, which were also documented in the stock assessment report, in order to examine the robustness of each BRP to the structural uncertainty.

3.1 Configuration and outputs of Stock assessment

Because the types of BRPs available and/or suitable could depend upon the configuration of assessment model, details of the model configuration and its output for PBF assessment are described below.

An annual time step, length based, sex-combined, age-structured, and forward simulation population model was implemented using Stock Synthesis (SS) Version 3.24f (Methot & Wetzel, 2013) for the stock assessment of PBF. The growth and removal processes were stratified into quarters. The model assumes a single well-mixed stock and does not consider a spatially explicated structure. The time period between 1952 and 2016 was modeled based on the observed catch, size composition, and abundance indices obtained from the catch per unit of effort (CPUE) with an appropriate standardization method.

Annual recruitments are estimated from 1952 to 2016 based on the standard Beverton-Holt stock recruitment (SR) relationship with a fixed steepness (h) and estimated natural log of unfished recruitment. Recruitment deviation from the SR relationship in log space were estimated and assumed to follow a lognormal distribution with a fixed standard deviation of 0.6. Due to the lack of information on early life stage as well as the contrast in historical spawning stock biomass for this species, the steepness of PBF is highly uncertain. Based on the independent estimates of steepness that incorporated biological characteristics (Iwata et al., 2012) or based on population dynamics estimated by the assessment model (Nakatsuka et al., 2017), steepness was fixed as 0.999.

Fleet-specific selectivity was assumed for 19 fleets and temporal change in the fleet specific selectivity (time-varying selectivity) was assumed to insure adequate model fit to the observed size composition data (Lee et al., 2017).

The main model outputs were the number of fish at each age in each quarter, annual recruitment (in the beginning of 1^{st} quarter), annual spawning stock biomass (in the beginning of 4^{th} quarter), and quarterly catch in number of fish at each age.

3.2 Variables used for the estimation

Since the instantaneous fishing mortality rate at each age is not outputted by the stock assessment model, we calculated annual fishing mortality at each age from the aggregated annual catch at each age ($C_{a, year}$), Number at each age in the beginning of the year ($N_{a, year}$), and natural mortality at each age by solving the Baranov catch equation.

For some of the BRPs based on the concepts of the yield per recruitment (YPR) or spawnner per recruitment (SPR), the body weight of fish at each age are assumed as weight at the beginning of spawning season (quarter 4 of fishing year), which is as same as the estimate of SSB in assessments.

3.3 Reference year(s)

Given the no detailed guideline for updating ISC/10/Plenary/04 available, we defined reference year for a demonstration purpose as follows;

for biomass RPs, reference year was assumed as the most recent year formally assessed by the stock assessment (2016);

for fishing mortality RPs, reference years were assumed as a couple of the most recent years when the current management measures for PBF were introduced in the both RFMOs (2015-2016).

4 Results and Discussion

The Table 1 includes candidates BRPs mentioned above, and were characterized using attributes including: the definition and management purpose, data needs, limit or target reference point, type of overfishing, pros/cons, and special comments.

4.1 Relationship between candidates and current management

Based on the preliminary calculation, SSB of PBF in 2016 is lower than all of the B-based candidate RPs and current (2015-16) F is higher than the most of F-based candidate RPs except F_{med}. If $F_{10\%\mathrm{SPR}}$ is a RP, $F_{2015\text{-}16}$ is almost identical with that RP.

Currently, there was a recovery plan including two recovery targets and a pre-agreed HCR, and the conservation advice based on the stock status for this species has been considered relative not only to the reference point estimations for given past years but also to some indicators associated with the future stock status such as the probability of achieving the rebuilding target at given year (ISC, 2018; IATTC SAC09-15 rev2, 2018). Only for a rebuilding period, a simulation based RPs such as a future fishing intensity (e.g. SPR) in which the probability of achieving a rebuilding target at given year is 60%, or future average SSB at given year in which the probability of achieving a rebuilding target at given year is 60%, are useful to assess the performance of the recovery plan which is already in force. The working group may want to discuss about the BRPs for the long-term management separately from some reference points during the rebuilding period such as rebuilding targets and simulation-based RPs. Basically, this paper focused on the BRPs for the long-term management.

4.2 Limit reference point

The main purpose of the LRP is to maintain the stock sustainability by avoiding a risk of impaired recruitment due to unsustainable exploitation and other environmental phenomena. Comparing to the TRP which may include socio-economic factors, a priority to develop the LRP should be relatively high.

For B-based LRP, associated management actions to prevent the stock falling below that LRP are also necessary to be developed while F-based LRP itself can be used as the upper limit F for management. There are two different ways in the management actions related to the LRPs; one is the way in which the management measure will be reinforced additionally when the stock exceeds that LRP (e.g. $20\%_{\mathrm{SSB0}}$ in WCPFC) and another way is that the stock will be managed not to be exceeded that LRP (e.g. $SSB_{0.5\mathrm{R0}}$ in IATTC). A common understanding about what is the expected action relative to the LRP is necessary when this topic is discussed in the RFMOs. In this context, if the LRP for PBF is developed for the latter way, that LRP should be able to consider recruitment overfishing (e.g. $SSB_{0.5\mathrm{R0}}$, SSB_{med}, depletion rate,,,,).

Developing a F-based LRP, in which management will be reinforced when the fishing exceed that F level (e.g. $F_{20\%\mathrm{SPR}}$, F_{max}, $F_{0.1}$), might be one of the precautional approach to avoid the possible impaired recruitment due to low stock size since there must be a time-lag between the exceeding F-Limit and exceeding the biomass point where the stock may suffer an impaired recruitment.

4.3 Target reference point

TRPs are more complicated since it can include several management objectives which can not evaluate by a simple performance index. The managers may expect a formal evaluation of the long-term management plan by the simulation testing work such as Management Strategy Evaluation.

5 References

Akita, T. and H. Ijima. 2016. Reference points under the hypothesis of a sex-specific life history. Working paper submitted to the ISC ALB Working Group Meeting, 08-15 November 2016, Nanaimo, British Colombia, Canada. ISC/16/ALBWG-03/12: 20p. Available at: http://isc.fra.go.jp/pdf/ALB/ISC16_ALB_2/ISC-16-ALBWG-02_WP12_Akita&Ijima_Reference_Points.pdf

IATTC. 2014. Proposal for biomass and fishing mortality limit reference point based on reduction in recruitment. SAC-05-14, Available at; https://www.iattc.org/Meetings/Meetings2014/SAC-05/Docs/_English/SAC-05-14_Proposal-for-limit-reference-points.pdf

IATTC. 2015. Preliminary management strategy evaluation to evaluate the IATTC interim reference points and proposed harvest control rule. SAC-06-10b, Available at; https://www.iattc.org/Meetings/Meetings2015/SAC-06/PDFs/Docs/_English/SAC-06-10b_Update-on-harvest-control-rules-reference-points-and-management-strategy-evaluation.pdf

IATTC. 2016. Resolution on Pacific Bluefin Tuna. C-16-03, 2016.

IATTC. 2018. Proposal for biomass and fishing mortality limit reference point based on reduction in recruitment. SAC-05-14, Available at; https://www.iattc.org/Meetings/Meetings2014/SAC-05/Docs/_English/SAC-05-14_Proposal-for-limit-reference-points.pdf

ISC. 2018. Staff recommendation for management and data collection, 2018. Available at: https://www.iattc.org/Meetings/Meetings2018/SAC-09/PDFs/Docs/_English/SAC-09-15-EN-REV-17-May-18_Staff-recommendations-2018.pdf.

Iwata, S., Fukuda, H., Abe, O., and Takeuchi, Y. 2012b. Estimation of steepness of PBFT -By using biological feature. Working paper submitted to the ISC PBF Working Group Meeting, 31 January-7 February 2012, La Jolla, California, USA. ISC/12/PBFWG-1/15: 9p. Available at: http://isc.fra.go.jp/pdf/PBF/ISC12_PBF_1/ISC12-1PBFWG15_Iwata.pdf

Lee, H.H., Piner, K.R., Maunder, M., Taylor I. G. and Methot, R.D. 2017. Evaluation of alternative modelling approaches to account for spatial effects due to age-based movement. Can. J. Fish. Aquat. Sci. 74(11): 1832-1844.

Nakatsuka, S., Y. Ishida, H. Fukuda, and T. Akita. 2017. A limit reference point to prevent recruitment overfishing of Pacific bluefin tuna. Marine Policy, 78: 107-113.

WCPFC. 2017. Harvest Strategy for Pacific bluefin tuna fisheries. HS-2017-02, 2017.

WCPFC. 2018. Conservation and Management Measure for Pacific Bluefin Tuna. CMM2018-02, 2018.

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 Candidate biological reference points for Pacific bluefin tuna with its definitions, characteristics, author's comments, and preliminary estimates.

BRPs	Definition	Limit/ Target	Type of overfishing that can be Diagnosed	Pros/Cons and Comments	Calculation	Reference year	Estimate		
							Base case	M_{old}_high	M_{old}_low
F_{msy}	Fishing mortality (F) that maximize average yield sustainably under existing environmental condition	either	Recruitment and Growth	Consistent with management goals; Difficult to estimate because of uncertain stock-recruitment relationship for PBF	F_{RY}/F_{msy} $(1/FAAmult_{msy})$	2015-2016			
F_{max}	F that maximize yield from a recruitment	either	Growth	Concept of maximum yield; Does not consider recruitment overfishing	F_{RY}/F_{max} $(1/FAA\,\mathrm{mult}_{max})$		1.36	1.20	1.57
$F_{0.1}$	F at which slope of Y/R is 10% of value at origin	either	Growth	Does not directory consider recruitment overfishing but its more precautional than F_{max}	$F_{RY}/F_{0.1}$ $(1/FAA\,\mathrm{mult}_{0.1})$		1.98	1.77	2.28
F_{med}	F corresponding to the median observed recruit/SSB ratio	either; not suitable for TRP for PBF	Recruitment	Depend on the narrow range of the historical observation of SSB and Recruitment	F_{RY}/F_{med} $(1/FAA\,\mathrm{mult}_{med})$		0.77	0.75	0.81
$F_{10\%SPR}$	F that produces given % of the unfished spawning potential (biomass) under equibrilium condition	either	Recruitment	Independent from the Stock-Recruitment estimates; Does not consider about yield; Choice of percentage is dificult	$(1-SPR_{RY})/(1-SPR_{xx\%})$		1.02	1.00	1.04
$F_{20\%SPR}$							1.15	1.13	1.17
$F_{30\%SPR}$							1.32	1.29	1.34
$F_{40\%SPR}$							1.54	1.5	1.57
SSB_{msy}	Spawning stock biomass (SSB) associated with maximum sustainable yield	either	Recruitment and growth	Consistent with management goals; Difficult to estimate because of uncertain stock-recruitment relationship for PBF	SSB_{RY}/SSB_{msy}	2016			
SSB_{med}	SSB at the median of observed time period	either; not suitable for TRP for PBF	Recruitment	Relatively robust to the structural uncertainty such as natural mortality assumption; Depend on the narrow range of the historical observation of SSB and Recruitment	SSB_{RY}/SSB_{med}		0.52	0.54	0.5
$10\%SSB_0$	SSB at given % of the estimated unfished level under equibrilium condition	either	Can consider Recruitment overfishing depend on percentage chosen	Consistent SSB_{MSY} proxi with the other RFMO; Does not consider about yield; Choice of percentage is difficult	$SSB_{RY}/10\%SSB_0$		0.33	0.42	0.25
$20\%SSB_0$					$SSB_{RY}/20\%SSB_0$		0.17	0.21	0.13
$30\%SSB_0$					$SSB_{RY}/30\%SSB_0$		0.11	0.14	0.08
$40\%SSB_0$					$SSB_{RY}/40\%SSB_0$		0.08	0.10	0.06
$SSB_{0.5R0}$	SSB associated to 50% of the unfished recruitment (R0) with assuming a stock-recruitment relationship	limit	Recruitment	Consider Recruitment overfishing explicitly; Choise of the steepness is difficult; percentage of R0 is arbitral choise	$SSB_{RY}/7.7\%SSB_0$ in the condition of (h=0.75 and $50\%R_0$)		0.43	0.54	0.32
SSB_{1stReb_tgt}	SSB at the median during 1952-2014; Initial rebuilding target for PBF in the WCPFC and IATTC	Current Rebuilding target	Recruitment	Easy to understand the concept as a rebuilding target; time period is an arbitral choice	$SSB_{RY}/SSB_{med1952-2014}$		0.50	0.53	0.48

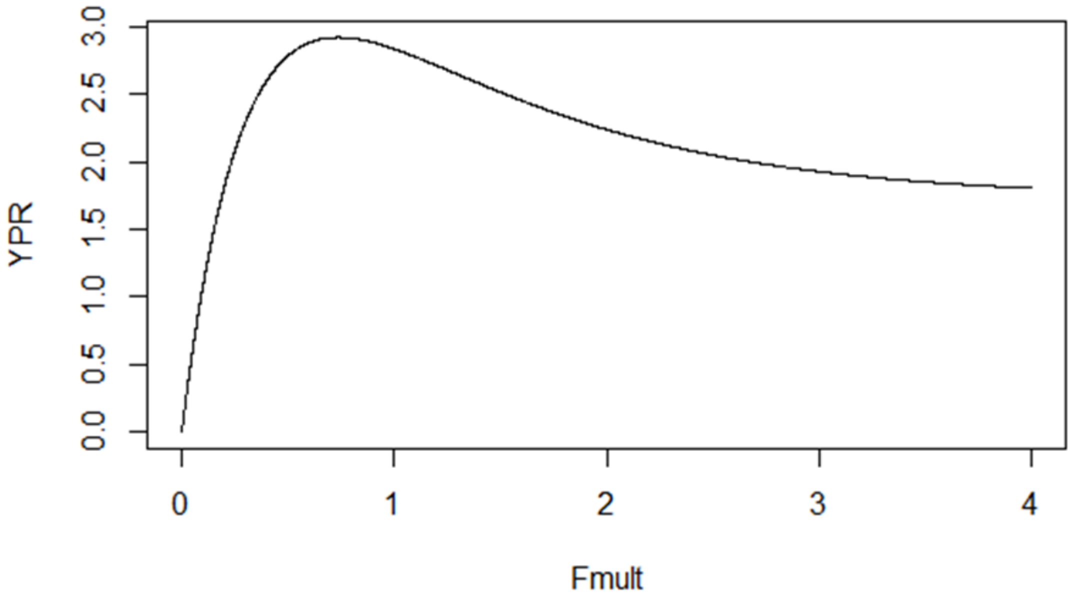

Fig. 1 YPR curve of Pacific blufin tuna (PBF) fishery corresponding to the reference year of 2015-16.

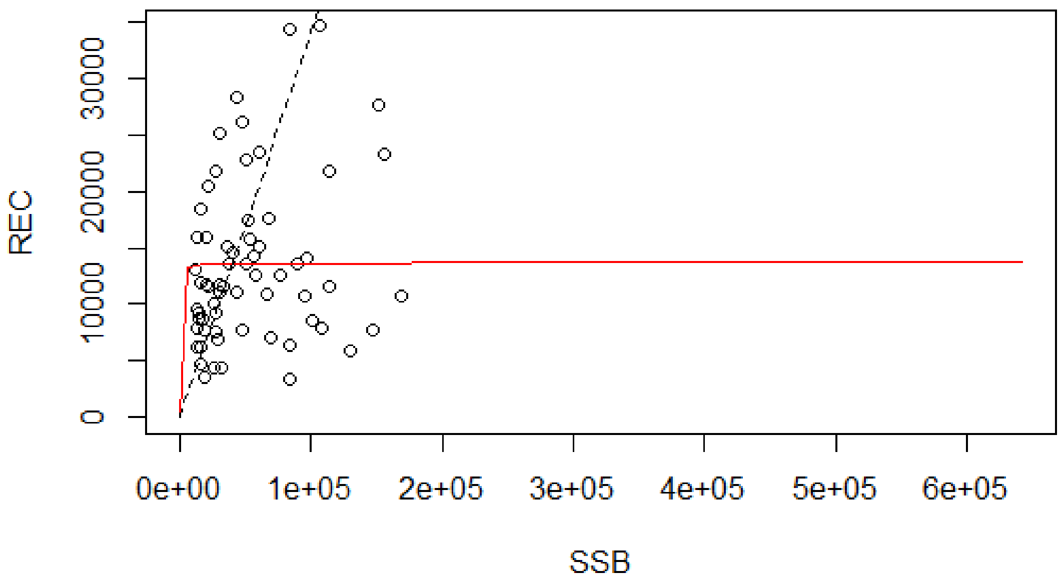

Fig. 2 Stock-recruitment relationship assumed in the stock assessment (red solid line), stock/recruitment estimates (open circle), and median SPR (black broken line) of PBF.