SCIENTIFIC COMMITTEE
FIFTEENTH REGULAR SESSION

12-20 August 2019
Pohnpei, Federated States of Micronesia

Evaluation of CMM 2018-01 for tropical tuna

WCPFC-SC15-2019/MI-WP-11
23 July 2019

Graham Pilling, Peter Williams and John Hampton

OFP
Pacific Community (SPC), Noumea, New Caledonia

1. EXECUTIVE SUMMARY

This paper evaluates the potential for CMM 2018-01 to achieve its objectives for each of the three WCPO tropical tuna stocks as specified in paragraphs 12 to 14. The evaluation is based upon the latest SC-agreed stock assessments, and hence does not use the 2019 WCPO skipjack assessment to be agreed at SC15. CMM 2018-01 notes 'The Commission at its 2019 annual session shall review and revise the aims set out in paragraphs 12 to 14 in light of advice from the Scientific Committee' (paragraph 15). This paper aims to support those SC15 discussions.

CMM 2018-01 contains minor adjustments to the CMM 2017-01 text. Key differences are:

- Removal of footnote 1 (Cook Islands charter): no impact on evaluation as overall purse seine effort is assumed to remain constant.
- Paragraph 18, exclusion of 'small amounts of … garbage without a tracking buoy attached' from the definition of a FAD: analysis of available observer data described herein indicates minimal impact on the evaluation. However, the current language of paragraph 18 requires interpretation, which hinders our ability to evaluate its impact on CMM performance. Although small, any increase in the number of 'FAD sets' due to this paragraph will lead to 'an increase in bigeye and small yellowfin tuna catch'.
- Paragraphs 19-20 (non-entangling FAD designs), no impact on the evaluation as non-entangling FADs and bio-degradable designs are expected to perform comparably to existing designs.
- Deletion of paragraph 29 (American Samoa clause): no impact on the evaluation as the overall purse seine effort for the fleet is assumed to remain constant, and the breakdown of set types to remain consistent with the scenarios being considered.
- Paragraph 40, ongoing transfer of 500mt of bigeye catch between Japan and China: for the purposes of this long-term evaluation, the transfer is assumed not to continue beyond February 2021. The consequence of this transfer for the 'optimistic scenario' longline scalar, which is the only scenario that would be affected, is calculated but not evaluated: this transfer would increase the longline catch scalar of the optimistic scenario only, from 0.98 to 0.99.

Overall, these changes do not materially affect the management conditions assumed under this evaluation. Therefore, this paper presents results comparable to those agreed by SC14 for bigeye tuna (SC14 Summary Report, paragraphs 40 to 51 and Section 4.1.1; Pilling et al., 2018) and as seen by WCPFC15 for all three stocks (SPC, 2018).

We use an approach similar to that within recent tropical tuna CMM evaluations to:

- Step 1. quantify provisions of each Option – i.e., translate each specified management Option into future potential levels of purse seine effort and longline catch;
- Step 2. evaluate potential consequences of each Option over the long-term for bigeye tuna, against the aims specified in CMM 2018-01.

STEP 1: QUANTIFYING PROVISIONS OF THE OPTION

We repeat the detailed evaluation approach used within previous tropical tuna CMM evaluations. Assumptions are made regarding the impact that the FAD closure period and/or high seas effort limits will have on FAD-related effort, and the potential future catches of longline fleets. These assumptions are consistent with those made in previous CMM evaluations, and include whether effort and catch limits specified within the CMM are taken by a flag, particularly where those limits are higher than recent fishing levels. Under these assumptions, we define three scenarios of future purse seine effort and longline catch, based upon a baseline average period of 2013-15, the most recent period in the latest tropical tuna assessments. These scenarios are summarised as:

‘2013-2015 avg’: purse seine effort and longline catch levels are maintained at the average levels seen over the years 2013-2015, providing a ‘baseline’ for comparison.

‘Optimistic’: under a 3 month FAD closure, purse seine CCMs make an additional 1/8th FAD sets relative to the average number over 2013-15, when a 4 month closure was in place (i.e. 8 months FAD fishing in those years). The additional 2-month high seas FAD closure (5 months in total) reduces the number of FAD sets by 1/8th of those made on the high seas in 2013-15. CCMs with longline limits take their 2019 catch limit or 2013-2015 average level if lower.

‘Pessimistic’: every CCM fishes the maximum allowed under the Measure. Purse seine CCMs undertake an additional 1/8th FAD sets relative to the average number over the period 2013-15 when a 4 month closure was in operation. The additional 2-month high seas FAD closure reduces the number of sets by 1/8th of those set on the high seas in 2013-15, but where specified high seas effort limits allow additional fishing relative to 2013-15, additional FAD sets are assumed on a proportional basis. Limited longline non-SIDS CCMs and US Territories take their entire 2019 specified/2000 mt limits, 2013-2015 average level assumed for other SIDS.

The second and third scenarios assume the change in FAD closure periods under CMM 2018-01 equates to a proportional increase/decrease in FAD sets (see also Appendix 1). Other key assumptions across stocks were that total purse seine effort remained constant (increases in associated effort led to a decrease in free school effort), while for yellowfin, longline catch changes were assumed to match those evaluated for bigeye tuna. ‘Other fisheries’, which have a notable impact on yellowfin stock status, were assumed to remain constant at 2013-15 average levels within the analysis.

STEP 2: EVALUATE THE POTENTIAL EFFECTIVENESS OF THE MEASURE ON STOCKS

We use stochastic stock projections to evaluate potential long-term consequences of resulting future fishing levels under each scenario, in comparison to 2013-2015 average conditions for each of the three tropical tuna stocks. For each, projections were run across the grid of models agreed by SC as the basis for advice.

The stated aims of CMM 2018-01 for bigeye and yellowfin were to maintain spawning biomass at or above the average $SB/SB_{F=0}$ for 2012-2015, while for skipjack tuna it was to maintain spawning biomass on average at a level consistent with the interim target reference point. The potential long-term performance of the CMM against those objectives varied between stocks.

For bigeye tuna, performance of CMM 2018-01 was strongly influenced by the assumed future recruitment levels (see Table 1). If recent positive recruitments continue into the future, all scenarios examined achieve the aims of the CMM, in that median spawning biomass is projected to remain stable or increase relative to recent levels, and median fishing mortality is projected to decline slightly (the exception to the latter being the pessimistic

CMM scenario, although median fishing mortality remains below F_{MSY}). If less positive longer-term recruitments continue into the future, spawning biomass depletion worsens relative to recent levels under all scenarios, and the future risk of spawning biomass falling below the limit reference point (LRP) increases to between 17 and 32%, dependent on the scenario. In turn, all three future fishing scenarios imply increases in fishing mortality under those recruitment conditions, more than doubling to median levels well above F_{MSY}.

For yellowfin and skipjack, long-term recruitment patterns were assumed to hold into the future.

Results for skipjack (Table 2) were consistent across the different CMM 2018-01 scenarios, as overall purse seine effort was assumed to remain constant at 2013-15 average levels, and the impact of longline catch is negligible. Under 2013-15 average levels and ‘long-term’ recruitment, the skipjack stock is projected to stabilise at 47% $SB/SB_{F=0}$, slightly below the TRP, and F/F_{MSY} to remain relatively stable (a 1-3% increase compared to recent assessed levels). There was no risk of breaching the adopted limit reference point.

For yellowfin tuna, results under the 2013-15 average and ‘optimistic’ scenarios are comparable (Table 2), with the stock stabilising at 33% $SB/SB_{F=0}$ (a 1% decrease from recent assessed levels) and F/F_{MSY} reducing to 0.68 (a 7-8% reduction). The pessimistic scenario, which implies a 35% increase in longline yellowfin catch, had a greater impact, with yellowfin biomass falling to 30% $SB/SB_{F=0}$ (an 8% reduction from recent levels), F/F_{MSY} remaining stable at $0.73F/F_{MSY}$, and the risk of breaching the adopted limit reference point increasing to 16%.

Table 1. Median values of reference point levels (adopted limit reference point (LRP) of 20% $SB_{F=0}$; F_{MSY}) and risk[1] of breaching reference points from the 2018 re-assessment of WCPO bigeye tuna incorporating 'updated new growth' models only, and in 2045 under the three future harvest scenarios (2013-2015 average fishing levels, optimistic, and pessimistic) and alternative recruitment hypotheses.

Scenario		Scalars relative to 2013-2015		Median $SB_{2045}/SB_{F=0}$	Median $SB_{2045}/SB_{F=0}$ v $SB_{2012-15}/SB_{F=0}$	Median $F_{2041-2044}/F_{MSY}$	Median $F_{2041-2044}/F_{MSY}$ v $F_{2011-14}/F_{MSY}$	Risk	
Recruitment	**Fishing level**	**Purse seine**	**Longline**					**SB_{2045} < LRP**	**F>F_{MSY}**
Bigeye assessment ('recent' levels)				0.36	-	0.77	-	0%	6%
Recent	2013-2015 avg	1	1	0.42	1.18	0.73	0.95	0%	11%
	Optimistic	1.11	0.98	0.41	1.15	0.75	0.98	0%	13%
	Pessimistic	1.12	1.35	0.36	1.00	0.89	1.15	5%	30%
Long-term	2013-15 avg	1	1	0.30	0.84	1.60	2.09	17%	93%
	Optimistic	1.11	0.98	0.29	0.82	1.64	2.13	18%	94%
	Pessimistic	1.12	1.35	0.25	0.70	1.84	2.38	32%	98%

[1] note risk within the stock assessment is calculated as the (weighted) number of models falling below the LRP (X / 36 models). Risk under a projection scenario is the number of projections across the grid that fall below the LRP (X / 3600 (36 models x 100 projections)).

Table 2. Median and relative values of reference points and risk of breaching reference points levels (adopted limit reference point (LRP) of 20% $SB_{F=0}$; F_{MSY}) in 2045 from the 2016 skipjack and 2017 yellowfin stock assessments, under the three future harvest scenarios (2013-2015 average fishing levels, optimistic, and pessimistic) and long-term recruitment patterns.

Stock	Fishing level	Scalars relative to 2013-2015		Median $SB_{2045}/SB_{F=0}$	Median $SB_{2045}/SB_{F=0}$ v $SB_{2012-15}/SB_{F=0}$	Median $F_{2041-2044}/F_{MSY}$	Median $F_{2041-2044}/F_{MSY}$ v $F_{2011-14}/F_{MSY}$	Risk	
		Purse seine	**Longline**					**SB_{2045} < LRP**	**F>F_{MSY}**
Skipjack tuna	2013-2015 avg	1	1	0.47	NA[1]	0.49	1.01	0%	0%
	Optimistic	1.11	0.98	0.47	NA[1]	0.49	1.02	0%	0%
	Pessimistic	1.12	1.35	0.47	NA[1]	0.49	1.03	0%	0%
Yellowfin tuna	2013-2015 avg	1	1	0.33	0.99	0.68	0.92	7%	2%
	Optimistic	1.11	0.98	0.33	0.99	0.68	0.93	7%	2%
	Pessimistic	1.12	1.35	0.30	0.92	0.73	0.99	16%	9%

[1] Stated aim of CMM 2018-01 for skipjack was to maintain the stock on average around the TRP of 50%$SB_{F=0}$ (CMM para 13).

2. QUANTIFYING THE PROVISIONS OF THE MEASURE

This CMM 2018-01 evaluation is based upon the latest SC-agreed stock assessment models for the three tropical tuna species (Vincent et al., 2018; Tremblay-Boyer et al., 2017; McKechnie et al, 2016), using those models SC selected as representing the best scientific information available. The 2019 assessment of WCPO skipjack is yet to be agreed by SC14, and is not used here. Abundance of each stock is projected into the future (30 years) under particular levels of either catch or effort within the different fisheries modelled in the assessment.

Therefore, the two parts of Step 1 are:

1. Estimate the levels of associated (FAD) and unassociated (free school) set purse seine effort and longline bigeye catch that would result from the provisions of the Measure. This estimation requires interpretation of the CMM text to estimate the most likely purse seine effort and longline catch levels that would result.
2. Express these levels of purse seine effort and longline catch as scalars relative to reported levels of these quantities for 2013-2015 (the last years of each assessment). This average period was selected to reduce the impact of FAD set fluctuations in individual years on evaluation results, while ensuring the FAD closure period (4 months) was consistent across those years.

We repeated the detailed approach used in the evaluation of CMM 2015-01 which was presented to WCPFC13 (WCPFC13-2016-15). Table 3 outlines the approach taken in relation to the relevant paragraphs of CMM 2018-01.

Table 3. Evaluation of the relevant paragraphs of CMM 2018-01.

Relevant CMM 2018-01 paragraphs	Evaluation Approach
Principles	
2	F/F_{MSY} is included as a performance indicator.
Area of application	
3 and 10	The area of application does not include archipelagic waters (AW). The evaluation will necessarily be for the WCPO (west of 150°W) rather than the WCPFC Convention Area because of the structure of the assessment model, which does not include catch and effort data from the overlap area. This should not significantly impact the results of the evaluation.
4	No guidance is given regarding level of any AW changes; we assume 2013-2015 average levels of effort will continue.
Harvest strategies and interim objectives	
11	While the measure acts as a bridge to the adoption of a harvest strategy for tropical tuna stocks, for the purpose of this evaluation we have examined where the stock would end up under longer-term application of this measure.
12-14	We use the spawning biomass depletion ratio ($SB/SB_{F=0}$) as a performance indicator, consistent with the limit reference point (LRP) formally adopted by WCPFC ($0.2SB_{F=0}$) for all three tropical tuna stocks, and the interim TRP for skipjack tuna, and relate the longer-term outcome of CMM2018-01 measures (over 30 years) to the average $SB_{2012\text{-}2015}/SB_{F=0,\ 2005\text{-}2014}$.
FAD set management	
16-17	CCMs apply an in-zone/high seas FAD closure of 3 months in 2019 (Jul-Sept). This was modelled as (1+1/8) x average FAD sets in 2013-2015. As a 4-month closure (or equivalent) was in operation over those years, a 3-month closure would allow on average 1/8th more FAD sets than were seen in the remaining 8 months of the year in which FAD sets were allowed. We note this does not take into account the potentially different pattern of fishing by those CCMs that selected FAD set limits in those years, but have assumed that the impact on the number of FAD sets performed was roughly equivalent for those CCMs.

	In addition, the reduction in FAD set numbers due to the specified 2-month additional high seas FAD closure was estimated (5 months in total). The impact of CCMs choosing different two-month pairs for the closure was assumed to be negligible for this evaluation. We have assumed that **high seas FAD sets were not transferred into EEZs, but were removed from the fishery.** We based the number of high seas FAD sets on the recent average sets in the high seas by CCM over 2013-2015 (a 4-month closure), and calculated the impact of removing 1/8th of those FAD sets at the CCM level, noting the exemption for Kiribati, and for Philippines in High Seas Pocket 1. Two options for future conditions were examined: - **Optimistic**: FAD sets were limited through the 3-month FAD closure and additional 2-month high seas closure as calculated above. High seas effort was maintained at 2013-2015 average levels. - **Pessimistic**: FAD sets were limited through the 3-month FAD closure and additional 2-month high seas closure as calculated above. Those CCMs with high seas effort limits were assumed to fish to their day limits, and corresponding additional high seas FAD sets were estimated (see 'purse seine effort control', below), incorporating the closure; 2013-2015 average levels were assumed for other fleets.
18	This paragraph 18 modifies the definition of a FAD in 2019 to exclude "small amounts of plastic or small garbage that do not have a tracking buoy attached". We evaluate the potential impacts of this paragraph on the CMM in a separate section in the main text below, using observer records. This evaluation suggests the impact can be assumed to be negligible.
19-24	No impact on the evaluation is expected due to the use of reduced-entanglement risk FAD designs. In the absence of information, the practical impact on the number of FAD sets made under the CMM through active instrumented buoy limits (para 23) was assumed to be negligible.
Purse seine effort control	
25-30	For simplicity, we did not assume that purse seine total effort in EEZs and high seas would increase as permitted under nominated EEZ effort levels (e.g. Pilling and Harley, 2015). We assumed overall effort (including within archipelagic waters) would remain at 2013-2015 effort levels (with the exception of the high seas effort limits, below). This assumption means that we do not expect EEZs where purse seine effort has been less than 1500 days annually over recent years to attract additional effort. Flag-based high seas effort limits are unchanged from CMM 2016-01. Many limited CCMs would be able to increase their high seas effort marginally under the CMM. This is incorporated within the 'pessimistic' scenario detailed above. Deletion of CMM 2017-01 paragraph 29 is assumed not to affect the overall level of fleet effort, and for the purposes of this analysis the impact was assumed to be negligible.
Longline fishery – bigeye catch limits	
39-44	Longline catch limits are not completely specified for all CCMs. Two options for future conditions were therefore examined: - **Optimistic**: Limited CCMs took their specified catch limit/2,000 mt catch limit, or their 2013-2015 average catch level whichever was <u>lower</u>, other CCMs took their 2013-2015 average catch level. - **Pessimistic**: Limited CCMs took their specified catch limit/2,000 mt catch limit, other CCMs took their 2013-2015 average catch level. A 2,000 mt limit is currently applied to US Territories in US domestic legislation, although there have been recent recommendations for this limit to be removed. Here the 2,000 mt limits have been applied under the pessimistic scenario, consistent with the approach taken for other CCMs with a 2,000 mt limit. We have assumed that non-limited fleets (those without limits specified in CMM Attachment 1, or the upper limit of 2,000 mt) will continue to operate at 2013-2015 levels, although those fleets could legitimately increase to any level under the CMM. If this occurs, then the extent of any reduction of longline catch will be over-estimated, or any increase under-estimated. While the one-off transfer of 500 mt of bigeye from Japan to China (Table 3 of CMM 2018-01) will continue for the life of the existing CMM, for the purposes of this long-term evaluation the transfer is not assumed to continue beyond February 2021. For information, this transfer would increase the longline catch scalar of the optimistic scenario only, from 0.98 to 0.99.
Capacity management	
45-49	Not relevant to the evaluation, assuming that total effort and catch measures are adhered to.
Other commercial fisheries	

50-51	There are neither estimates of capacity nor effort for the majority of fisheries in this category; therefore, we assume continuation of 2013-2015 average catch levels.

EVALUATION OF CMM 2018-01 PARAGRAPH 18

Paragraph 18 of CMM 2018-01 specifies that "any set where small amounts of plastic or small garbage that do not have a tracking buoy attached are detected shall not be considered to be a FAD set for the purposes of the FAD closure". As noted in the table above, we evaluated the potential implications of this paragraph for the CMM evaluation, using observer data. While the conclusion is that the paragraph did not have impacts of sufficient magnitude to include within the CMM scenarios, the analysis raised issues that require SC consideration. We therefore detail the approach, results and issues raised here.

We examined historical observer records over the period March 2010 to June 2019 where fishing activities related specifically to associated sets (which under paragraph 18 would then be considered 'unassociated' if it met the specified criteria). The aim was to identify the frequency of those events, so that an estimate of the potential occurrence over a 3-month FAD closure period could be calculated.

Using the observer comment section of reports, we searched for activities leading up to a set (activity ID #8 – investigate free school; #9 – investigate floating object/log) where specific keywords were included within the observer comment section: 'garbage'; 'flotsam'; 'debris'; 'detritus'; 'branch'; 'rubbish'; 'paper'; 'pollution'; 'bag'; 'litter'; 'chopstick'; 'plastic', 'net', 'wrapper' and 'waste'. Where these activities were followed by an associated set by that vessel (on log or drifting FAD) within 90 minutes of the investigation activity, those activities were assumed to relate to that subsequent set. Under this analysis, those sets would be considered non-FAD sets under paragraph 18[1]. Natural logs did not fall under the paragraph 18 definition and were excluded. All objects where an observer noted an attached buoy were also excluded.

The analysis requires interpretation of the wording of observer notes. For example 'debris' was noted frequently by observers, but could be related to logs/natural objects rather than man-made waste. We therefore present the evaluation for two sets of results:

1. where only those records that specified 'plastic', 'rubbish', 'bag', 'net', 'food wrappers' and 'garbage' were included (these were the specific keywords used by observers over this period that were identified within the evaluation); and
2. where 'debris' was assumed to relate to objects that would fall within the paragraph 18 definition, in addition to the records specified in (1).

For (1), there were 24 records across the 112-month period over which the observer records were evaluated. This equates to 0.2 sets per month, or 0.6 sets within a 3-month FAD closure that would no longer be counted as a FAD set (i.e. an increase in the purse seine scalar of < 0.001).

For (2), there were 250 records when 'debris' was included within the keywords, equating to 2.2 sets per month or 6.7 sets within a 3-month FAD closure (i.e. an increase in scalar of <0.001).

---

[1] Where notes on investigation activities contained the keywords but the subsequent set was considered unassociated by the observer, it was not included within the current analysis as it would not be subject to the FAD closure given that unassociated set designation.

It is challenging to evaluate the potential impact of paragraph 18 on the performance of CMM 2018-01. While the current calculations imply a negligible impact resulting from this paragraph, we do not know how consistently observers have noted various keywords over the historical period. We have also had to interpret keywords that the observers have used primarily in relation to 'plastic or garbage'. We are unable to identify whether these records relate to 'small amounts'. In turn, there may have been times when the observer may not have seen 'small amounts of garbage', or seen it and not reported it, and continued to record the set type as an unassociated set. Finally, while we have mainly been considering isolated occurrences of 'garbage', the potential for tuna associations with large aggregations of garbage to become more frequent in future, particularly in convergence zones, is a concern.

There is a need to consider how the impacts of this paragraph will ultimately be evaluated following 2019. If the intent of paragraph 18 remains, its evaluation would be aided by a more precise and quantifiable definition. The current description is open to interpretation of:

- what constitutes 'garbage', and
- what is the definition of 'small', given it is a relative term used in the CMM without any defined baseline.

Improved precision of the definition is needed to help observers collect consistent and appropriate information to allow the impact of paragraph 18 to be judged.

However, while the impact on this CMM evaluation is assumed to be negligible, any increase in the number of 'FAD sets' due to this paragraph will 'result in increased catches of bigeye and small yellowfin tuna' (paragraph 18).

ESTIMATION OF SCALARS FOR PURSE SEINE ASSOCIATED EFFORT AND LONGLINE CATCH

The interpretation of the CMM provisions detailed within Table 3 define future levels of purse seine associated effort and longline catch for each scenario ('optimistic' and 'pessimistic'). Resulting scalars (Table 4) are calculated relative to 2013-2015 average fishing levels[2], and represent aggregate scalars across all CCMs.

Table 4. Scalars for purse seine effort and longline bigeye catch under alternative CMM 2018-01 scenarios, relative to 2013-2015 average conditions.

	Purse Seine	Longline[3]
Optimistic	1.11	0.98
Pessimistic	1.12	1.35

For purse seine, as noted, overall effort was assumed to remain constant at 2013-15 average levels. Therefore, where future scenarios assumed that purse seine FAD (associated) set effort increased, purse seine free school set effort was reduced to maintain constant overall effort. This assumption was applied for all three stocks.

While longline skipjack catch is negligible, assumptions must be made on the impact of longline bigeye catch multipliers on resulting yellowfin catch levels for the evaluation. The

---

[2] The tables used to estimate these values are presented in Appendix 1 and are based upon data in WCPFC15-2018-IP06.

[3] If the assumption was made that all CCMs with longline limits took those limits, but that all other fleets caught at the 2013-2015 average catch level, the resulting longline scalar was 1.11 (see Appendix 1). This additional level was not analysed here, but potential outcomes can be inferred from the analysed scenarios.

assumption was made that changes in bigeye catch estimated under each scenario also applied to future yellowfin tuna catch levels (i.e. a 1:1 relationship was assumed between changes in bigeye catch and yellowfin catch). For example, under the 'pessimistic' scenario, yellowfin longline catches were increased by 35%.

3. EVALUATION OF THE POTENTIAL EFFECTIVENESS OF THE MEASURE

We use the purse seine associated effort and longline catch scalars estimated in Step 1 within projection analyses to evaluate the outcomes in relation to the stated objectives of the CMM regarding each tropical tuna stock. The main indicators used are:

- the spawning biomass at the end of the 30 year projection in relation to the average unfished level ($SB_{2045}/SB_{F=0}$)[4] compared to both the agreed limit reference point of 0.2 $SB_{F=0}$, $SB_{2012\text{-}2015}/SB_{F=0}$, and skipjack interim TRP; and
- the median fishing mortality at the end of the projection period (2041-2044) in relation to the fishing mortality at maximum sustainable yield (F/F_{MSY}) and to the estimated level $F_{2011\text{-}2014}/F_{MSY}$.

Additional indicators requested by SC14 are also calculated.

Analysis of the impact of potential future purse seine associated effort and longline catch is conducted using the full uncertainty framework approach as endorsed by SC:

- Projections are conducted from each assessment model within the uncertainty grid selected by SC for management advice for each stock.
- For each model, 100 stochastic projections, which incorporate future recruitments randomly sampled from historical deviates, are performed for the estimated purse seine associated effort and longline catch provisions of CMM 2018-01 (scalars estimated in Step 1, applied to 2013-2015 average fishing conditions). The outputs of the projections ($SB_{2045}/SB_{F=0}$ and F/F_{MSY}) are combined across the relevant uncertainty grid.
- For bigeye tuna, two scenarios for future recruitment in the projection period were examined:
    - Future recruitment was determined by randomly sampling from ONLY the 2005-2014 recruitment deviations from the stock-recruitment relationship estimated in each assessment model, consistent with previous WCPFC SC decisions for bigeye tuna. This effectively assumes that the above-average recruitment conditions of the past 10 years, in particular those in the most recent years, will continue into the future.
    - As requested by SC12, a sensitivity analysis assuming relatively more pessimistic long-term recruitment patterns (sampled from 1962-2014) continue into the future.
- For yellowfin and skipjack tuna, future recruitment in the projection period was based upon long-term recruitment patterns (sampled from 1962-2014 and 1982-2015, respectively).

---

[4] $SB_{F=0}$ 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. spawning biomass in future year *y* was related to the spawning biomass in the absence of fishing averaged over the period *y*-10 to *y*-1 (e.g. $SB_{2045}/SB_{F=0,\ 2035\text{-}2044}$).

RESULTS

Results are described by stock.

Bigeye tuna

Table 5 summarises the median values of $SB/SB_{F=0}$ and F/F_{MSY} achieved in the long-term, along with the potential risk of breaching the limit reference point (LRP) and exceeding F_{MSY}, under each of the future fishing and recruitment combinations. Figure 1 presents the corresponding distributions of long-term $SB/SB_{F=0}$ and Figure 2 those for F/F_{MSY}. At the request of SC14, Table 6 provides equivalent information at different time periods within the projection, while Figure 3 presents the overall spawning biomass trajectories of the projections.

Potential outcomes under 2013-15 average and CMM scenario conditions were strongly influenced by the assumed future recruitment levels.

Under the assumption that recent positive recruitments will continue into the future, spawning biomass relative to unfished levels is predicted to increase from recent levels under all examined future scenarios by 0-18% ($SB_{2045}/SB_{F=0}$ ranges from 0.36 to 0.42; Table 5, Figure 1). There is a 0 to 5% risk of future spawning biomass falling below the LRP. Fishing mortality falls slightly under both the 2013-15 average and optimistic scenarios, assuming recent recruitment. However, fishing mortality increases under the pessimistic scenario, but remains below F_{MSY} (30% risk of $F > F_{MSY}$[5]; Table 5, Figure 2).

Under the assumption that less positive long-term recruitments are experienced in the future, spawning biomass relative to unfished levels will decline under all scenarios ($SB_{2045}/SB_{F=0}$ ranges from 0.25 to 0.30). The risk of spawning biomass falling below the LRP increases to between 17% and 32% (Table 5). In all fishing scenarios, fishing mortality increases relative to recent levels (by 109-138%) and is well above F_{MSY}. Risk of fishing mortality exceeding F_{MSY} ranges from 93% to 98%.

Skipjack tuna

Results for skipjack, based upon the 2016 assessment model, are consistent across the different CMM 2018-01 scenarios, as overall purse seine effort is assumed to remain constant at 2013-15 average levels within the analysis, and the impact of longline fisheries is negligible (Table 7, Figure 4, Figure 5). Under 'long-term' recruitment, the skipjack stock is projected to stabilise at 47% $SB/SB_{F=0}$, slightly below the TRP, and F/F_{MSY} to remain relatively stable (a 1-3% increase compared to recent assessed levels). Small differences between CMM scenarios result from the relative impact of free school and associated sets on skipjack tuna; there is a small negative impact on skipjack status where there is an increased proportion of associated sets, as those sets tend to catch smaller skipjack tuna (see Hampton and Pilling, 2015).

Yellowfin tuna

For yellowfin tuna, results under the 2013-15 average and 'optimistic' scenarios are comparable, with the stock stabilising at 33% $SB/SB_{F=0}$ (a 1% decrease from recent assessed levels), F/F_{MSY} falling to 0.68 (a 7-8% reduction), and a 7% risk of falling below the LRP (Table 7, Figure 6, Figure 7. Again, as overall purse seine effort is assumed to remain

---

[5] Future MSY levels are influenced by changes in the gear-specific future effort and catch defined under the optimistic and pessimistic scenarios.

constant, differences between these two CMM scenarios largely result from the small relative impact of increased associated set proportions on yellowfin tuna (see Hampton and Pilling, 2014), which are comparable to those seen for skipjack, offset by the small reduction in longline catch. The pessimistic scenario, which implies a 35% increase in longline yellowfin catch, has a more notable impact, with yellowfin biomass falling to 30% $SB/SB_{F=0}$ (an 8% reduction from recent levels), F/F_{MSY} remaining stable at 0.73 F/F_{MSY} and a 16% risk of breaching the adopted limit reference point. It should be noted that 'other fisheries', which have a notable impact on yellowfin stock status, are assumed to remain constant at 2013-15 average levels within this analysis.

3. DISCUSSION

We have evaluated CMM 2018-01 using stochastic projections (incorporating variation in future recruitment), across the SC-agreed assessment grids as used for advice. This evaluation provides an indication of whether the CMM as it currently stands will achieve the objective of paragraphs 12 to 14 in the long-term, to allow "the Commission at its 2019 annual session [to] review and revise the aims set out in paragraphs 12 to 14 in light of advice from the Scientific Committee" (CMM paragraph 15).

The potential long-term performance of CMM 2018-01 for bigeye tuna is strongly influenced by assumed future recruitment levels. If recent positive recruitments continue into the future, all scenarios examined achieve the aims of the CMM, in that spawning biomass is projected to increase relative to recent levels, and fishing mortality is projected to decline (the exception to the latter being the pessimistic CMM scenario). If less optimistic longer-term recruitments continue into the future, spawning biomass depletion worsens relative to recent levels under all scenarios, and the future risk of spawning biomass falling below the LRP increases to 17-32%, dependent on the scenario. In turn, all three future fishing scenarios imply notable increases in fishing mortality under those recruitment conditions, to median levels well above F_{MSY}.

Results for skipjack were consistent across the different CMM 2018-01 scenarios, as overall purse seine effort was assumed to remain constant at 2013-15 average levels, and the impact of any change in proportional longline catch is negligible. Under 2013-15 average levels and 'long-term' recruitment, the skipjack stock is projected to stabilise at 47% $SB/SB_{F=0}$, slightly below the TRP, and F/F_{MSY} to remain relatively stable (a 1-3% increase compared to recent assessed levels). There was no risk of breaching the adopted limit reference point.

For yellowfin tuna, results under the 2013-15 average and 'optimistic' scenarios are comparable, with the stock stabilising at 33% $SB/SB_{F=0}$ (a 1% decrease from recent assessed levels) and F/F_{MSY} reducing to 0.68 (a 7-8% reduction). The pessimistic scenario, which implies a 35% increase in longline yellowfin catch, had a greater impact, with yellowfin biomass falling to 30% $SB/SB_{F=0}$ (an 8% reduction from recent levels), F/F_{MSY} remaining stable at 0.73 F/F_{MSY}, and the risk of breaching the adopted limit reference point increasing to 16%.

As in previous CMM evaluations (e.g. SPC, 2018), it is not possible to define precisely what levels of future fishing will result from CMM provisions. Estimating future levels for the purse seine fishery requires the assumption that the number of future FAD sets performed in a year is proportional to the additional month of FAD fishing allowed, and that the choice of paired high seas FAD closure months will not affect the assumption of a proportional decrease in high seas FAD sets. We also assume that the potential increase in purse seine fishing effort permissible under recently nominated EEZ effort levels will not occur, under the logic that we do not expect EEZs where purse seine effort has been less than 1500 days annually over recent years to attract additional effort. However, those increases are theoretically permitted under the CMM. For the longline fishery, future fishing levels will depend on the degree to which those fleets recently under-fishing their defined catch limits continue to do so, and the future levels of fishing undertaken by currently unlimited fleets.

4. ACKNOWLEDGEMENTS

We would like to thank Steven Hare and Steve Brouwer for helpful comments on an earlier version of this paper.

5. REFERENCES

Hampton, J. and Pilling, G. (2014). Relative impacts of FAD and free-school purse seine fishing on yellowfin tuna stock status. WCPFC-SC10-2014/MI-WP-05.

Hampton, J. and Pilling, G. (2015). Relative impacts of FAD and free-school purse seine fishing on skipjack tuna stock status. WCPFC-SC11-2015/MI-WP-05.

McKechnie, S., Hampton, J., Pilling, G.M. and Davies, N. (2016). Stock assessment of skipjack tuna in the western and central Pacific Ocean. WCPFC-SC12-2016/SA-WP-04.

Pilling, G. and Harley, S. (2015). Estimating potential tropical purse seine fleet sizes given existing effort limits and candidate target stock levels. WCPFC-SC11-2015/ MI-WP-10.

Pilling, G, Vincent, M., Williams, P and Hampton, J. (2018). Evaluation of CMM 2017-01 for bigeye tuna. WCPFC-SC14-2018/ MI-WP-08.

SPC (2018). Evaluation of CMM 2017-01 for bigeye tuna with additional evaluations for skipjack and yellowfin tuna. WCPFC15-2018-12_rev2.

Tremblay-Boyer, L., McKechnie, S., Pilling, G. and Hampton, J. (2017). Stock assessment of yellowfin tuna in the western and central Pacific Ocean. 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.

6. TABLES

Table 5. Median values of reference point levels (adopted limit reference point (LRP) of 20% $SB_{F=0}$; F_{MSY}) and risks[1] of breaching reference points from the 2018 bigeye stock assessment incorporating 'updated new growth' models only, and in 2045 under the three future harvest scenarios (2013-2015 average fishing levels, optimistic, and pessimistic) and alternative recruitment hypotheses.

Scenario		**Scalars relative to 2013-2015**		**Median $SB_{2045}/SB_{F=0}$**	**Median $SB_{2045}/SB_{F=0}$ v $SB_{2012-15}/SB_{F=0}$**	**Median $F_{2041-2044}/F_{MSY}$**	**Median $F_{2041-2044}/F_{MSY}$ v $F_{2011-14}/F_{MSY}$**	**Risk**	
Recruitment	**Fishing level**	**Purse seine**	**Longline**					**SB_{2045} < LRP**	**F>F_{MSY}**
Bigeye assessment ('recent' levels)				0.36	-	0.77	-	0%	6%
Recent	2013-2015 avg	1	1	0.42	1.18	0.73	0.95	0%	11%
	Optimistic	1.11	0.98	0.41	1.15	0.75	0.98	0%	13%
	Pessimistic	1.12	1.35	0.36	1.00	0.89	1.15	5%	30%
Long-term	2013-15 avg	1	1	0.30	0.84	1.60	2.09	17%	93%
	Optimistic	1.11	0.98	0.29	0.82	1.64	2.13	18%	94%
	Pessimistic	1.12	1.35	0.25	0.70	1.84	2.38	32%	98%

[1] note risk within the stock assessment is calculated as the (weighted) number of models falling below the LRP (X / 36 models). Risk under a projection scenario is the number of projections across the grid that fall below the LRP (X / 3600 (36 models x 100 projections)).

Table 6. Median $SB/SB_{F=0}$ values and associated risk of breaching the adopted limit reference point (LRP) of 20% $SB_{F=0}$ for the bigeye stock in 2020, 2025 and 2045 under the three future harvest scenarios (2013-2015 average fishing levels, optimistic, and pessimistic) and alternative recruitment hypotheses. Note: Only 'Updated new growth' models used.

Scenario		Scalars relative to 2013-2015		Median $SB_{2020}/SB_{F=0}$	Median $SB_{2025}/SB_{F=0}$	Median $SB_{2045}/SB_{F=0}$	Risk SB_{2020} < LRP	Risk SB_{2025} < LRP	Risk SB_{2045} < LRP
Recruitment	**Fishing level**	**Purse seine**	**Longline**						
Recent	2013-2015 avg	1	1	0.42	0.41	0.42	0%	1%	0%
	Optimistic	1.11	0.98	0.41	0.40	0.41	0%	1%	0%
	Pessimistic	1.12	1.35	0.38	0.35	0.36	0%	4%	5%
Long-term	2013-2015 avg	1	1	0.35	0.30	0.30	2%	12%	17%
	Optimistic	1.11	0.98	0.35	0.30	0.29	2%	13%	18%
	Pessimistic	1.12	1.35	0.32	0.26	0.25	7%	26%	32%

Table 7. Median and relative values of reference points and risks of breaching reference points levels (adopted limit reference point (LRP) of 20% $SB_{F=0}$; F_{MSY}) in 2045 from the 2016 skipjack and 2017 yellowfin stock assessments, under the three future harvest scenarios (2013-2015 average fishing levels, optimistic, and pessimistic).

Stock	Fishing level	Scalars relative to 2013-2015		Median $SB_{2045}/SB_{F=0}$	Median $SB_{2045}/SB_{F=0}$ v $SB_{2012-15}/SB_{F=0}$	Median $F_{2041-2044}/F_{MSY}$	Median $F_{2041-2044}/F_{MSY}$ v $F_{2011-14}/F_{MSY}$	Risk	
		Purse seine	**Longline**					**SB_{2045} < LRP**	**$F>F_{MSY}$**
Skipjack tuna	2013-2015 avg	1	1	0.47	NA[1]	0.49	1.01	0%	0%
	Optimistic	1.11	0.98	0.47	NA[1]	0.49	1.02	0%	0%
	Pessimistic	1.12	1.35	0.47	NA[1]	0.49	1.03	0%	0%
Yellowfin tuna	2013-2015 avg	1	1	0.33	0.99	0.68	0.92	7%	2%
	Optimistic	1.11	0.98	0.33	0.99	0.68	0.93	7%	2%
	Pessimistic	1.12	1.35	0.30	0.92	0.73	0.99	16%	9%

[1] Stated aim of CMM 2018-01 for skipjack was to maintain the stock on average around the TRP of 50%$SB_{F=0}$ (CMM para 13).

7. FIGURES

Recent recruitments Long-term recruitment

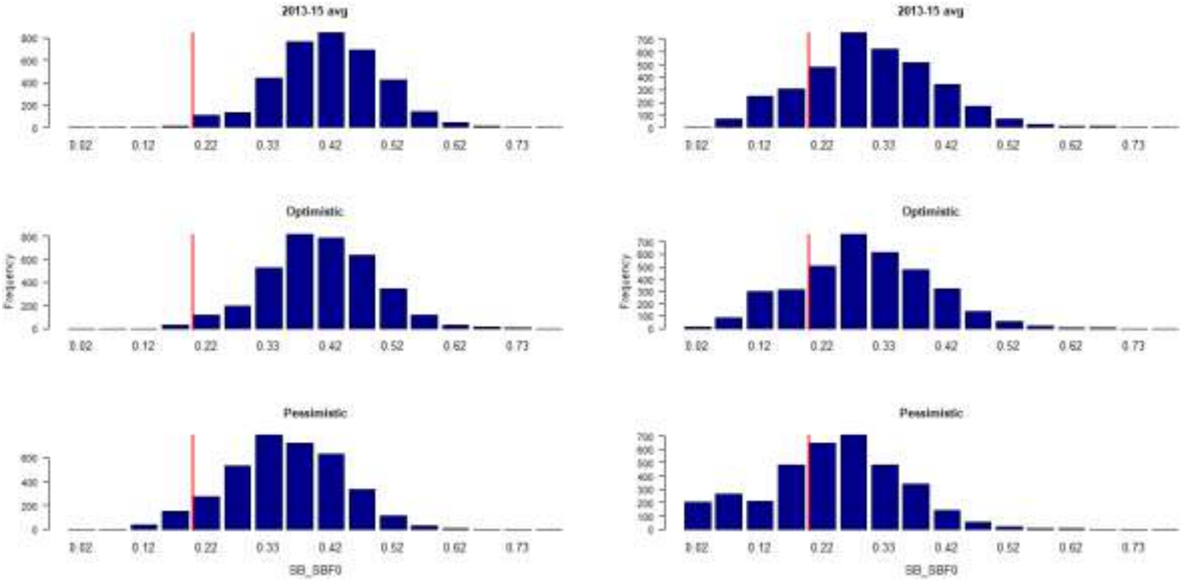

Figure 1. Distribution of $SB_{2045}/SB_{F=0}$ for <u>bigeye</u> tuna assuming recent and long-term recruitment conditions (left and right columns, respectively), under the three future fishing scenarios: 2013-15 avg. (2013-15 average conditions, top row); optimistic conditions (middle row); and pessimistic conditions (bottom row). Projection results from 'updated new growth' models (3,600 projections) only. Red line indicates the LRP ($20\%SB_{F=0}$).

Recent recruitments Long-term recruitment

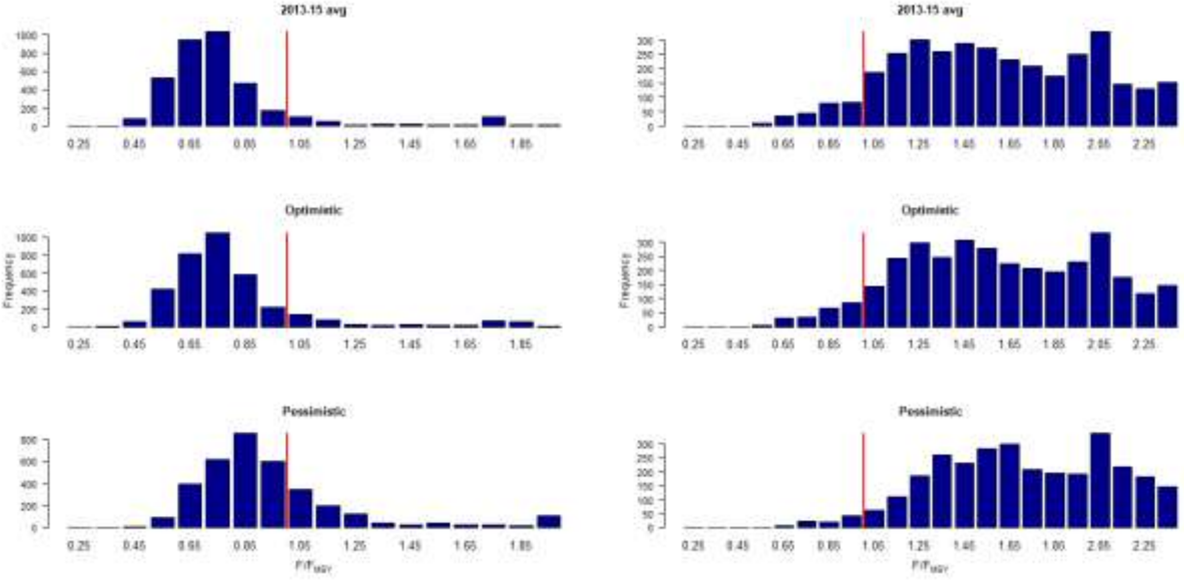

Figure 2. Distribution of F/F_{MSY} for <u>bigeye</u> tuna assuming recent and long-term recruitment conditions (left and right columns, respectively), under the three future fishing scenarios: 2013-15 avg. (2013-15 average conditions, top row); optimistic conditions (middle row); and pessimistic conditions (bottom row). Projection results from 'updated new growth' models (3,600 projections) only. Red line indicates $F = F_{MSY}$.

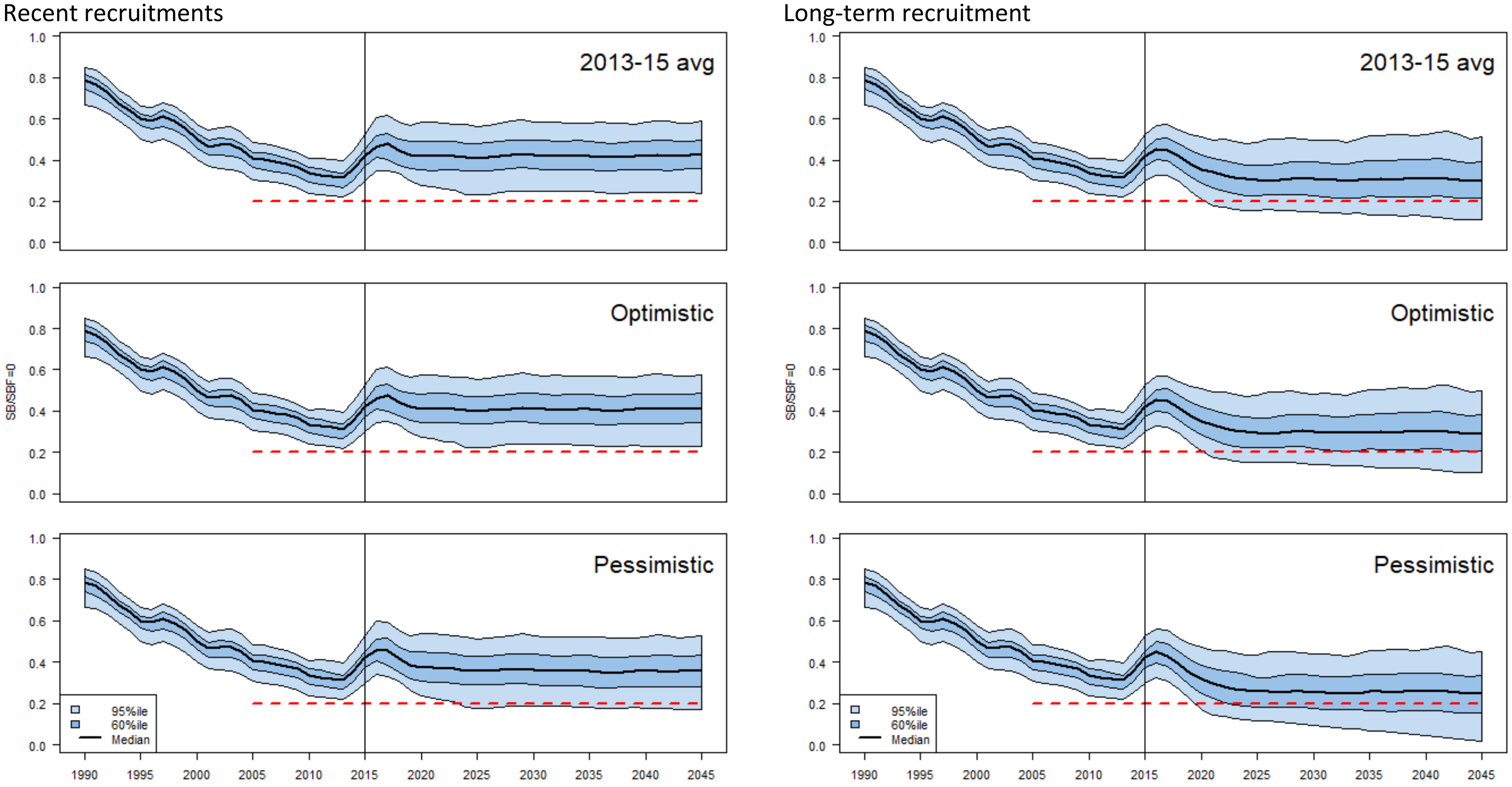

Figure 3. Time series of WCPO bigeye tuna spawning biomass ($SB/SB_{F=0}$) from the uncertainty grid of assessment model runs for the period 1990 to 2015 (the vertical line at 2015 represents the last year of the assessment), and stochastic projection results for the period 2016 to 2045 under the three future fishing scenarios ("2013-15 avg", "Optimistic" and "Pessimistic"; rows). During the projection period (2016-2045) levels of recruitment variability are assumed to match those over the "recent" time period (2005-2014; left panel) or the time period used to estimate the stock-recruitment relationship (1962-2014; right panel). The red dashed line represents the agreed limit reference point.

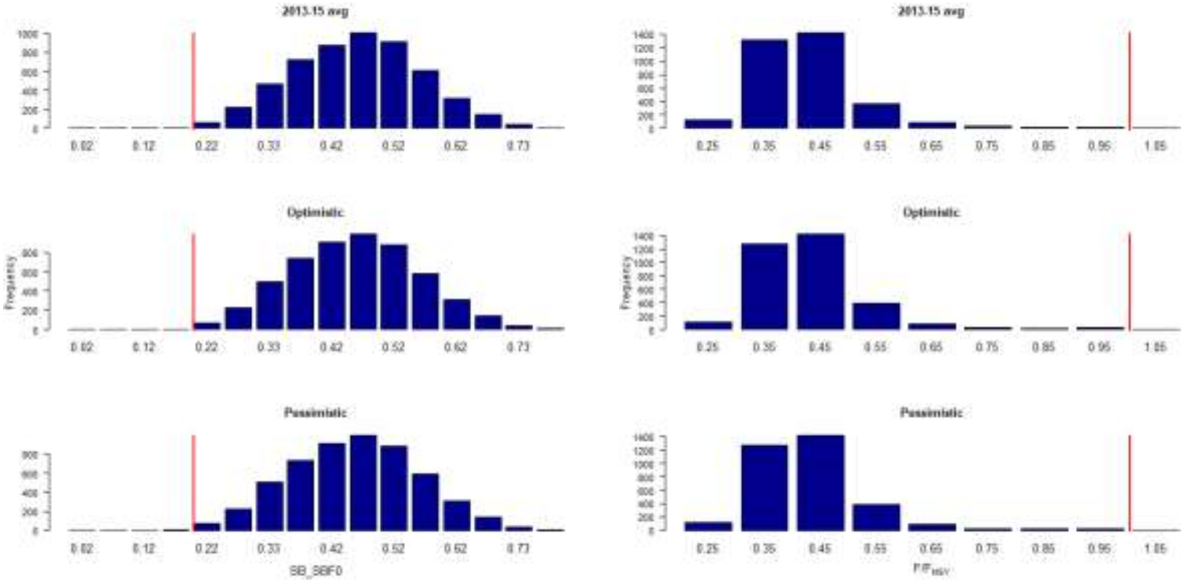

Figure 4. Distribution of $SB_{2045}/SB_{F=0}$ (left column), and F/F_{MSY} for skipjack tuna assuming long-term recruitment conditions, under the three future fishing scenarios: 2013-15 avg. (2013-15 average conditions, top row); optimistic conditions (middle row); and pessimistic conditions (bottom row). Red line indicates the LRP ($20\%SB_{F=0}$) and $F=F_{MSY}$, respectively.

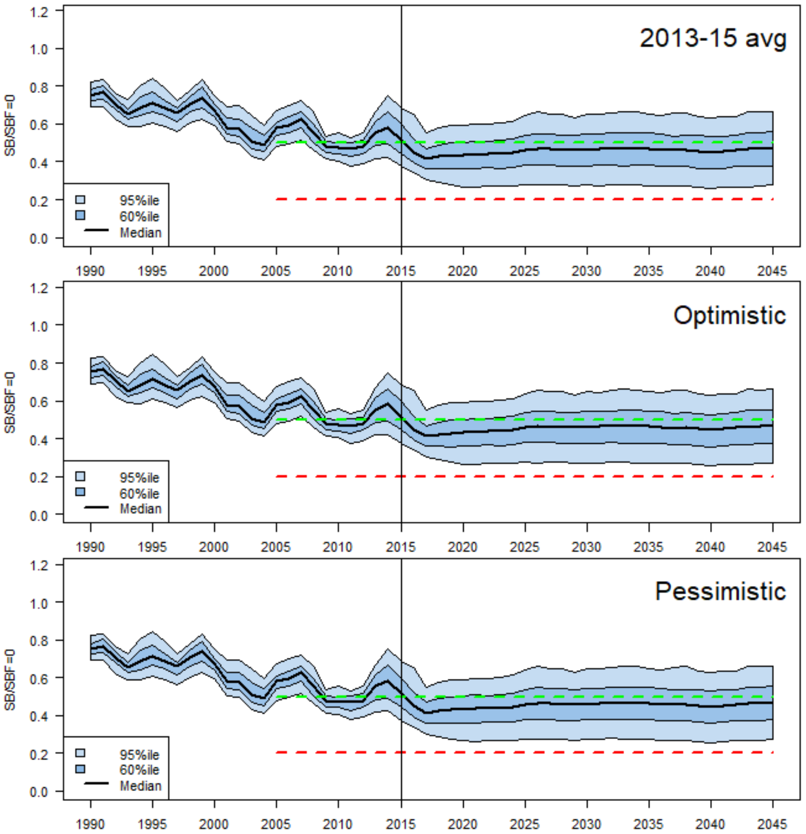

Figure 5. Time series of WCPO skipjack tuna spawning biomass ($SB/SB_{F=0}$) from the uncertainty grid of assessment model runs for the period 1990 to 2015 (the vertical line at 2015 represents the last year of the assessment), and stochastic projection results for the period 2016 to 2045 under the three future fishing scenarios ("2013-15 avg", "Optimistic" and "Pessimistic"; rows). During the projection period (2016-2045) levels of recruitment variability are assumed to match those over the time period used to estimate the stock-recruitment relationship (1982-2015). The red dashed line represents the agreed limit reference point, the green dashed line the interim target reference point.

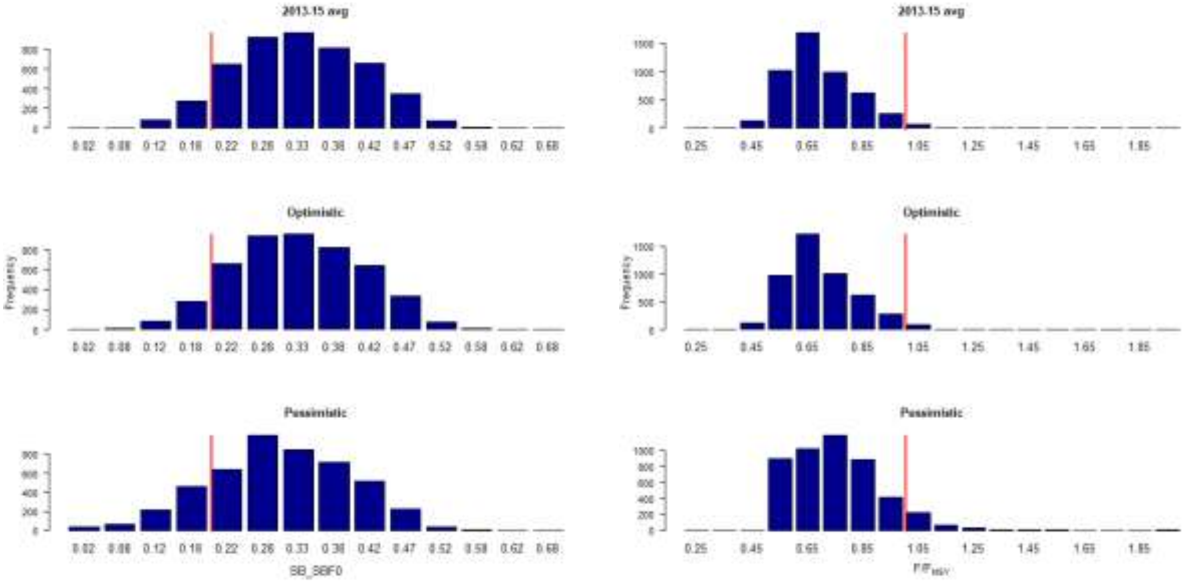

Figure 6. Distribution of $SB_{2045}/SB_{F=0}$ (left column), and F/F_{MSY} for yellowfin tuna assuming long-term recruitment conditions, under the three future fishing scenarios: 2013-15 avg. (2013-15 average conditions, top row); optimistic conditions (middle row); and pessimistic conditions (bottom row). Red line indicates the LRP ($20\%SB_{F=0}$) and $F=F_{MSY}$, respectively.

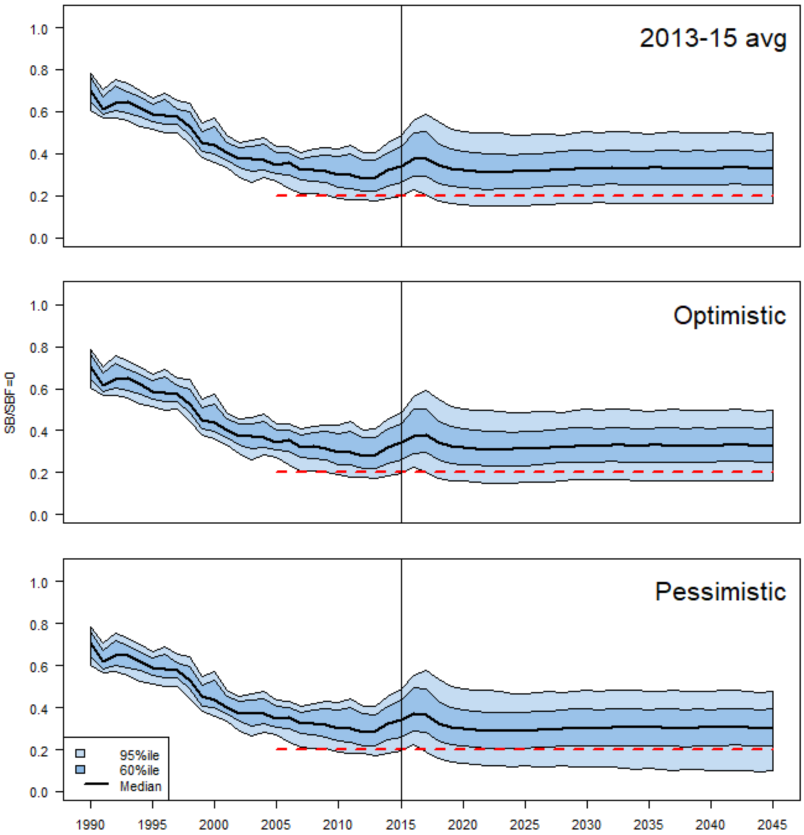

Figure 7. Time series of WCPO yellowfin tuna spawning biomass ($SB/SB_{F=0}$) from the uncertainty grid of assessment model runs for the period 1990 to 2015 (the vertical line at 2015 represents the last year of the assessment), and stochastic projection results for the period 2016 to 2045 under the three future fishing scenarios ("2013-15 avg", "Optimistic" and "Pessimistic"; rows). During the projection period (2016-2045) levels of recruitment variability are assumed to match those over the time period used to estimate the stock-recruitment relationship (1962-2014). The red dashed line represents the agreed limit reference point.

8. APPENDIX 1. ESTIMATION OF SCENARIOS

Purse seine FAD set numbers assumed for CCMs, and corresponding scalars relative to 2013-2015 average conditions under the two scenarios.

Optimistic PS scenario

	Non-SIDS		SIDS				
	3 mth FAD closure	Additional 2mth high seas removes:	3mth FAD closure	Additional 2mth high seas removes:	Non-SIDS	SIDS	Total
CHINA	1365	0			1365		1365
ECUADOR	285	8			277		277
EL SALVADOR	292	14			279		279
FSM			661	3		658	658
JAPAN	1019	0			1019		1019
KIRIBATI			963	0		963	963
MARSHALL ISLANDS			1285	7		1278	1278
NEW ZEALAND	110	2			107		107
PAPUA NEW GUINEA			1585	7		1578	1578
PHILIPPINES (distant-water)	464	0			464		464
REPUBLIC OF KOREA	1422	4			1418		1418
SOLOMON ISLANDS			128	0		128	128
EU (SPAIN)	477	29			449		449
CHINESE TAIPEI	2591	3			2588		2588
TUVALU			61	0		61	61
USA	3330	59			3271		3271
VANUATU			230	0		230	230
	11355	**119**	**4912**	**17**	**11236**	**4895**	**16131**

Scalar V 2013-15 avg **1.11**

Pessimistic PS scenario: additional high seas sets under specified effort limits

	CMM HS day limit	Avg 13-15HS days	Avg HS sets/day	Additional HS sets
CN	26	15.3	0.04	0.5
ES	403	327.7	0.62	46.7
JP	121	39.3	0.08	6.9
NZ	160	59.3	0.28	28.2
KR	207	146.0	0.20	12.4
TW	95	67.3	0.36	10.0
US	1270	1279.3	0.37	0.0

Additional HS sets **105**

Longline bigeye catch assumed for CCMs, and corresponding scalars relative to 2013-15 average conditions under the two scenarios, plus intermediate analysis of consequences where CCMs limited to 2000 mt take their recent average catch levels.

	Pessimistic		**Optimistic**
CCM	2017 CMM levels if limited, otherwise 2000mt (non sids) or 2013-2015 avg	2017 CMM levels if limited, otherwise 2013-2015 avg	2017 CMM levels or 2013-15 if lower
AMERICAN SAMOA	2,000	421	421
AUSTRALIA	2,000	588	588
BELIZE	2,000	72	72
CHINA	8,224	8,224	8,224
COOK ISLANDS	181	181	181
EU-PORTUGAL	2,000	65	65
EU-SPAIN	-	47	47
FSM	1,377	1,377	1,377
FIJI	1,300	1,300	1,300
FRENCH POLYNESIA	776	776	776
GUAM	2,000	277	277
INDONESIA	5,889	5,889	3,411
JAPAN	18,265	18,265	14,290
KIRIBATI	469	469	469
MARSHALL ISLANDS	27	27	27
NAURU	0	0	0
NEW CALEDONIA	57	57	57
NEW ZEALAND	2,000	118	118
NIUE	0	0	0
NORTHERN MARIANAS	2,000	831	831
PALAU	0	0	0
PAPUA NEW GUINEA	33	33	33
PHILIPPINES	2,000	77	77
REPUBLIC OF KOREA	13,942	13,942	12,095
SAMOA	44	44	44
SENEGAL	2,000	0	0
SOLOMON ISLANDS	2,481	2,481	2,481
TONGA	18	18	18
TUVALU	128	128	128
CHINESE TAIPEI	10,481	10,481	10,017
USA	3,554	3,554	3,554
VANUATU	3,670	3,670	3,670
WALLIS AND FUTUNA	0	0	0
Total	88,916	73,411	64,649
Scalar from 2013-15	**1.35**	**1.11**	**0.98**