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Biologically reasonable rebuilding timeframes for bigeye tuna

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Abstract

Through the harvest strategy work plan, WCPFC12 tasked the Scientific Committee to determine 'a biologically reasonable timeframe for rebuilding bigeye tuna to [or above] its limit reference point'. We present the results of stock projection analyses that examine the potential rebuilding time of WCPO bigeye, based upon five potential rebuilding levels, and five scenarios for management intervention.

Rebuilding levels were defined based upon the adopted limit reference point (LRP) for bigeye tuna, and minimum stock levels consistent with four levels of risk (5, 10, 15 and 20%) of the stock falling below that LRP. Management scenarios included the status quo (2012 levels); a fishery 'closure'; and three scenarios developed within the 2015 evaluation of CMM 2014-01 to encapsulate CMM implementation uncertainty. Using the bigeye reference case assessment model, 200 stochastic projections were run for each scenario. Future recruitment was determined by randomly sampling from the 2002-2011 recruitment deviations from the stock-recruitment relationship. The speed of rebuilding will be strongly influenced by this assumption. The median adult biomass ($SB/SB_{F=0}$) trajectory for each scenario was calculated. The resulting average rebuilding times are summarised in the table below.

Biologically reasonable timeframes can be specified in terms of stock generation time, or the time the stock would need to rebuild in the absence of fishing. For the former, the generation time for bigeye in the WCPO is estimated to be <u>around 4 years</u>. For the latter, reaching the minimum rebuilding level (the LRP) took <u>2 years, and up to 4 years</u> for the higher rebuilding levels (comparable to the generation time).

A number of alternative example timeframes were considered to rebuild the stock based on relevant example national and regional management policies. The ability of a management scenario to achieve rebuilding within those specified timeframes depended upon the rebuilding level selected. All scenarios were compatible with rebuilding to the LRP within the timeframes, but the status quo and 'pessimistic' scenarios (that had smaller reductions in fishing) failed to meet the rebuilding timeframe if a rebuilding level consistent with lower levels of risk (5-20%) was selected. For timescales based upon the absence of fishing, by definition only the 'closure' scenario was consistent.

The rebuilding period has scientific and management implications. As the length of rebuilding time increases, biological advice becomes increasingly uncertain.

We invite WCPFC-SC12 to:

- Note the estimated bigeye generation time of 4 years, and minimum rebuilding time in the absence of fishing of 2-4 years;
- Note that timeframes are influenced by the rebuilding level specified, and assumptions of future recruitment patterns;
- Note that the Commission's consideration of acceptable risk for the bigeye stock falling below the limit reference point will influence the findings;
- Acknowledge that it will be important to examine not only the timeframe but also the stock trajectory of rebuilding; and
- Consider the issues raised in this analysis when providing advice to WCPFC13.

Rebuilding level	Basis	Status quo	‘Pessimistic’	‘2015 choices’	‘Optimistic’	‘Closure’
20% $SB_{F=0}$	Adopted LRP	8 years	8 years	7 years	6 years	2 years
24% $SB_{F=0}$	Consistent with 20% risk of falling below LRP	13 years	13 years	8 years	7 years	3 years
25% $SB_{F=0}$	Consistent with 15% risk of falling below LRP	18 years	15 years	10years	8 years	3 years
26% $SB_{F=0}$	Consistent with 10% risk of falling below LRP	22 years	20 years	11 years	8 years	4 years
28% $SB_{F=0}$	Consistent with 5% risk of falling below LRP	>30 years	>30 years	13 years	9 years	4 years

Introduction

WCPFC11 adopted CMM 2014-06, a Conservation and Management Measure establishing a harvest strategy for key fisheries and stocks in the Western and Central Pacific Ocean (WCPO). WCPFC12 agreed a work plan for the adoption of those harvest strategies (WCPFC, 2015), which tasked the Scientific Committee to determine 'a biologically reasonable timeframe for rebuilding bigeye tuna to [or above] its limit reference point', helping WCPFC13 to define a rebuilding timeframe for the stock[1].

Biologically reasonable rebuilding timeframes will be defined by the biological characteristics of the stock in question (i.e. they should be shorter for shorter-lived, more productive species). Those timeframes can be specified in terms of: the generation time for the stock in question; the time the stock would need to rebuild in the absence of fishing; or as an absolute timeframe. In Table 1 we provide a non-exhaustive summary of rebuilding timeframes specified in some relevant national and regional policies.

We note that options for the rebuilding timeframe are frequently provided within a policy, which still provides a maximum specified period for rebuilding. This flexibility allows managers to temper the timeframe with considerations of the level of social and economic impacts they are willing to endure (e.g. FAO, 2003). Timeframes will also depend upon the status of the stock relative to the rebuilding level when the strategy is initiated, and the success with which that rebuilding strategy is implemented (e.g. SPC-OFP, 2015). For this examination of biologically reasonable timeframes, we ignore those issues.

For tuna stocks, a rapid review of tRFMOs indicates that in the absence of documented policies, rebuilding strategies and advice may implicitly rather than explicitly incorporate consideration of biologically realistic rebuilding times on a stock-by-stock basis. For example, recent IOTC scientific advice for yellowfin notes that the Commission's current management objective ($SB>SB_{MSY}$) would be "achieved with 50% probability by 2024 [i.e. in 10 years] if catches were reduced by 20% from 2014 levels. Higher probabilities of rebuilding require longer timeframes and/or larger reduction of current catches" (IOTC, 2016). Within both CCSBT and ICCAT, approximately 20 year rebuilding plans for bluefin tuna have been adopted (e.g. the CCSBT Management Procedure; ICCAT recommendation 14-05). These timeframes reflect the implicit trade-offs between the biological productivity of the stock and the socio-economic consequences of rebuilding strategies.

We present the results of stock projection analyses that examine the potential rebuilding time of WCPO bigeye, based upon different scenarios for management intervention. These results are discussed in light of the biologically reasonable timeframes specified within the policies summarised in Table 1.

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[1] In this paper, we use the term 'rebuilding' to mean recovery of the stock to or above the limit reference point. We note that the words 'recovery' and 'rebuilding' are both frequently used within fisheries policies, but may not be interchangeable. One may refer to rebuilding to a limit reference point, while other policies require recovery plans to be developed when the stock is below a target reference point. Here we use the word 'rebuilding' to describe rebuilding to the LRP or related level, but note that WCPFC nomenclature may need to be clarified with the move towards adopting target reference points.

Methods

Definition of rebuilding level

The request to the Scientific Committee from WCPFC12 called for an examination of alternative rebuilding levels ('rebuilding bigeye tuna to [or above] its limit reference point'). We therefore define alternative levels of rebuilding based upon:

- the adopted limit reference point for bigeye based upon the 2014 stock assessment (20% $SB_{F=0, 2002\text{-}2011}$); and
- the results of analyses presented in SPC-OFP (2014) that define minimum bigeye stock levels consistent with four levels of risk of the stock falling below that limit reference point (risks of 5%, 10%, 15% and 20%).

This provided five potential rebuilding levels (Table 2) which represent the medians of probability distributions consistent with the defined risk of the stock falling below the limit reference point. They therefore define an "uncertainty buffer" above the LRP. If stock status advice based upon the reference case assessment only indicates a biomass estimate at the median of the uncertainty distribution (as performed here – see 'projection approach') then the corresponding risk level should not have been exceeded.

Within the analysis, the term 'rebuilt' was defined as the year in which the stock achieved the specified rebuilding level on average (50% probability).

Definition of fishery scenarios for the evaluation

The bigeye fishery is primarily impacted by the purse seine associated (FAD) fishery and the longline fishery (Harley et al., 2014). A wide range of relative combinations of longline catches and purse seine associated effort levels can achieve the same level of bigeye status, and that status could be achieved in many different timescales. It was therefore necessary to define a limited set of fishery scenarios to inform the rebuilding timeframe analysis. We defined five fishery scenarios to examine the implications for bigeye rebuilding to the five potential levels (Table 3). This included fishery scenarios developed within the evaluation of CMM 2014-01 (SPC-OFP, 2015; see Appendix). These scenarios attempt to bracket the wide range that could be selected to examine rebuilding timescales. Each scenario is defined as scalars on 2012 purse seine effort and longline catch levels.

Projection approach

We use the purse seine associated (FAD) effort and longline catch scalars defined under each management scenario (Table 3) within bigeye tuna stock projections to evaluate the timescale over which those fishery scenarios achieve rebuilding to each of the specified levels (Table 2).

Projections were run for 30 years. In general, the stock reached equilibrium with the fishing levels within that period, and hence extending the projection period would make no difference to whether the rebuilding level was achieved or not.

Unlike the evaluation of the tropical tuna CMM (SPC-OFP, 2015), which conducted the analysis over the full uncertainty framework approach endorsed by SC10, in this analysis we examined stochastic stock status outputs from the reference case stock assessment only. Therefore future uncertainty in rebuilding time was based upon that in terms of future recruitment, but not model uncertainty. This is consistent with the presentation of advice to the Commission on stock status primarily derived from reference case stock assessments adopted by Scientific Committee.

Two hundred projections were run for each scenario. Future recruitment in the projections was determined by randomly sampling from ONLY the 2002-2011 recruitment deviations from the stock-recruitment relationship estimated in the 2014 reference case assessment model run[2]. This effectively assumes that the above-average estimated recruitment conditions of the last 10 years will continue into the future. This aims to take year class effects into account, and allows a probabilitistic view of rebuilding, a consideration required within many identified fisheries rebuilding policies.

The median biomass ($SB/SB_{F=0}$) trajectory for each rebuilding scenario was calculated from the reference case projection results. The year in which the median of the 200 runs crossed each specified rebuilding level was identified, and noted as the year following implementation of the management intervention.

Estimation of bigeye generation time

Generation time is the average age of parents at the time their young are born. Long lived, slow growing species typically have long generation times whilst short-lived, fast growing species have very short generation times. This period is indicative of future stock reproductive capacity and is influential for rebuilding timeframes as well as other factors including population structure and environmental conditions.

Generation time was defined consistent with the approach used by Berger *et al*. (2013), as the age of fish that generates maximum egg production. It was calculated using estimates of natural mortality (M) and the von Bertalanffy growth parameters (t_0, L_{inf}, K) as follows (Beverton 1992):

$$G = t_0 - ln\left(1 - \frac{L_{opt}}{L_{inf}}\right) / K$$

The generation time was estimated based upon the outputs to the most recent bigeye stock assessment reference case run (Harley et al., 2014). MULTIFAN-CL provides estimates of unfished biomass-at-age which was averaged over a long-term period (1962 – 2011; the estimate was relatively robust to the time period chosen), and used to estimate the length class with the highest biomass in the population (L_{opt}).

Results

Rebuilding times under alternative management scenarios are presented in Table 4. The no-fishing scenario resulted in rapid rebuilding times of 2-4 years, dependent upon the rebuilding level specified. The 'optimistic' scenario arising from the evaluation of CMM 2014-01 provided the next most rapid stock rebuilding, implying rebuilding times between 6 and 9 years, followed by the '2015 choices' scenario which implied a rebuilding time between 7 and 13 years. Under the 'pessimistic' scenario of the CMM 2014-01 evaluation, rebuilding times of 8-20 years were achieved. Finally, under the status quo (2012 fishing levels) scenario, rebuilding took 8 to 22 years. Under the last two scenarios the stock did

[2] We note that the choice of recent or long-term recruitment has quite different projection outcomes (Pilling *et al*., 2014), with the 2002-2011 recent average recruitment conditions being notably more optimistic than the long term SRR.

not on average rebuild to the level equivalent to the 5% acceptable risk of falling below the limit reference point within the 30 years.

The estimated generation time for bigeye tuna, rounded to the nearest complete year implies a single generation time of 4 years (actual estimate: 4.1 years). The estimated age that maximized egg production corresponded well with the age at which 50% of adult bigeye were sexually mature (~ 4 years), an alternative approach for estimating generation time.

Discussion

Biologically reasonable rebuilding timeframes will depend upon the life history of the stock, and be influenced by the rebuilding level to be achieved, and the distance the stock is from that level. We identify five alternative rebuilding levels based upon the adopted LRP for bigeye and the risk of the stock being below that LRP, and evaluate the time taken to achieve them dependent upon alternative future scenarios for two key bigeye fishery components.

As shown in Table 1, biologically reasonable timeframes can be specified in terms of the generation time for the stock in question, or in terms of the time the stock would need to rebuild in the absence of fishing. For the former, the generation time for bigeye in the WCPO is estimated to be around 4 years, compatible with the evaluation of Berger *et al.* (2013; 5 years) that was based upon the 2011 stock assessment. For the latter, the minimum rebuilding level (the LRP) takes 2 years from the 2012 stock level and up to 4 years for the higher rebuilding levels (comparable to the generation time).

The exception was timescales based upon the absence of fishing, where by definition only the 'closure' scenario was consistent.

Table 5 summarises whether the rebuilding timeframes specified in Table 1 would be achieved based upon the rebuilding scenarios examined here. This was clearly dependent upon the rebuilding level selected. All scenarios were compatible with the majority of specified rebuilding timeframes if the lower LRP rebuilding level was selected, but the two scenarios requiring smaller reductions in fishing levels (status quo and 'pessimistic') failed to achieve the longest specified rebuilding timeframe if a higher rebuilding level (15% risk or lower) was selected. The exception was timescales based upon the absence of fishing, where by definition only the 'closure' scenario was consistent.

As noted in the Introduction, fisheries managers can select a recovery timescale based upon a multiplier on – for example – the stock generation time that best meets management goals balancing the economic and social impacts of that rebuilding (e.g. Powers, 1999). However, that rebuilding period comes with scientific and management implications. As the length of time for rebuilding increases, the biological advice that can be provided becomes increasingly uncertain, given for example uncertainty in future recruitment levels and the form of the stock recruitment relationship.

While the stock may rebuild within a given timeframe, the trajectory of that rebuilding can have different consequences for fisheries exploiting the stock. As shown in Pilling *et al*. (2016), the recovery of south Pacific albacore to the candidate target reference point can be achieved through a number of different pathways, which have considerably different economic implications for the southern longline fleet. Scientific advice can be provided on those consequences for bigeye.

Some of the rebuilding policies identified specify a probability of being above the rebuilding level (e.g. the New Zealand Fisheries Act). In this study, we have assumed the median of the range of stochastic projections as the indicator for rebuilding time (i.e. a 50% probability)[3]. However, considerations of risk as defined by managers will influence these discussions, along with the rebuilding levels assumed. The WPCFC Harvest Strategy work plan (WCPFC, 2015) schedules a Commission decision on risk for WCPFC13.

Once rebuilding has been achieved, there will be a need to transition to a fishery management regime that maintains the stock around the agreed target reference point, if different. This process, and indeed the rebuilding strategy, should be evaluated for performance through Management Strategy Evaluation to ensure it is robust to uncertainty (Scott *et al.*, 2016). In practical terms, strategies will also require monitoring during the rebuilding period to ensure that they are performing adequately in the face of future recruitment levels (both good and bad), unforeseen shifts in fishing strategies and implementation issues.

We note that this rebuilding analysis used the 2014 bigeye stock assessment reference case model, and re-emphasise that a critical assumption within the analysis is that recent relatively high estimated recruitments will continue into the future. The speed of rebuilding will be strongly influenced by this assumption given that long-term recruitment patterns lead to a decline in bigeye adult biomass under status quo conditions (Pilling *et al.*, 2014). Recommendations on biologically reasonable rebuilding timeframes should consider the implications of this issue.

We invite WCPFC-SC12 to:

- Note the estimated bigeye generation time of 4 years, and minimum rebuilding time in the absence of fishing of 2-4 years;
- Note that timeframes are influenced by the rebuilding level specified, and assumptions of future recruitment patterns;
- Note that the Commission's consideration of acceptable risk for the bigeye stock falling below the limit reference point will influence the findings;
- Acknowledge that it will be important to examine not only the timeframe but also the stock trajectory of rebuilding; and
- Consider the issues raised in this analysis when providing advice to WCPFC13.

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[3] Here consideration of risk has been incorporated by defining a rebuilding level above the LRP, and the median of runs has been used to indicate whether management is consistent with that level. The alternative would be to use the LRP as the rebuilding level, but consider risk by requiring a higher probability of being above the LRP. In that case, the full uncertainty grid would need to be used within evaluations.

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Tables

Table 1. Summary of some relevant rebuilding timeframes adopted in fishery management policies around the world.

Policy	Timeframe 1	Timeframe 2	Notes
US Magnuson-Stevens Fishery Conservation and Management Act (US MSRA, 2007)	'As short as possible' (in absence of fishing)	'Should not exceed 10 years' (but see notes)	'except where the biology of the stock, or management measures under an international agreement in which the United States participates, dictate otherwise'. If rebuilding within 10 years cannot be achieved: Tmin = absence of fishing Tmax = Tmin+ one generation Target time: Bounded between Tmin and Tmax, as short as possible
Australia's Commonwealth Fisheries Harvest Strategy Policy and Guidelines (DAFF, 2007)	'period of 10 years plus one mean generation time'	'three times the mean generation time'	Whichever is lower. Mean generation time is defined as the average age of a reproductively mature animal in an unexploited population
New Zealand Fisheries Act (1996, 2008)[4]	Minimum: theoretical number of years required to rebuild a stock to the defined level in the absence of fishing (Tmin)	Maximum: twice Tmin (to take account socio-economic issues)	Stocks will be considered to have been fully rebuilt when it can be demonstrated that there is at least a 70% probability that the level has been achieved.
European Union	Not specifically specified, but 10 years frequently assumed[5]		Recovery is to 'safe biological levels'.

[4] http://www.legislation.govt.nz/act/public/1996/0088/latest/DLM394192.html; http://www.legislation.govt.nz/act/public/2008/0096/latest/whole.html

[5] E.g. Wakeford et al., 2007. We note that the 2009 reform of the Common Fisheries Policy, taking into account international agreements such as the 2002 Johannesburg Summit on Sustainable Development, set MSY as the main target for all fisheries, with the aim of setting fishing mortality to F_{MSY} where possible by 2015, and by 2020 at the latest.

Table 2. Bigeye stock levels used to define rebuilding levels.

Stock rebuilding level ($SB/SB_{F=0}$)	Basis
0.20	Adopted limit reference point, implicitly consistent with 50% risk of falling below the LRP
0.24	Consistent with a 20% risk of falling below the LRP
0.25	Consistent with a 15% risk of falling below the LRP
0.26	Consistent with a 10% risk of falling below the LRP
0.28	Consistent with a 5% risk of falling below the LRP

Table 3. Five scenarios selected to examine rebuilding timescales for bigeye tuna. For details on Pessimistic, 2015 Choice and Optimistic see Appendix 1.

Scenario	Scalars relative to 2012	
	Purse seine (Effort)	Longline (Catch)
Status quo	1	1
Pessimistic	1.02	0.97
2015 choices	0.95	0.84
Optimistic	0.76	0.84
'Closure'[1]	0.01	0.01

[1] for the closure scenario, all other fisheries were scaled to 0.01 x 2012 levels.

Table 4. Average (median) rebuilding time to defined stock level ($\%SB_{F=0}$), under different scenarios of purse seine FAD effort and longline catch.

Rebuilding level	Basis	Status quo	'Pessimistic'	'2015 choices'	'Optimistic'	'Closure'
$20\%SB_{F=0}$	LRP	8 years	8 years	7 years	6 years	2 years
$24\%\ SB_{F=0}$	20% acceptable risk	13 years	13 years	8 years	7 years	3 years
$25\%\ SB_{F=0}$	15% acceptable risk	18 years	15 years	10years	8 years	3 years
$26\%\ SB_{F=0}$	10% acceptable risk	22 years	20 years	11 years	8 years	4 years
$28\%\ SB_{F=0}$	5% acceptable risk	>30 years	>30 years	13 years	9 years	4 years

Table 5. Ability of management scenarios to achieve rebuilding timeframes specified in existing fisheries policy frameworks.

Policy	Equivalent BET rebuilding timeframe		Status quo	'Pessimistic'	'2015 choices'	'Optimistic'	'Closure'
	Definition	Yrs[1]					
US M-S Act	Absence of fishing (Tmin)	2-5	×	×	×	×	✓
	<=10 years	<=10	(✓)	(✓)	(✓)	✓	✓
	Tmin + 1 generation	6-9	(✓)	(✓)	(✓)	✓	✓
AU Harvest Strategy	Min (10 years + (1 x generation time), or (3 x generation time))	14	(✓)	(✓)	✓	✓	✓
NZ Fisheries Act	Tmin	2-5	×	×	×	×	✓
	2 x Tmin	4-10	(✓)	(✓)	(✓)	(✓)	✓

[1] ranges shown across the different rebuilding levels where relevant. (✓) indicates rebuilding timeframe achieved only where a lower rebuilding level was selected.

Appendix I. Summary of scenarios arising through the CMM 2014-01 evaluation.

SPC-OFP (2015) evaluated the long-term impact of maintaining CMM measures, using equilibrium indicators. The analysis therefore considered the Measure's final form (i.e., 2017) and assumed those conditions were maintained into the future. Noting that it was not possible to define precisely what levels of purse seine effort and longline catch would result through the Measure, due to "either/or" choices, exemptions or exclusions, and decisions yet to be made, three different scenarios for 2017 conditions were evaluated to examine the implementation uncertainty. The scenarios are summarised as:

'Pessimistic': everyone takes the maximum they are allowed to under the Measure. Purse seine CCMs maximise FAD sets through their FAD closure duration/annual FAD set limits choices, including the average 2010-2012 FAD set ceiling for those who choose the FAD closure option; limited longline non-SIDS CCMs take their entire 2017 specified/2000 mt limits, 2014 level for SIDS.

'2015 choices': purse seine CCMs apply the FAD closure duration/annual FAD set limits choice they made in 2015. This results in lower FAD sets in particular, because some CCMs did not choose the option that would maximise their FAD sets in 2015 (based on our evaluation). Limited longline CCMs take the lower of their catch limit or 2014 level.

'Optimistic': purse seine CCMs maximise FAD sets through their FAD closure duration/annual FAD set limits choices, but those that choose the FAD closure do not increase FAD sets outside the closure period; longline CCMs take their catch limit or 2014 level if lower. This scenario assumes the Measure works 'as intended' and FAD closures remove FAD sets from the fishery.

High seas FAD closure is applied in all cases, and is assumed to remove FAD sets from the fishery, rather than transferring them to EEZs.

Resulting scalars on purse seine FAD effort and longline bigeye catch relative to 2012 levels are summarised in Table 3. For further detail, see SPC-OFP (2015).