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Biologically reasonable rebuilding timeframes for bigeye tuna

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Graham Pilling, Robert Scott and John Hampton

Oceanic Fisheries Programme (OFP), The Pacific Community (SPC)

Summary

The harvest strategy work plan tasked the Scientific Committee with providing advice on determining 'a biologically reasonable timeframe for rebuilding[1] bigeye tuna to [or above] its limit reference point'. Following discussion, SC12 recommended a revised version of paper MI-WP-02 be forwarded to WCPFC13. Here we concentrate on the findings and discussion. The approach is described in Appendix 1.

Biologically reasonable rebuilding timeframes will be defined by the:

1. stock's biological characteristics (i.e. shorter for short-lived, more productive species);
2. rebuilding level to be achieved; and
3. distance the stock is from that level.

A non-exhaustive summary of rebuilding timeframes specified in some relevant national and regional policies is provided in Appendix 2. From that review, timeframes can be specified in terms of:

1. the generation time (the average age of parents at the time their young are born) for the stock (for WCPO bigeye this is estimated to be around 4 years);
2. the time needed for the stock to rebuild in the absence of fishing; or
3. an absolute timeframe.

We identified five rebuilding levels 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. Recovery times to those levels were evaluated under five different purse seine and longline management scenarios: the status quo (2012 levels); a fishery 'closure'; and three scenarios developed within the 2016 evaluation of CMM 2015-01 to encapsulate CMM implementation uncertainty (see Appendix 1). Stochastic projections from the bigeye reference case assessment model only[2] were used to predict when – on average – the stock would recover to each rebuilding level under a management scenario, where future recruitment was assumed consistent with recent (2002-2011) recruitment patterns. Rebuilding time will be strongly influenced by this assumption. Following SC12 advice, we also summarise results based on projections where future recruitment is consistent with longer-term (1962-2011) estimates (Appendix 3).

Rebuilding times under alternative management scenarios are presented in Table 1.

- The no-fishing scenario resulted in rapid rebuilding times of 2-5 years, dependent upon the rebuilding level specified.
- The 'optimistic' scenario of the CMM 2015-01 evaluation provided the next most rapid stock rebuilding, implying rebuilding times between 5 and 8 years.
- The '2016 choices' CMM scenario implied a rebuilding time between 6 and 11 years.
- The 'pessimistic' CMM scenario achieved rebuilding times of 7 to 21 years.
- Under the status quo (2012 fishing levels) scenario, rebuilding took 7 to 14 years.

Under the last two scenarios the stock did not on average rebuild to the level equivalent to the 5% acceptable risk of falling below the limit reference point (also 10% risk for pessimistic) within the 30 years.

Whether a management scenario achieves rebuilding within specified timeframes depends upon the rebuilding level selected. Scenarios were generally compatible with rebuilding to the LRP within the

[1] We use the term 'rebuilding' to mean recovery of the stock to or above the limit reference point. The words 'recovery' and 'rebuilding' are both frequently used, but may not be interchangeable. For example, some policies may require recovery plans to be developed when the stock is below a target reference point. WCPFC nomenclature may need to be clarified as it adopts target reference points.

[2] This is different from the CMM 2015-01 evaluation, where the full uncertainty grid was used.

commonly specified rebuilding timeframes (e.g. rebuilding time in the absence of fishing + 1 generation time), but the status quo and 'pessimistic' scenarios (that specified smaller reductions in fishing) failed to meet those rebuilding timeframes 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.

Table 1. Average rebuilding time to each bigeye stock rebuilding level ($\%SB_{F=0,y-10-y-1}$), under scenarios of purse seine FAD effort and longline catch.

Average rebuilding level	Basis	Status quo	'Pessimistic'	'2016 choices'	'Optimistic'	'Closure'
20% $SB_{F=0}$	Adopted LRP[1]	7 years	7 years	6 years	5 years	2 years
24% $SB_{F=0}$	Consistent with 20% risk of falling below LRP	10 years	12 years	7 years	6 years	3 years
25% $SB_{F=0}$	Consistent with 15% risk of falling below LRP	12 years	21 years	8 years	7 years	4 years
26% $SB_{F=0}$	Consistent with 10% risk of falling below LRP	14 years	>30 years	9 years	7 years	4 years
28% $SB_{F=0}$	Consistent with 5% risk of falling below LRP	>30 years	>30 years	11 years	8 years	5 years

[1] this is consistent with a half of all runs falling below the LRP (a 50% risk)

In addition to observations made above, we also note that:

- managers may temper rebuilding timeframes with considerations of the level of social and economic impacts they are willing to endure;
- a rebuilding target can be achieved within a given timeframe through many different approaches, but the resulting stock trajectory has different consequences for fisheries exploiting the stock. Scientific advice can be provided on those consequences for bigeye;
- timeframes depend on the success with which that rebuilding strategy is implemented;
- the rebuilding period has scientific and management implications. As the length of time for rebuilding extends, the biological advice that can be provided becomes increasingly uncertain;
- some policies specify a probability of being above the rebuilding level. In this study, achieving the rebuilding target on average assumes a 50% probability[3]. Considerations of risk as defined by managers will influence these discussions, and the rebuilding levels assumed;
- this analysis used the SC-agreed assumption that recent relatively high estimated recruitments will continue into the future. Rebuilding timeframes will be strongly influenced by this assumption. As noted earlier, we include in Appendix 3, results of a sensitivity analysis that assumes long-term (more pessimistic) bigeye recruitment patterns continue.

Ultimately, the choices of rebuilding time frame and level, probability of achieving that level within a specified time frame, and the set of future fishery-specific mortality rates to achieve the level are linked and need to be jointly considered in the development of a viable rebuilding plan. In turn, although this practical issue is not directly addressed here, it is also important to consider the effects of implementation uncertainty on the likely success of the plan.

[3] Consideration of risk has been incorporated by defining a rebuilding level above the LRP, and the average across projections from the reference case assessment model run only used to indicate when that level is reached. The alternative would be to use the LRP as the rebuilding level, but risk considered by requiring a higher probability of runs being above the LRP. In that case, the full uncertainty grid would need to be used within evaluations.

Appendix 1: Summary of analysis approach

In this section we summarise the approach used within this analysis.

Definition of rebuilding level

The harvest strategy work plan 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 (adult biomass relative to the recent average spawning biomass in the absence of fishing) based upon:

- the adopted limit reference point for bigeye (20% $SB_{F=0}$); and
- the results of analyses presented in MOW3-WP-02 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 1) which represent the average stock status consistent with those risk levels under the uncertainty included within the analysis. They therefore define an "uncertainty buffer" above the LRP. If stock status advice based upon the reference case assessment alone 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. Many different 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. 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.

Two of the scenarios represented status quo conditions (where fishing continued at purse seine FAD effort and longline bigeye catch levels experienced in 2012) and a no fishing scenario (where all fisheries were 'closed'). The remaining three scenarios were based upon the SPC evaluation of the long-term impact of the measures specified within tropical tuna CMM 2015-01 (paper to this meeting). To summarise, that analysis 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. The scenarios were:

'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, 2015 level for SIDS.

'2016 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 2015 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, and the option for 2015 FAD set numbers is included within the choices; longline CCMs take their catch limit or 2015 level if lower. This scenario assumes the Measure works 'as intended' and FAD closures remove FAD sets from the fishery.

High seas FAD closure applied in all cases, and was assumed to remove FAD sets from the fishery, rather than transferring them to EEZs. The closure exemption under footnote 5 of the CMM was incorporated within the analysis.

Resulting scalars on purse seine FAD effort and longline bigeye catch relative to 2012 levels are summarised in the table below. For further detail, see the evaluation of the tropical tuna CMM (paper to this meeting).

Five scenarios selected to examine rebuilding timescales for bigeye tuna.

Scenario	Scalars relative to 2012	
	Purse seine (Effort)	Longline (Catch)
Status quo	1	1
Pessimistic	1.02	1.08
2016 choices	0.95	0.80
Optimistic	0.64	0.80
'Closure'[1]	0.01	0.01

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

Projection approach

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

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, 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 general presentation of advice to the Commission on stock status primarily derived from reference case stock assessments adopted by Scientific Committee. It should be noted, however, that the specification of potential rebuilding targets as a function of risk of exceeding the LRP was based upon the full uncertainty framework currently used. Therefore, by using those potential targets, risk is being treated in the context of that full framework.

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[4]. 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 average biomass ($SB/SB_{F=0}$) trajectory for each rebuilding scenario was calculated from the reference case projection results. $SB_{F=0}$ was calculated consistent with the approach defined in CMM 2015-06, and as used within recent stock assessments, whereby the 10 year averaging period was shifted relative to the year in which the SB was evaluated; i.e. adult biomass in future year *y* was related to the $SB_{F=0}$ averaged over the period *y*-10 to *y*-1. (e.g. $SB_{2032}/SB_{F=0,2022\text{-}2031}$). The year in which the average 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 in SC9-MI-WP-02, 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:

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

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

[4] We note that the choice of recent or long-term recruitment has quite different projection outcomes, with the 2002-2011 recent average recruitment conditions being notably more optimistic than the long term SRR. See Appendix 3.

(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}). For more information, refer to the associated spreadsheet. For parameter estimates, refer also to the 2014 bigeye stock assessment report (SC10-SA-WP-01) and associated assessment output files.

The estimated generation time for bigeye tuna, rounded to the nearest complete year implies a single generation time of 4 years (actual estimate = 3.5 years). The estimated age that maximized egg production, an alternative approach for estimating generation time, corresponded well with the age at which 50% of adult bigeye were sexually mature (~ 3.9 years).

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Appendix 2. Summary of some relevant rebuilding timeframes adopted in fishery management policies around the world and rapid review of relevant plans for tuna.

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)[5]	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[6]		Recovery is to 'safe biological levels'.

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.

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

[6] 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.

Appendix 3. Alternative assumption of future recruitment levels.

SC has agreed that 'recent recruitment' levels be used as the primary assumption for future recruitments within bigeye projection analyses. However, noting that projection results are strongly influenced by the assumptions made for future recruitment levels, SC12 recommended that a sensitivity analysis be performed to examine the potential consequences for the stock where future recruitment conforms to that defined by recruitment levels over the 'longer-term' (i.e. 1962 – 2011). For bigeye tuna, this implies on average poorer future recruitments than in the main analysis presented above. Under that alternative assumption, Table 2 presents the rebuilding timeframes consistent with the targets and fishery conditions described in Table 1. Again, adult biomass in future year *y* was related to the $SB_{F=0}$ averaged over the period *y*-10 to *y*-1. Only in the case of a fishery 'closure' and 'optimistic' conditions did rebuilding occur, assisted by the relatively high recruitments estimated within the final years of the assessment model period. Under other scenarios, this was offset by the higher rates of fishing mortality.

Table 2. Average rebuilding time to each bigeye stock rebuilding level (%$SB_{F=0,\ y\text{-}10\text{-}y\text{-}1}$), under scenarios of purse seine FAD effort and longline catch, and the long-term recruitment assumption.

<table>
<tr><th>Average rebuilding level</th><th>Basis</th><th>Status quo</th><th>'Pessimistic'</th><th>'2016 choices'</th><th>'Optimistic'</th><th>'Closure'</th></tr>
<tr><td>20% $SB_{F=0}$</td><td>Adopted LRP[1]</td><td rowspan="5">Rebuilding level not achieved ($SB_{2042}/SB_{F=0}$ = 0.09)</td><td rowspan="5">Rebuilding level not achieved ($SB_{2042}/SB_{F=0}$ = 0.07)</td><td rowspan="5">Rebuilding level not achieved ($SB_{2042}/SB_{F=0}$ = 0.15)</td><td>5 years</td><td>2 years</td></tr>
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</table>

[1] this is equivalent to a 50% risk of falling below LRP