COMMISSION
SIXTEENTH REGULAR SESSION
Port Moresby, Papua New Guinea
5 – 11 December 2019

MINIMUM TARGET REFERENCE POINTS FOR WCPO YELLOWFIN AND BIGEYE TUNA CONSISTENT WITH ALTERNATIVE LRP RISK LEVELS, AND MULTISPECIES IMPLICATIONS

WCPFC16-2019-15[1]
8 November 2019

SPC-OFP
Pacific Community (SPC), Noumea, New Caledonia

[1] Update of WCPFC-SC15-2019/MI-WP-01: This paper has been modified from the SC15 paper. The results for skipjack have been updated based upon the SC15-agreed 2019 assessment. The paper has also been modified so that results for all three stocks can be viewed within individual tables, and analyses of gear-specific fishing combinations are now presented in an Appendix. A further Appendix is provided that relates the scalars presented in Tables 1 and 2 to more recent fishing levels.

Executive Summary

SC14 reviewed information on the minimum values for candidate spawning biomass depletion-based target reference points (TRPs) for yellowfin tuna that avoided breaching the agreed limit reference point (LRP) with a specified level of probability under the current uncertainty framework (SC14-MI-WP-01). The analysis was expanded to bigeye tuna and presented to WCPFC15 (WCPFC15-2018-13_rev1), and to SC15 following further analysis. SC14 noted the main biological consideration for a TRP is that it should be sufficiently above the LRP, and that the choice of a TRP can be based on a combination of biological, ecological and socio-economic considerations. WCPFC15 separately noted it might not be possible to achieve simultaneously precautionary TRPs for all key tuna species in the WCPFC fishery.

In this paper, we re-present median levels of spawning biomass depletion ($SB/SB_{F=0}$) that are consistent with specified risk levels of breaching the limit reference point (LRP) of $0.2SB_{F=0}$. To do this, we used:

- the structural uncertainty grid of models used by SC13 for advice from the 2017 yellowfin tuna assessment,
- the structural uncertainty grid containing only 'updated new growth' models used by SC14 as the basis for advice from the 2018 update bigeye tuna assessment, under both the 'recent' and 'long term' assumptions for future bigeye recruitment, and
- the structural uncertainty grid of models from the 2019 skipjack tuna assessment, weighted as used by SC15 for advice,

to generate 30 year projections that included stochastic variability in future recruitment under a variety of fishing levels scaled to the 2013-2015 averages. The results are summarised in the tables below. Those tables present values of $SB/SB_{F=0}$ that, if achieved on average, are predicted to result in the specified levels of risk of breaching the LRP, and thus may be interpreted as minimum levels of $SB/SB_{F=0}$ consistent with those specific risk levels, under the current uncertainty framework.

The choice of TRP will depend upon stock management objectives. We used the general objectives detailed in CMM 2018-01 (paragraphs 12 to 14) as guidance, specifically that the spawning biomass depletion ratio of both bigeye and yellowfin stocks should be maintained at or above the 'recent' average level estimated in the most recent stock assessments (paragraphs 12 and 14), and that the skipjack stock remain around the interim TRP on average (paragraph 13).

WCPFC15 noted the multispecies considerations involved in TRP discussions. The relative consequences of the fishery conditions (equal changes in purse seine effort and longline catch) that achieved each minimum TRP level for a specific stock were therefore examined for the other tropical tuna stocks. Separate analyses examining the trade-offs between purse seine and longline fishing levels that could achieve a given TRP are presented in the Appendix of this paper.

A yellowfin TRP consistent with a 5% risk will achieve the CMM 2018-01 objective for that stock, and implies a small reduction in overall fishery impact. A TRP consistent with a 7% risk (reached assuming 2013-15 average fishing levels continue) would very marginally fail to meet the CMM 2018-01 objective for yellowfin. Both levels would lead to improved stock status of bigeye tuna and no LRP risk if recent recruitments hold (pattern over 2005-2014), but a decline and 17% risk if long-term bigeye recruitment patterns hold (pattern over from 1962-2014). Maintaining 2013-15 baseline purse seine effort levels, or a 5% reduction from it (equivalent to the conditions that achieve the 7% or 5% risk levels for yellowfin, respectively) would lead to a skipjack stock below the current interim TRP (0.41 and 0.43 $SB_{F=0}$, respectively). The objectives outlined in paragraphs 12 and 14 may therefore be achieved (under recent

bigeye recruitment patterns) under fishery conditions equivalent to a TRP of 5%-7% risk for yellowfin tuna, but paragraph 13 is not.

For bigeye tuna, if recent recruitments hold, achieving minimum TRPs consistent with all levels of risk implies declines in all three stocks. Paragraphs 12 to 14 are not achieved as a result, and a TRP corresponding to a less depleted bigeye stock level would be required to do so. If long term recruitments occur in the future, only a TRP consistent with a 5% risk leads to an increase in the bigeye stock, which would also lead to increases in the yellowfin stock. This would meet paragraphs 12 and 14. Where an equivalent 20% reduction in purse seine effort from 2013-15 average levels is assumed, the skipjack tuna stock would increase to 0.47 $SB_{F=0}$. This would remain below the current interim TRP and hence paragraph 13 would not be met.

We highlight that the results are based upon some strong assumptions:

- The comparison between stocks assumes that there is no shift in species targeting to achieve reductions or increases in catch. For example, a 10% increase in bigeye catch is assumed to correspond to a 10% increase in yellowfin catch.
- Within the main body of this paper, it is assumed that changes in fishing affect both purse seine (effort) and longline (catch) by the same amount. All other fisheries remain at baseline levels.
- For all fisheries, CPUE is assumed proportional to abundance and catchability is constant (i.e. no hyperstability or effort creep).
- Results are conditioned on the assessment uncertainty framework for each stock.

SC15:

1. noted that while the main biological consideration for a TRP is that it should be sufficiently above the LRP, the choice of a TRP can be based on a combination of biological, ecological and socioeconomic considerations. In this regard consideration of other factors (such as CPUE and the financial performance of typical vessels) in the selection of candidate TRPs would be welcome;
2. welcomed the consideration of multi-species impacts based on the selection of a minimum TRP based on a given risk of exceeding the LRP for a given species, and whilst desirable noted the difficulty in extending this analysis to include the impact on South Pacific albacore;
3. recommended that the Science Service Provider update the analysis to incorporate the updated assessment for skipjack, and that WCPFC16 take note of these results when identifying appropriate TRPs for yellowfin tuna and bigeye tuna in 2019 as scheduled in the Harvest Strategy Work Plan. In so doing WCPFC16 should clarify the management objectives for these species.

Median levels of long-term yellowfin tuna $SB/SB_{F=0}$ for the four nominated levels of risk of breaching the LRP, and the stock level and risk under 2013-15 average fishing levels. Status of bigeye and skipjack stocks ($SB/SB_{F=0}$) under those conditions also presented in the final three columns. Shading indicates stock status relative to CMM 2018-01 objectives (dark grey = clearly not achieved; light grey = approximately achieved; clear = achieved).

		Yellowfin results				Bigeye $SB/SB_{F=0}$		Skipjack $SB/SB_{F=0}$
	Risk level	$SB/SB_{F=0}$	Scalar (relative to 2013-15 average conditions)	$SB/SB_{F=0}$ relative to $SB_{2012\text{-}15}/SB_{F=0}$		Recent recruitment	Long term recruitment	
	5%	0.34	0.95	1.02		0.42	0.31	0.43
Fishing @ 2013-15 average	7%	0.33	1.00	0.99		0.42	0.30	0.41
	10%	0.32	1.05	0.96		0.39	0.29	0.40
	15%	0.30	1.12	0.91		0.37	0.27	0.39
	20%	0.28	1.20	0.84		0.35	0.26	0.38

Median levels of long-term bigeye tuna $SB/SB_{F=0}$ for the four nominated levels of risk of breaching the LRP, and stock level and risk under 2013-15 average fishing levels, under two future stock recruitment hypotheses. Status of yellowfin and skipjack stocks ($SB/SB_{F=0}$) under those conditions also presented in the last two columns. Shading indicates stock status relative to CMM 2018-01 objectives (dark grey = clearly not achieved; light grey = approximately achieved; clear = achieved).

'Recent' recruitment

	Risk level	Bigeye results			Yellowfin $SB/SB_{F=0}$	Skipjack $SB/SB_{F=0}$
		$SB/SB_{F=0}$	Scalar (relative to 2013-15 average conditions)	$SB/SB_{F=0}$ relative to $SB_{2012\text{-}15}/SB_{F=0}$		
Fishing @ 2013-15 average	(0%)	0.42	1.00	1.18	0.33	0.41
	5%	0.33	1.23	0.93	0.28	0.38
	10%	0.30	1.33	0.85	0.26	0.36
	15%	0.29	1.4	0.82	0.25	0.35
	20%	0.28	1.46	0.79	0.24	0.35

'Long term' recruitment

	Risk level	Bigeye results			Yellowfin $SB/SB_{F=0}$	Skipjack $SB/SB_{F=0}$
		$SB/SB_{F=0}$	Scalar (relative to 2013-15 average conditions)	$SB/SB_{F=0}$ relative to $SB_{2012\text{-}15}/SB_{F=0}$		
	5%	0.38	0.80	1.07	0.38	0.47
	10%	0.34	0.89	0.96	0.35	0.44
	15%	0.32	0.97	0.90	0.33	0.42
Fishing @ 2013-15 average	17%	0.30	1.00	0.84	0.33	0.41
	20%	0.29	1.06	0.82	0.31	0.40

Introduction

The specification of target and limit reference points (TRPs and LRPs) are a critical part of the harvest strategy approach. LRPs are places we want to stay away from, while TRPs represent places we want to be. The choice of a LRP is based primarily on biological considerations relating to the resilience of the stock in question, i.e. what is the level of spawning biomass where the risk of recruitment overfishing becomes unacceptable. WCPFC has decided that the LRP for key tuna stocks is 20% of the unfished spawning biomass (0.2 $SB_{F=0}$). The choice of TRP is normally based on a combination of biological, ecological and socio-economic considerations. The main biological consideration is that a TRP should be sufficiently above the LRP so that if the TRP is achieved on average, the risk of breaching the LRP will be acceptably small. To inform WCPFC's consideration of potential TRPs for yellowfin and bigeye tuna, this paper attempts to answer the question "what is the minimum setting for a spawning-biomass depletion-based TRP that on average avoids breaching the LRP with a specified probability?"

This paper builds upon the analyses presented in WCPFC15-2018-13_rev1 and SC15-MI-WP-01, and aims to answers this question for yellowfin and bigeye at 5%, 10%, 15% and 20% levels of probability of breaching the LRP. The structural uncertainty grids from the latest stock assessments are used in projection mode to identify scalars of future fishing effort and/or catch that resulted in the specified levels of risk of breaching the LRP. Based on the assessments and their uncertainty frameworks, the median levels of $SB/SB_{F=0}$ that were consistent with breaching the LRP with the specified probabilities can then be defined. These median levels could then be interpreted as minimum settings for a spawning biomass depletion-based TRP, for each probability level of breaching the LRP.

WCPFC15 noted that it might not be possible to achieve simultaneously precautionary TRPs for all key tuna species in the complex WCPFC fishery. This is because fishing within the WCPFC is not species-specific; fishing gears influence the status of more than one stock. Hence the selection of management objectives, and ultimately a TRP, for one stock will have implications for another. WCPFC has noted candidate objectives for all fisheries and their stocks. In turn, CMM 2018-01 provides some practical guidance of the desired performance of that Measure for tropical tunas. Specifically for bigeye and yellowfin, paragraphs 12 and 14 specify the aim to maintain the spawning biomass depletion ratio ($SB/SB_{F=0}$) of both stocks at or above the average $SB/SB_{F=0}$ for 2012-2015 ('recent' levels). In turn, paragraph 13 calls for the spawning biomass of skipjack tuna to be maintained on average at the interim TRP.

We note that the interim TRP for skipjack was defined based upon the 2014 stock assessment. The 2019 skipjack assessment has incorporated new biological knowledge and model settings, leading to revised biomass depletion estimates compared to those used to define the interim TRP (see SPC-OFP, 2019).

In this paper results for bigeye and yellowfin are compared to the levels of each stock estimated in the most recent assessments, which allows TRP performance to be related to paragraphs 12 and 14 of CMM 2018-01. To begin to address the multispecies issues raised by WCPFC15, we evaluate the trends in the other stocks under conditions that achieve those species-specific minimum TRP levels. Noting that a given bigeye or yellowfin stock depletion level can be achieved through a number of alternative combinations of longline catch and purse seine effort, this multispecies issue is evaluated further in the Appendix to this paper.

Methods

The approach to calculating minimum TRP levels consistent with different levels of risk used the most recent tropical tuna stock assessments (yellowfin: Tremblay-Boyer *et al.*, 2017; bigeye: Vincent *et al.*, 2018; skipjack: Vincent et al., 2019) and their corresponding agreed structural uncertainty grids:

- For yellowfin tuna, SC13 chose a grid of 48 models to represent the structural uncertainty in the assessment.
- For bigeye tuna, SC14 chose a grid of 36 models to represent the structural uncertainty. SC14 agreed that the 'updated new growth' model, which incorporated new age-at-size information collected since 2017, represented the best available science on bigeye growth and that the 'old growth' model should not be used to provide management advice.
- For skipjack tuna, SC15 chose a grid of 54 models to represent the structural uncertainty. Models in this grid were weighted according to expert opinion on their biological plausibility.

The analysis proceeded as follows:

- Run 100 stochastic projections for 30 years (2016-2045 for bigeye and yellowfin, 2019-2048 for skipjack) for each model in the grid – each simulation representing a possible 'future' trajectory for recruitment, under a specific level of fishing effort or catch;
- Recruitment trajectories were constructed by computing a mean recruitment resulting from the estimated stock-recruitment relationship and adding recruitment deviations randomly sampled from:
    - For bigeye, the last 10 years of the assessment (2005-2014, 'recent recruitment'), with recruitments then distributed to seasons and regions according to the average distributions within the same 10-year period;
    - For all three stocks, the alternative 'long-term' recruitment assumption where recruitments were sampled across the period used to estimate the stock recruitment relationship (1962-2014 for bigeye and yellowfin, 1982-2017 for skipjack).
- Combine the results across model runs and calculate the median level of spawning biomass in the last year of the projection, compared to $SB_{F=0}$ ($SB_{204x}/SB_{F=0}$);
- For bigeye and yellowfin:
    - Calculate the percentage of projections that had a biomass in the final year below the agreed LRP;
    - Repeat the above steps with different scalars of effort/catch, until the future fishing levels that resulted in the percentage of projections that had a biomass in the final year below the agreed LRP equalling the risk levels of 5, 10, 15, and 20% were identified. Scalars were applied to the seasonal average of the catch or effort over the years 2013-2015 for each fishery. The same scalars were applied to all fisheries simultaneously. Future scenarios for longline fisheries were expressed as constant catch[2], while scenarios for other fisheries were expressed as constant effort.
- Subsequently, for skipjack and the other tropical tuna stock, examine the stock status that resulted under the purse seine scalars (skipjack) or purse seine and longline scalars (yellowfin/bigeye) that achieve the candidate minimum TRP levels for bigeye or yellowfin.

[2] In a number of projections, the constant-catch scenarios for longline fisheries resulted in some age-classes in some regions tending towards zero abundance. In such cases, the catches of the longline fisheries in those regions were reduced to avoid negative numbers-at-age.

Results

The median long term depletion level ($SB/SB_{F=0}$) associated with each of the four levels of risk of breaching the LRP for yellowfin and bigeye are presented in Table 1 and 2. These values can be interpreted as the minimum levels of $SB/SB_{F=0}$ that, if achieved on average, would be consistent with remaining above the LRP at each level of risk. Figure 1 presents the distributions of $SB_{2045}/SB_{F=0}$ for each risk level for those two stocks.

As the choice of TRP depends upon the management objectives for stocks, we have related results to the current general objectives detailed in CMM 2018-01. Specifically, that the spawning biomass depletion ratio of both bigeye and yellowfin should be maintained at or above the recent average level. For skipjack, the objective of CMM 2018-01 is to maintain the stock around the interim TRP.

For yellowfin tuna:

- The 2017 stock assessment estimated the median $SB_{recent}/SB_{F=0}$ to be 0.33 and the 2015 level to be 0.37. These estimated levels of spawning biomass depletion would be consistent with long-term risks of breaching the LRP of 0-10%.
- Continuing to fish under 2013-15 average conditions would lead to an LRP risk of 7%, and the stock would decline very slightly from recent estimated levels (Table 1).

For bigeye tuna:

- The 2018 updated stock assessment estimated the median $SB_{recent}/SB_{F=0}$ to be 0.36 and the 2015 level to be 0.46. These estimated levels of spawning biomass depletion would be consistent with risks of breaching the LRP of 0-10% under the long-term recruitment scenario, and zero risk under recent recruitments.
- Continuing to fish under 2013-15 average conditions would lead to the stock increasing and zero LRP risk if recent recruitments continue, and the stock declining and an LRP risk of 17% under the long-term recruitment scenario (Table 2).

For skipjack tuna:

- The 2019 stock assessment estimated the weighted median $SB_{recent}/SB_{F=0}$ to be 0.44, and the 2018 level to be 0.42.
- Continuing to fish under 2013-15 average conditions would lead to a decline to 41% $SB_{F=0}$, a level below the interim TRP, but no LRP risk.

Management at 2013-15 average levels therefore achieves the CMM 2018-01 objective for bigeye if recent recruitment holds, very marginally fails to meet objective for yellowfin tuna, and results in a skipjack stock at levels below the interim TRP and hence fails to meet paragraph 13.

Table 1 and Table 2 also present the potential median consequences for the other tropical tuna stocks of the levels of fishing that achieve each minimum TRP level, to support multispecies considerations.

A yellowfin TRP consistent with a 5% risk will achieve the CMM 2018-01 objective for that stock, and implies a small reduction in overall fishery impact. A TRP consistent with a 7% risk (2013-15 average fishing levels) would very marginally fail to meet the CMM 2018-01 objective. Both levels would lead to improved stock status of bigeye tuna if recent recruitments hold, but a decline if long-term bigeye recruitment patterns hold. A 5% reduction in purse seine effort from 2013-15 baseline levels equivalent to the

conditions that achieve the 5% risk level for yellowfin would increase the skipjack stock relative to that under 2013-15 conditions to $0.42SB_{F=0}$, but would be below the current interim TRP. Paragraphs 12 and 14 may therefore be achieved (under recent bigeye recruitment patterns) under fishery conditions equivalent to a TRP of 5%-7% risk for yellowfin tuna, but paragraph 13 is not.

For bigeye tuna, if recent recruitments hold, TRPs consistent with all levels of risk imply declines in all three stocks. Paragraphs 12, to 14 are not achieved as a result, and a TRP corresponding to a less depleted stock level would be required to do so. If long term recruitments occur, only a TRP consistent with a 5% risk leads to an increase in the bigeye stock, which would also lead to increases in the yellowfin stock. This would meet paragraphs 12 and 14. Where an equivalent 20% reduction in purse seine effort from 2013-15 average levels is assumed, the skipjack tuna stock would increase to $0.47SB_{F=0}$. This would remain below the current interim TRP and hence paragraph 13 would not be met.

Discussion

In order to recommend a specific level of $SB/SB_{F=0}$ as a TRP, it is necessary to:

- Agree on an acceptable level of risk of breaching the LRP in order to define the minimum TRP in terms of $SB/SB_{F=0}$. This issue was summarised previously (SPC-OFP, 2014) in the following terms:
  > "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."
- Consider other ecological and socio-economic factors that might be relevant in recommending specific TRPs that may be more conservative than the risk-based 'limiting' levels described in this paper.

We highlight that the results presented here are based upon some strong assumptions:

- The comparison between stocks assumes that there is no shift in species targeting to achieve reductions or increases in catch. For example, a 10% increase in bigeye catch will correspond to a 10% increase in yellowfin catch.
- Within the main body of this paper, it is assumed that changes in fishing affect both purse seine (effort) and longline (catch) by the same amount. All other fisheries remain at baseline levels.
- For all fisheries, CPUE is assumed proportional to abundance and no effort creep is occurring.

The method used here to estimate minimum TRPs is consistent with that used in the past and has been generally accepted by WCPFC. However, it should be noted that results of such analyses are conditioned on the uncertainty framework used. In this analysis, the structural uncertainty frameworks in the 2017 yellowfin and 2018 bigeye tuna assessments, plus stochastic variability in future recruitment, were used. The amount of uncertainty incorporated will impact the 'spread' of the future distributions of $SB/SB_{F=0}$, which in turn will affect the estimated risks of breaching the LRP. In general, more uncertainty = greater risk, and higher median $SB/SB_{F=0}$ levels would be required to meet a particular risk of breaching the LRP.

References

Pilling, G., Williams, P. and Hampton, J. (2019). Evaluation of CMM 2018-01 for tropical tuna. WCPFC-SC15-2019/MI-WP-11.

SPC-OFP (2014). 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. MOW3-WP-02.

SPC-OFP (2017). An evaluation of the management options for purse seine and longline fisheries defined by the TT CMM intersessional meeting. WCPFC14-2017-10_REV1.

SPC-OFP (2019). Current and projected stock status of WCPO skipjack tuna to inform consideration of an updated target reference point. WCPFC16-2019-14.

Tremblay-Boyer L., S. McKechnie, G. Pilling and J. Hampton (2017). Stock assessment of yellowfin tuna in the western and central Pacific Ocean Rev 1 (26 July 2017). WCPFC-SC13-2017/SA-WP-06.

Vincent, M.T., Pilling, G. and Hampton, J. (2018). Incorporation of updated growth information within the 2017 WCPO bigeye stock assessment grid, and examination of the sensitivity of estimates to alternative model spatial structures. WCPFC-SC14-2018/SA-WP-03.

Vincent, M.T., Pilling, G. and Hampton, J. (2019). Stock assessment of skipjack tuna in the western and central Pacific Ocean. WCPFC-SC15-2019/SA-WP-05.

Tables and figures

Table 1. Median levels of yellowfin tuna $SB/SB_{F=0}$ for the four nominated levels of risk of breaching the LRP, and the stock level and risk resulting from fishing at 2013-15 average levels. Status of bigeye and skipjack stocks ($SB/SB_{F=0}$) under those conditions are also presented in the final three columns. Shading indicates status relative to CMM 2018-01 objectives (dark grey = clearly not achieved; light grey = approximately achieved; clear = achieved).

	Risk level	Yellowfin results			Bigeye $SB/SB_{F=0}$		Skipjack $SB/SB_{F=0}$
		$SB/SB_{F=0}$[1]	Scalar (relative to 2013-15 average conditions)	$SB/SB_{F=0}$ relative to $SB_{2012\text{-}15}/SB_{F=0}$	Recent recruitment	Long term recruitment	
	5%	0.34	0.95	1.02	0.42	0.31	0.43
Fishing @ 2013-15 average	7%	0.33	1.00	0.99	0.42	0.30	0.41
	10%	0.32	1.05	0.96	0.39	0.29	0.40
	15%	0.30	1.12	0.91	0.37	0.27	0.39
	20%	0.28	1.20	0.84	0.35	0.26	0.38

[1] note: these values are slightly different from those presented in SC14-MI-WP-01. They have been re-calculated using the long-term recruitment assumption, which is consistent with that used within the tropical tuna CMM evaluation.

Table 2. Median levels of bigeye tuna $SB_{2045}/SB_{F=0}$ for the four nominated levels of risk of breaching the LRP, and the stock level and risk resulting from fishing at 2013-15 average levels, under the two future recruitment assumptions of 'recent' (sampling from the last 10 years) and 'long term' (sampling across 1962 to 2014). Status of yellowfin and skipjack stocks ($SB/SB_{F=0}$) under those conditions is also presented in the final two columns. Shading indicates status relative to CMM 2018-01 objectives (dark grey = clearly not achieved; light grey = approximately achieved; clear = achieved).

'Recent' recruitment

	Risk level	Bigeye results			Yellowfin $SB/SB_{F=0}$	Skipjack $SB/SB_{F=0}$
		$SB/SB_{F=0}$	Scalar (relative to 2013-15 average conditions)	$SB/SB_{F=0}$ relative to $SB_{2012-15}/SB_{F=0}$		
Fishing @ 2013-15 average	(0%)	0.42	1.00	1.18	0.33	0.41
	5%	0.33	1.23	0.93	0.28	0.38
	10%	0.30	1.33	0.85	0.26	0.36
	15%	0.29	1.4	0.82	0.25	0.35
	20%	0.28	1.46	0.79	0.24	0.35

'Long term' recruitment

	Risk level	Bigeye results			Yellowfin $SB/SB_{F=0}$	Skipjack $SB/SB_{F=0}$
		$SB/SB_{F=0}$	Scalar (relative to 2013-15 average conditions)	$SB/SB_{F=0}$ relative to $SB_{2012-15}/SB_{F=0}$		
	5%	0.38	0.80	1.07	0.38	0.47
	10%	0.34	0.89	0.96	0.35	0.44
	15%	0.32	0.97	0.90	0.33	0.42
Fishing @ 2013-15 average	17%	0.30	1.00	0.84	0.33	0.41
	20%	0.29	1.06	0.82	0.31	0.40

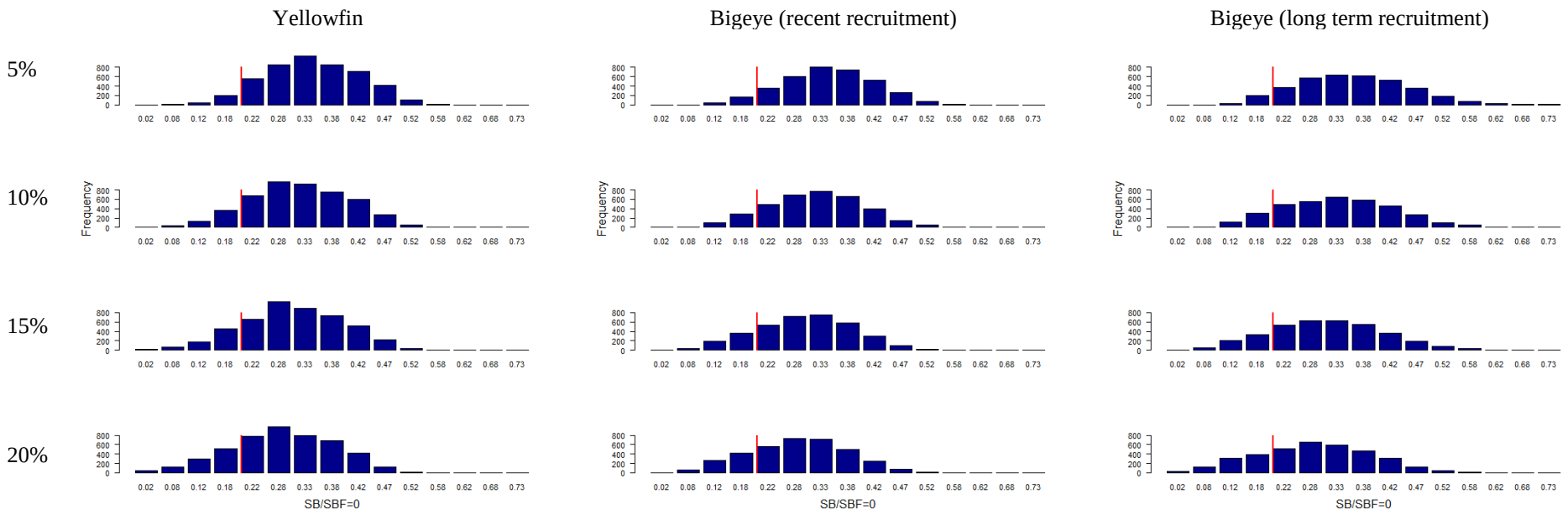

Figure 1. The distribution of $SB_{2045}/SB_{F=0}$ for the four nominated levels of risk of breaching the LRP for yellowfin and bigeye (for the latter, for each of the two SRR assumptions). Red vertical line in each panel represents 20% of $SB_{F=0}$

Appendix 1. Multi-species, multi-gear issues for TRPs

WCPFC15 noted the multispecies considerations involved in TRP discussions. The relative consequences of each minimum TRP level for a stock was therefore examined for the other tropical tuna stocks in the main body of this paper. That evaluation assumes equal changes in purse seine effort and longline catch. However, a specific stock level can be achieved across a range of combinations of fishing by the major fishing gears. This is examined here using deterministic projections (rather than stochastic projections, due to time constraints). The choice of TRP will depend upon stock management objectives. We again use the general objectives detailed in CMM 2018-01 as guidance.

Approach

We used deterministic projections assuming different combinations of purse seine effort[3] and longline catch scalars ranging from 0.5 to 1.5 times 2013-2015 average levels (see for example SPC-OFP, 2017). 30 year deterministic projections were performed across the grid of assessment models for bigeye and yellowfin and the median $SB_{2045}/SB_{F=0}$ under each purse seine/longline fishery combination calculated. Under deterministic projections, future recruitment is assumed to correspond to the estimated stock recruitment relationship for both stocks, while for bigeye the projections were also run under assumptions equivalent to the 'recent' recruitment scenario.

From the resulting grid of stock status under different fishing levels, alternative fishery combinations that resulted in stock status levels consistent with each minimum TRP were identified[4]. By mapping those fishery combinations onto the equivalent deterministic projection results for the other tuna stock, the implications of a given candidate minimum TRP level for the biomass trend of that other stock were examined. It must be noted that this assumes no change in targeting between the two stocks – i.e. that a decline in the catch of yellowfin tuna within the longline fishery corresponds to an equivalent decline in the catch of bigeye tuna in that fishery.

Results

A minimum TRP stock level consistent with a given level of risk can be achieved under a range of purse seine and longline fishing combinations. These generally involve trade-offs between purse seine and longline fishing levels, and result in the diagonal patterns seen in Figure 2a and b for yellowfin TRPs, and Figure 3a and b for bigeye. The smaller the level of risk a TRP corresponds with, the closer to the top left of the Figure the band of fishing combinations is found. The consequences of different minimum candidate TRPs of one stock for the other are also summarised in those figures, based upon the colouration of the bands.

When considering minimum TRP levels for yellowfin tuna:

[3] For bigeye tuna, the majority of the stock impact by purse seine is through associated effort. For that stock, effort multipliers can be viewed as associated-set specific. As yellowfin is caught in both associated and unassociated sets, effort multipliers refer to total effort, rather than being associated-set-specific.

[4] Deterministic projection results should be consistent with the average from stochastic projections. However, when calculating across the assessment uncertainty grid, this was not always the case. Therefore the grid of deterministic projection results was scaled by any difference to stock depletion estimated using stochastic projections at each risk level. For example, the yellowfin the grid was scaled downward by 0.01 to 0.02 $SB/SB_{F=0}$, dependent on risk level.

- A TRP consistent with a 5% LRP risk level generally implies a small reduction in the fishing level of purse seine, longline or both gears, and would allow a small increase in yellowfin stock status relative to recent levels.
- TRPs consistent with higher LRP risk levels allow overall increases in fishing (with trade-offs between one gear and the other), but imply declines in yellowfin stock status from recent levels.
- Only minimum TRPs consistent with lower LRP risk levels (primarily 5 and 10% risk) are consistent with concurrent increases in the bigeye stock across the majority of compatible longline and purse seine fishing combinations if recent recruitments continue. As risk levels increase, the bigeye stock will decline if longline catch levels increase above 2013-15 average levels, while by comparison purse seine effort levels could be allowed to increase further.
- If the long term recruitment assumption holds for bigeye, all minimum TRP levels for yellowfin imply declines in the bigeye stock from recent levels. The objective to maintain bigeye at or above the recent average $SB/SB_{F=0}$ (para 12, CMM 2018-01) would not be met.

For bigeye tuna:

- if recent recruitments continue, achieving all minimum TRPs implies allowable increased fishing levels, but also declines in bigeye stock status from recent levels.
- If long term recruitments occur, achieving TRPs consistent with 5-15% risk levels generally require reduced overall fishing levels. Only for the 5% risk level are those reductions sufficient to lead to increases in bigeye stock status from recent levels under those recruitment conditions.
- Fishing at levels consistent with all minimum bigeye TRPs under the recent recruitment assumption imply declines in the yellowfin stock from recent levels.
- Under the long-term recruitment assumption for bigeye, minimum TRPs consistent with 15% or lower LRP risks generally require reductions in fishing from one or both gears. Those minimum TRP levels will result in increases in, or maintenance of, the yellowfin stock at recent levels, except at the higher purse seine effort scalar levels compatible with a 15% risk. At the 20% TRP level for bigeye, the yellowfin stock will generally decline where purse seine effort, and to a lesser extent longline catch, is increased.

We highlight that the results of these deterministic projections are based upon some strong assumptions:

- As noted earlier, the comparison between stocks assumes that there is no shift in species targeting to achieve reductions or increases in catch. For example, a 10% increase in bigeye catch will correspond to a 10% increase in yellowfin catch.
- To estimate the median stock status that leads to specific levels of risk calculated from the stochastic projections, scalars are applied equally across purse seine effort and longline catch. When relating these to the deterministic projection results:
    - We assume that the same stock status from the deterministic results will lead to the same level of risk for all gear-specific combinations. However unequal gear-specific scalars may lead to different distributions of stock status outcomes (i.e. the gear-specific combination that results in a given median may be from a more skewed distribution of estimated results, and hence the actual corresponding risk may be different).
    - The median stock status calculated from the deterministic results over the assessment grid did not exactly match the median estimate from the stochastic results. We therefore scaled the deterministic estimates (by maximum +0.04 and -0.03) to match the values presented in Tables 1 and 2. The results of the deterministic projection analyses should therefore be viewed as indicative.
- For all fisheries, CPUE is assumed proportional to abundance and no effort creep is occurring.

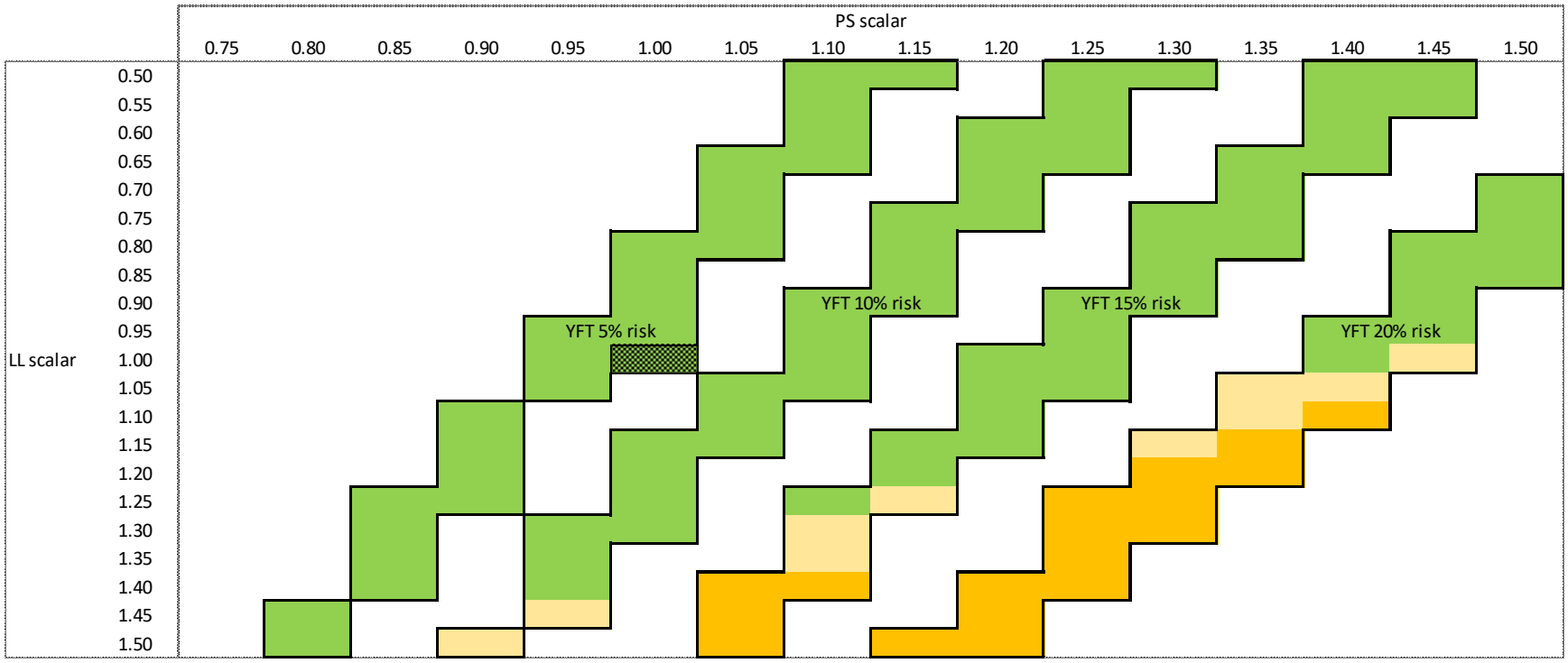

Figure 2a. For yellowfin tuna, the combination of longline catch and purse seine effort (scaled off 2013-15 average levels) that achieve the 'minimum TRP' $SB/SB_{F=0}$ consistent with each of the four levels of risk examined (5%, 10%, 15%, 20% risk of falling below the LRP). For each PS/LL fishing combination, the colour indicates the corresponding future trend in the bigeye stock relative to recent assessed levels ($SB_{2012-2015}/SB_{F=0}$ = 0.36) under 'recent' recruitment assumptions (orange = decline, yellow=maintained, green = increased). Greyed square indicates the location of yellowfin '2013-15 average conditions'. Note this point is scaled to 0.33 (see Table 1)

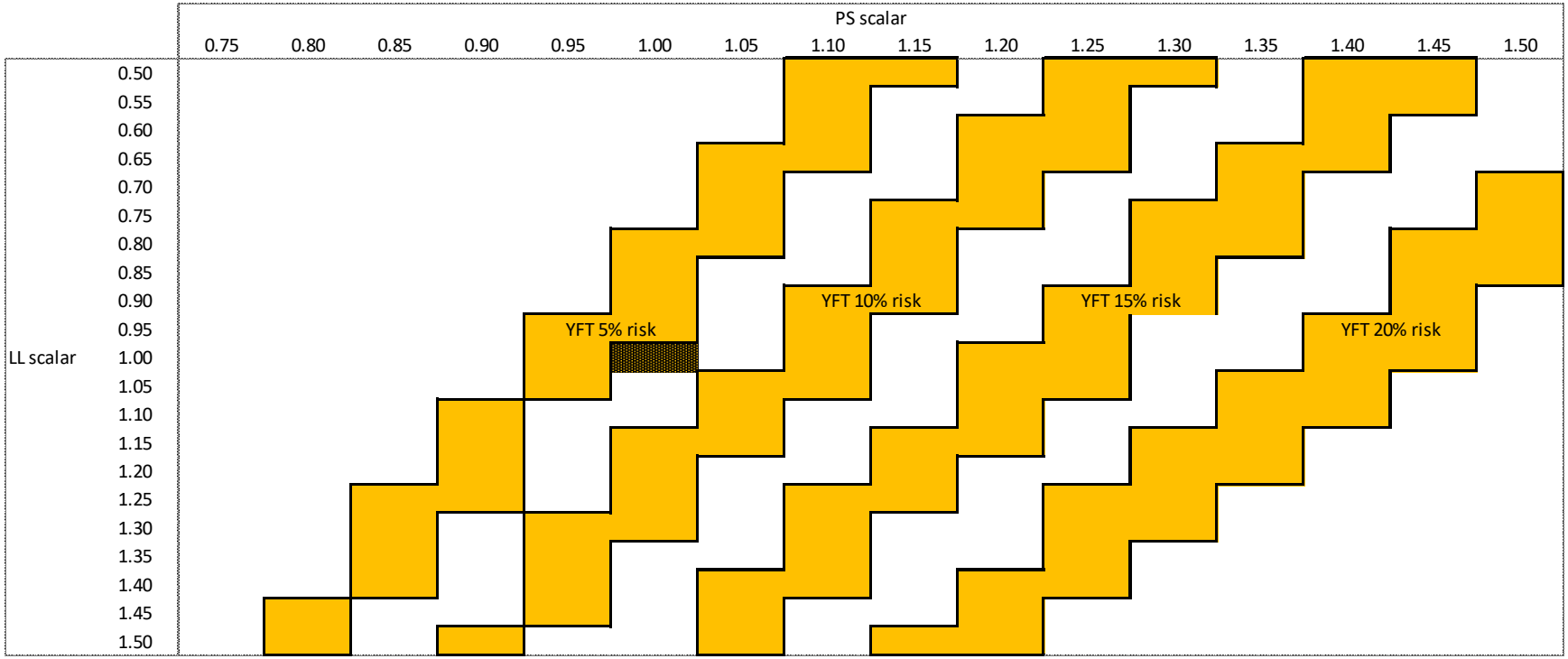

Figure 2b. For yellowfin tuna, the combination of longline catch and purse seine effort (scaled off 2013-15 average levels) that achieve the 'minimum TRP' $SB/SB_{F=0}$ consistent with each of the four levels of risk examined (5%, 10%, 15%, 20% risk of falling below the LRP). For each PS/LL fishing combination, the colour indicates the corresponding future trend in the bigeye stock relative to recent assessed levels ($SB_{2012-2015}/SB_{F=0}$ = 0.36) under 'long term' recruitment assumptions (orange = decline, yellow=maintained, green = increased). See caption of Figure 2a for more details.

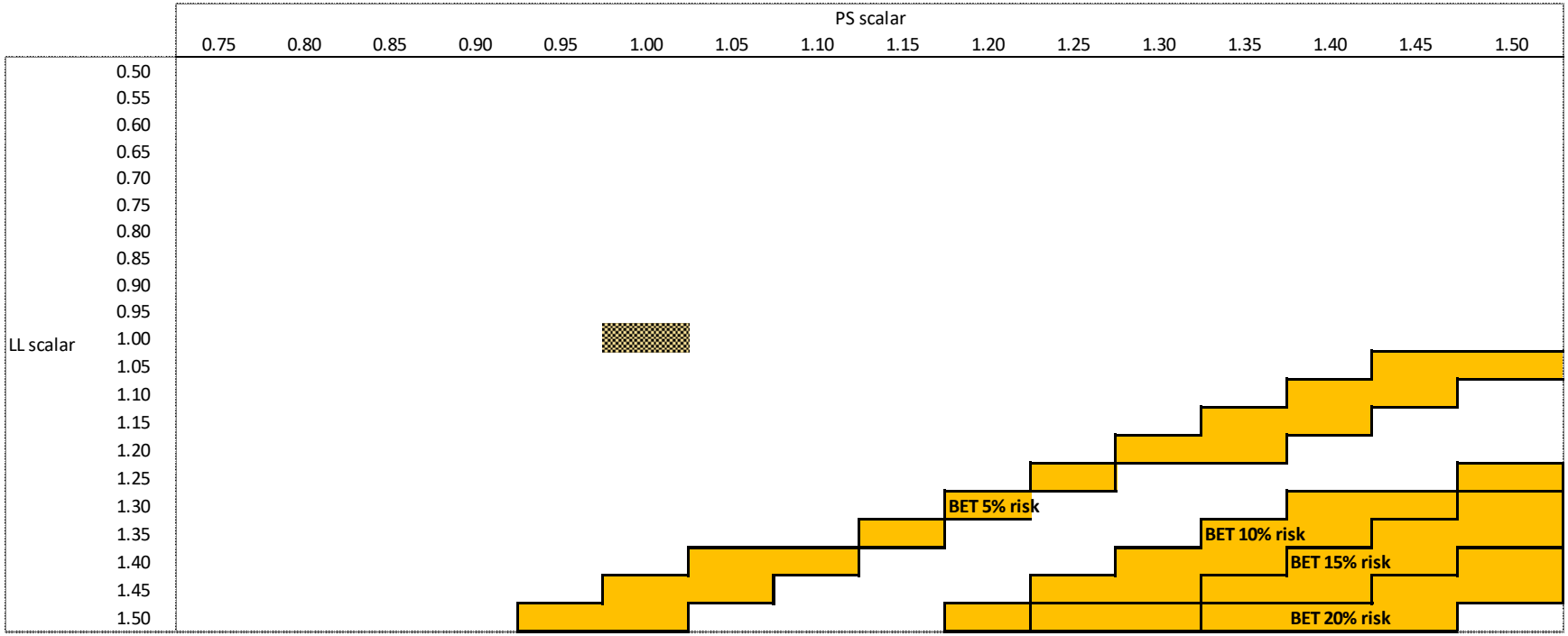

Figure 3a. For bigeye tuna under 'recent recruitment' levels, the combination of longline catch and purse seine effort (scaled off 2013-15 average levels) that achieve the 'minimum TRP' $SB/SB_{F=0}$ consistent with each of the four levels of risk examined (5%, 10%, 15%, 20% risk of falling below the LRP). For each PS/LL fishing combination, the colour indicates the corresponding future trend in the yellowfin stock relative to recent assessed levels ($SB_{2012\text{-}2015}/SB_{F=0}$ = 0.33) (orange = decline, yellow=maintained, green = increased). See caption of Figure 2a for more details.

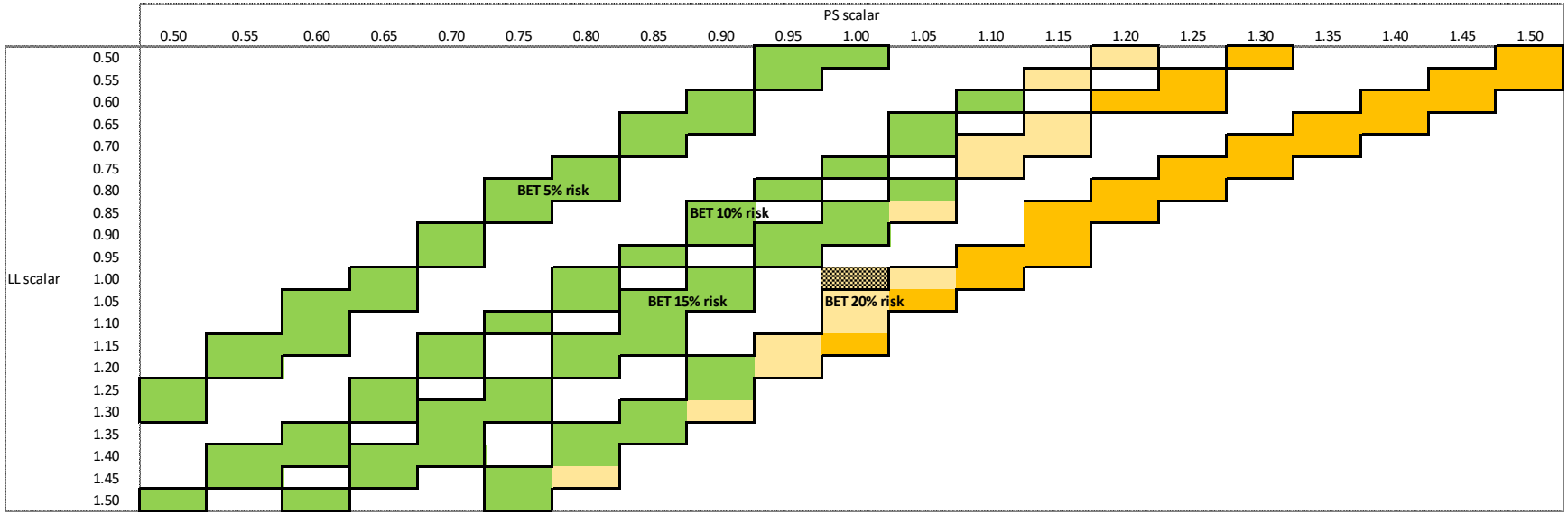

Figure 3b. For bigeye tuna under 'long-term recruitment' levels, the combination of longline catch and purse seine effort (scaled off 2013-15 average levels) that achieve the 'minimum TRP' SB/$SB_{F=0}$ consistent with each of the four levels of risk examined (5%, 10%, 15%, 20% risk of falling below the LRP). For each PS/LL fishing combination, the colour indicates the corresponding future trend in the yellowfin stock relative to recent assessed levels (orange = decline, yellow=maintained, green = increased). See caption of Figure 3a for more details.

Appendix 2. Scalars from the 2013-15 baseline related to the more recent period of 2016-18.

The baseline years of 2013-15 used to define the scalars were selected as they are the most recent years contained within the bigeye and yellowfin stock assessments. To allow WCPFC members to relate the scalars presented in Table 1 and Table 2 to a more recent period, Table 3 and Table 4 present comparable scalars, but relative to the 2016-2018 average longline catch and purse seine effort. We note:

- 2018 longline catch in particular is likely to be updated over the coming year which will affect the scalar values;
- While identical scalars were applied to longline catch and purse seine effort relative to the 2013-15 average baseline period, specific scalars for longline catch and purse seine effort need to be calculated for the more recent 2016-2018 average baseline, since effort and catch in those two fisheries will not have changed by the same amount over that period;
- Scalars for purse seine are based upon effort. While yellowfin catch in particular in the recent period has been notably higher than over the 2013-2015 baseline, purse seine effort has by comparison been lower.

Table 3. Scalars for the yellowfin TRP levels from the 2013-15 average baseline period, and equivalent scalars if the 2016-18 average period were used.

Risk level	Scalar 2013-15	Longline 2016-18	Purse seine 2016-18
5%	0.95	1.09	1.05
7%	1.00	1.14	1.10
10%	1.05	1.20	1.16
15%	1.12	1.28	1.24
20%	1.20	1.37	1.32

Table 4. Scalars for the bigeye TRP levels from the 2013-15 average baseline period, and equivalent scalars if the 2016-18 average period were used.

Risk level	Scalar 2013-15	Longline 2016-18	Purse seine 2016-18
(0%)	1.00	1.28	1.10
5%	1.23	1.58	1.36
10%	1.33	1.71	1.47
15%	1.4	1.80	1.54
20%	1.46	1.88	1.61
5%	0.80	1.03	0.88
10%	0.89	1.14	0.98
15%	0.97	1.25	1.07
17%	1.00	1.28	1.10
20%	1.06	1.36	1.17