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Consideration of acceptable levels of risk of exceeding Limit Reference Points for the four main tuna stocks: uncertainty and implications for Target Reference Points and Harvest Control Rules

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Overview

In conjunction with target and limit reference points (TRPs and LRPs) and harvest control rules (HCRs), acceptable levels of risk form a critical part of a management strategy (**Figure 1**). Limit reference points are places we want to stay away from, while targets represent places we want to be. The key question we address in this paper is "how do we set our targets so that we are confident of avoiding the LRP?"

In this paper we define risk as "*the % of times a population is predicted to be below the LRP when projected into the future under a particular management strategy*" where the strategy could be something as simple as a catch or effort limit or as complex as the tropical tuna CMMs. Acceptable risk is defined as "*the risk level that we are willing to accept with a particular management strategy*", i.e. a given catch limit is predicted to reduce bigeye below the LRP y% of the time – if that 'y' is okay with us, that is a management option we can consider.

A key factor in addressing this question is that of uncertainty. Here we consider two sources: a) we are not sure about what levels of recruitment might occur in the future; and b) we are not completely confident that we know the present status either – there are other assessment model runs that have different implications for the stock, which are considered to be quite plausible. This is two steps away from the deterministic (on average) projections we typically undertake with a single (reference case) model, where the future status is presented as a single number with no uncertainty!

This paper aims to:

1. Introduce the concept of uncertainty in the evaluation of management options;
2. Demonstrate the relationship between acceptable risk and uncertainty and potential minimum standards for target reference points;
3. Show what this all means for where the stocks are now; and
4. Highlight the importance of developing Harvest Control Rules so that we can more fully evaluate the implications of particular levels of risk – particularly their robustness to uncertainty in the stock assessments.

The analyses in this paper should assist in the Commission's consideration of both Annex II of the Fish Stock Agreement, which states in paragraph 5 "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low", and of minimum standards for TRPs that are consistent with the agreed LRPs; e.g. you can't have a TRP which is too close to the LRP.

Approach

We used the most recent stock assessments for bigeye, skipjack, yellowfin, and south Pacific albacore tunas (2014 for the first three and 2012 for the last). For each assessment, the Scientific Committee (SC10) chose a small set of model runs for each assessment to capture our uncertainty in current and historical stock status; SC10 also provided plausibility weights for each of these models based on 'expert opinion' on how plausible they were considered to be relative to the reference case model (see **Annex 1** for details of the model runs and plausibility weights).

The basic approach for each species is as follows:

- Run 200 simulations into the future for each model – each simulation representing a possible 'future' trajectory for recruitment, under a specific level of fishing effort;
- Taking into account the plausibility weightings, combine the results across model runs and calculate the % of simulations that had a terminal (final year) biomass that was below the agreed LRP, i.e. calculate the risk for that given future level of fishing. Also calculate the median level of terminal spawning biomass compared to $SB_{F=0}$ and fishing mortality in relation to F_{MSY}. The LRP was calculated as 20% of the average of the spawning biomass over the

WCPFC agreed 10 year period that would have occurred in the absence of fishing, and was calculated separately for each model run ($0.2SB_{F=0}$); and

- Repeat the above steps 20-30 times for different multipliers of effort until we identified the future fishing levels that resulted in risk levels of 5, 10, 15, and 20%.

For bigeye tuna alone the analyses required 27,000 projections and created 40GB of output.

Using south Pacific albacore as an example, **Figure 2** shows how the results from projections vary when taking into account differing levels of uncertainty. In the first panel (left), we assume 'perfect' knowledge of current status (i.e. we use the output from only one model run considered to be the 'best') and no variability in the future (e.g. constant recruitment). In the middle panel, we again assume 'perfect' knowledge of current status (one model run considered) but include uncertainty arising in the future due to e.g. recruitment variability. In the third (right hand) panel, we include uncertainty in our knowledge of current status (i.e. we use the outputs from a number of model runs) and are hence are starting projections not from a single point, but from a range of current stock levels. In addition, we include uncertainty in the future due to e.g. recruitment variability. It is the distribution from the final box of that boxplot (terminal year) that was used here to calculate risk.

Analysis

The median spawning biomass depletion ($SB/SB_{F=0}$) for each species associated with each of the four levels of risk of exceeding the limit reference point are provided in **Table 1**. Equivalent values of median fishing mortality in relation to the fishing mortality at MSY (F/F_{MSY}) are shown in **Table 2**. These values represent the minimum levels of $SB/SB_{F=0}$ and maximum levels of F/F_{MSY} that would be consistent with remaining above the LRP at each level of risk.

Figure 3 breaks down the distribution of $SB/SB_{F=0}$ in the last year of the projection for the different assessment models considered for each species, to illustrate what drives the variation and in particular the risk.

The distribution of $SB/SB_{F=0}$ for South Pacific albacore is bi-modal, with the lower peak defining the level of risk for a given set of conditions. All of the risk of exceeding the LRP comes from runs where natural mortality is assumed to be low (M=0.3). The uncertainty in future status of albacore is much wider than seen for the tropical tuna species. Median $SB/SB_{F=0}$ values range from 0.33 (20% risk) to 0.38 (5% risk). If the stock were below those levels on average, the permissible risk would be exceeded. They therefore represent the minimum level a TRP can be set for a given level of LRP risk, based on the uncertainty included here.

The distribution for bigeye is comparatively narrow. Risk levels were strongly influenced by those model runs where steepness of the stock-recruitment relationship was low (the stock was less productive) and/or tag mixing was fast. Median $SB/SB_{F=0}$ values range from 0.24 (20% risk) to 0.28 (5% risk).

Risk levels for skipjack were influenced by runs where steepness of the stock-recruitment relationship was low, particularly where a slow tag mixing rate was also assumed. Median $SB/SB_{F=0}$ values range from 0.25 (20% risk) to 0.29 (5% risk).

Of the tropical tunas, yellowfin showed the widest distribution of final year $SB/SB_{F=0}$ values. Risk levels were strongly influenced by model runs where steepness was assumed to be low, and/or tag mixing was assumed to be fast. Median $SB/SB_{F=0}$ values range from 0.25 (20% risk) to 0.31 (5% risk).

Based on the most recent stock assessments for the four stocks (**Table 3**), the current level of $SB/SB_{F=0}$ for south Pacific albacore, skipjack and yellowfin are above the minimum TRP levels estimated for the four levels of acceptable risk. Likewise, the estimates of F/F_{MSY} are estimated to be below the maximum values consistent with all four levels of risk. The current estimates for bigeye tuna, however, are below the 'minimum' $SB/SB_{F=0}$ level (and indeed is below the agreed limit reference point), and above the maximum F/F_{MSY} level consistent with all four risk levels.

There are three key conclusions from the work.

- With respect to alternative levels of acceptable risk, the lower the acceptable risk, the higher and further away from the LRP you need to keep the stock.
- With respect to levels of uncertainty, for a given level of risk, the greater the uncertainty that you need to admit, the higher and further away from the LRP you need to keep the stock.
- With respect to the adoption of target reference points, there is the potential for TRPs and LRPs to be incompatible, i.e. too close together. Thus the expected average biomass levels here give some indication of the minimum value of a TRP that could be compatible with the LRP and a given risk level.

Ultimately, the desired TRP should reflect management objectives for the stock. To be achieved, those objectives may require a stock biomass TRP much higher and further away from the LRP than the 'minimum' level permissible defined by a given level of risk.

Discussion points

- How do we decide on a risk level?
    - Ultimately the acceptable level of risk is a management decision and will be strongly influenced by the severity of the consequences of exceeding the LRP, be those consequences biological, economical, ecological or social. Low stock size is likely to be associated with lower production (catches) and higher variability in productivity, along with the increased potential for other unexpected but bad consequences that we have not experienced in the past ('unknown unknowns'). When considering the acceptable level of risk, the importance of the stock to the people of the region and to the ecosystem may be important factors to consider;
    - Management Strategy Evaluation (MSE) – once we have some HCRs in place we can evaluate how certain risk levels perform in terms of catch, catch variability, and catch rates (related to the management objectives). We can also examine the impacts and risk of what happens when we get things wrong (e.g. within the assessment, a failure to take into account the effects of effort creep).
- As for a decision on risk, the level of TRPs is a management decision. How can the results of this analysis inform this debate, when combined with existing management objectives?
- The perception of risk and the level of the TRP are strongly influenced by the level of uncertainty included within analyses. How much uncertainty should we be looking to include, and what difference does it make?
    - For example, inclusion of model runs with different levels of assumed natural mortality appears to increase the level of uncertainty (compare the results for south Pacific albacore with those for the tropical tunas).
    - Future uncertainty in these evaluations is captured through recruitment variability alone. There are a number of values that are currently fixed into the future that likely vary in reality. These need to be considered to better capture uncertainty.

  Therefore uncertainty within the analyses may be underestimated, and more work needs to be done to fully characterise uncertainty. At the same time, there is a need to settle on a framework quickly to ensure consistency over time.

Table 1. Median levels of spawning biomass depletion ($SB/SB_{F=0}$) associated with a given risk of exceeding the limit reference point of $0.2SB_{F=0}$ for the four main tuna stocks.

Acceptable risk	SP-albacore	Bigeye tuna	Skipjack tuna	Yellowfin tuna
5%	0.38	0.28	0.29	0.31
10%	0.37	0.26	0.27	0.28
15%	0.35	0.25	0.26	0.27
20%	0.33	0.24	0.25	0.25

Table 2. Median levels of fishing mortality in relation to fishing mortality at MSY (F/F_{MSY}) associated with a given risk of exceeding the limit reference point of $0.2SB_{F=0}$ for the four main tuna stocks.

Acceptable risk	SP-albacore	Bigeye tuna	Skipjack tuna	Yellowfin tuna
5%	0.86	0.87	1.17	1.05
10%	0.88	0.93	1.26	1.13
15%	0.91	0.97	1.30	1.19
20%	0.95	1.00	1.36	1.23

Table 3. Current levels of spawning biomass depletion ($SB/SB_{F=0}$) and fishing mortality in relation to the fishing mortality at MSY (F/F_{MSY}) for the four main tuna stocks (reference case models of most recent assessments).

Indicator	SP-albacore	Bigeye tuna	Skipjack tuna	Yellowfin tuna
$SB/SB_{F=0}$	0.70	0.16	0.48	0.38
F/F_{MSY}	0.14	1.57	0.62	0.72

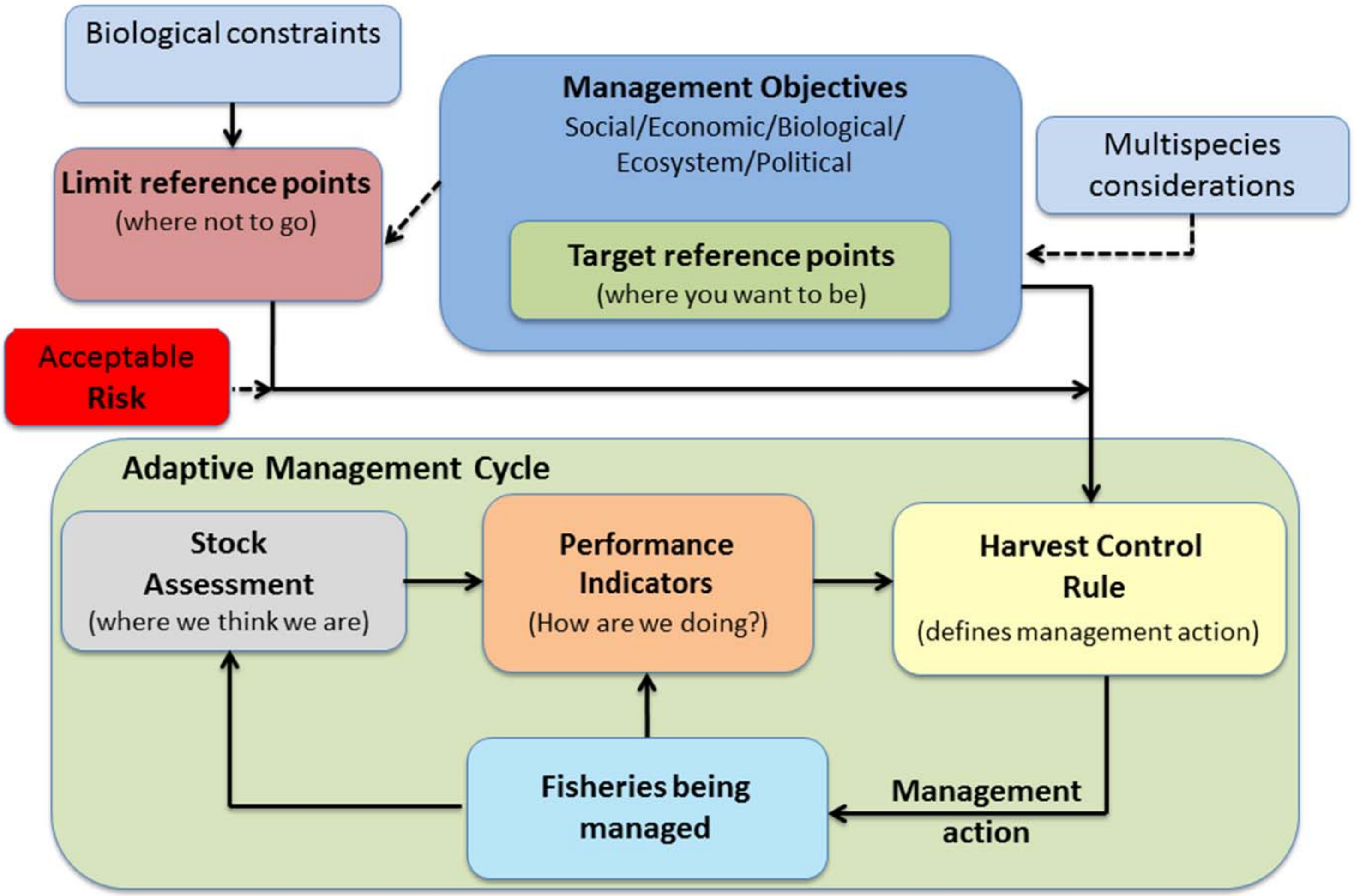

Figure 1. The management framework.

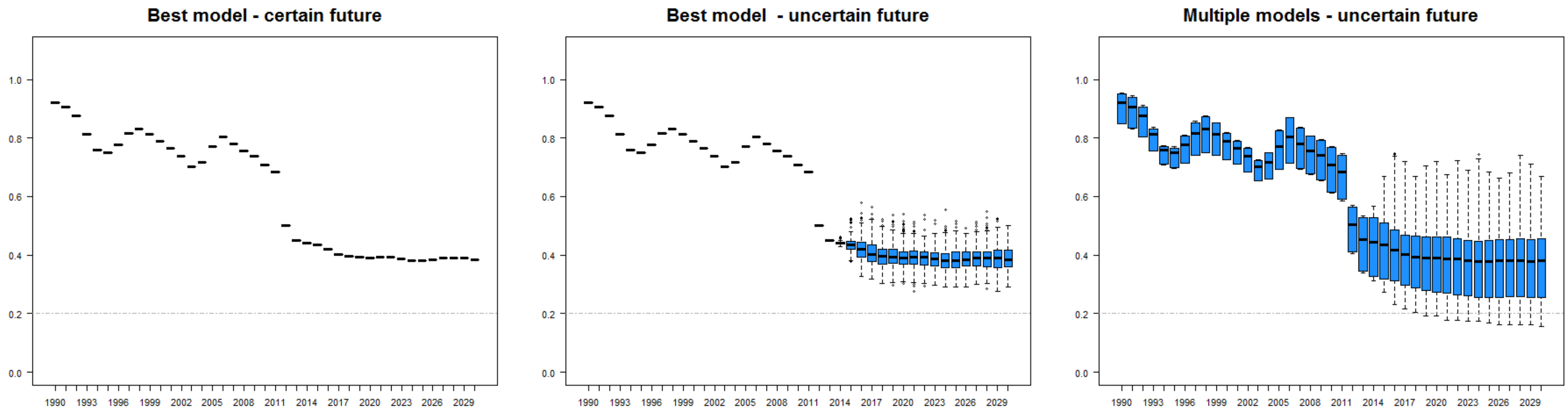

Figure 2. Plots demonstrating the impact of including different types of uncertainty within the risk analyses. Left panel: assumption of 'perfect' knowledge of current status (i.e. output from the single 'best' assessment model run) and no variability in the future (e.g. constant recruitment). Middle panel: assumption of 'perfect' knowledge of current status ('best' model run) but include uncertainty arising in the future due to e.g. recruitment variability. Right panel: include uncertainty in our knowledge of current status (i.e outputs from a number of model runs) as well as uncertainty in the future due to e.g. recruitment variability. It is the distribution from the final box of this right hand boxplot (terminal year) that was used here to calculate risk.

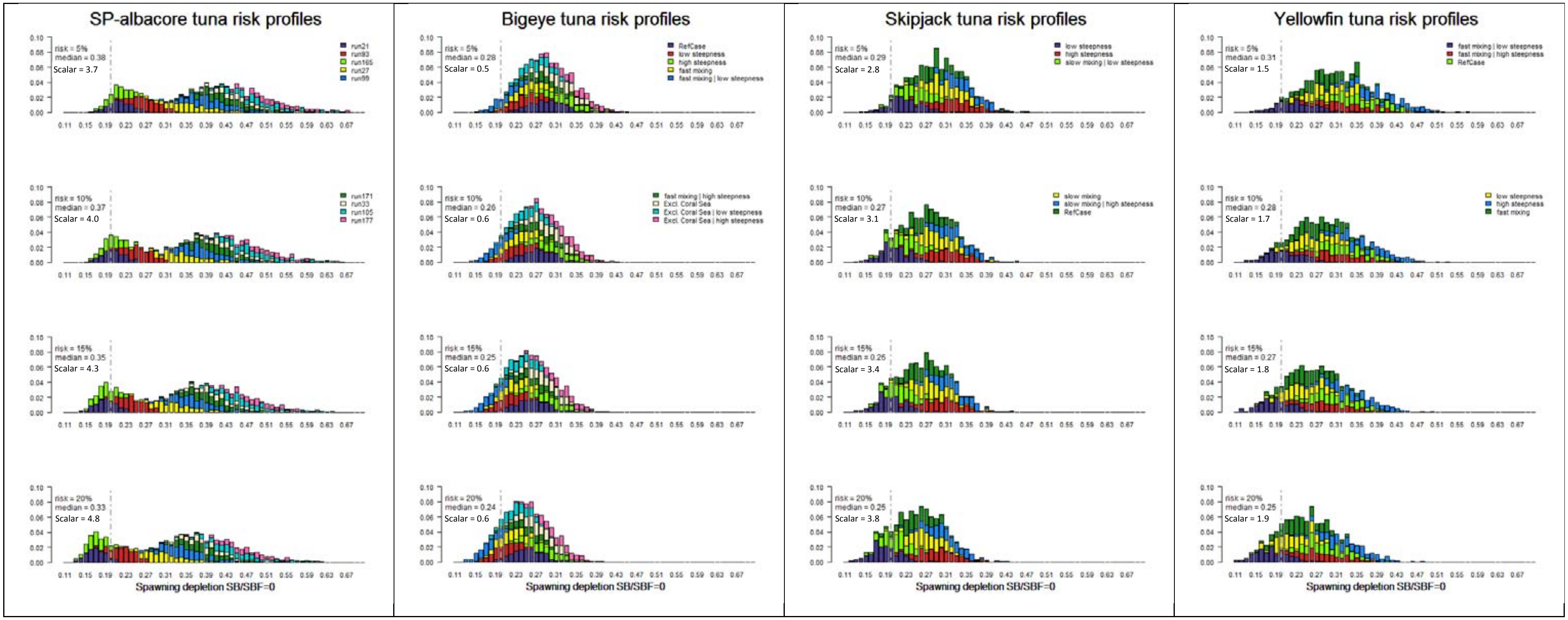

Figure 3. Histograms of the distribution of $SB/SB_{F=0}$ in the final year of the projections for each stock (columns) under each risk level (rows, from 5% risk at the top, to 20% risk at the bottom). Different colours indicate the results from the different assessment model runs included within the analysis for each species (see also Annex 1). The vertical grey line represents the limit reference point level ($0.2SB_{F=0}$). The median $SB/SB_{F=0}$ is presented for each risk level, along with the approximate scalar from 2012 conditions (2010 for south Pacific albacore) that achieves that level of risk.

Annex 1: Model runs and weights used for the analysis

South Pacific albacore tuna		
Run name	**Description**	**Relative weight**
Run21	Low steepness | low M	0.64
Run93	Medium steepness | low M	0.8
Run165	High steepness | low M	0.64
Run27	Low steepness | medium M	0.8
Run99	Medium steepness | medium M	1.0
Run171	High steepness | medium M	0.8
Run33	Low steepness | high M	0.64
Run105	Medium steepness | high M	0.8
Run177	High steepness | high M	0.64
Bigeye tuna		
Run name	**Description**	**Relative weight**
037_L0W0T0M0H0	Reference case	1.0
038_L0W0T0M0H1	Low steepness	0.8
039_L0W0T0M0H2	High steepness	0.8
043_L0W0T1M0H0	Fast mixing	0.8
044_L0W0T1M0H1	Fast mixing | low steepness	0.64
045_L0W0T1M0H2	Fast mixing | high steepness	0.64
049_L0W0T2M0H0	Exclude Coral Sea	1.0
050_L0W0T2M0H1	Exclude Coral Sea | low steepness	0.8
051_L0W0T2M0H2	Exclude Coral Sea | high steepness	0.8
Skipjack tuna		
Run name	**Description**	**Relative weight**
RefCase	Reference case	1.0
001_L0W0T0M1	Low steepness	0.8
023_L0W0T0M2	High steepness	0.8
032_L0W0T1M0	Slow mixing	1.0
031_L0W0T1M1	Slow mixing | low steepness	0.8
033_L0W0T1M2	Slow mixing | high steepness	0.8
Yellowfin tuna		
Run name	**Description**	**Relative weight**
Run37	Reference case	1.0
steep_0.65	Low steepness	0.8
steep_0.95	High steepness	0.8
tagmix_1qtr	Fast mixing	0.8
019_H1W0M0T1C0	Fast mixing | low steepness	0.64
035_H2W0M0T1C0	Fast mixing | high steepness	0.64