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Proposed F-based limit reference points for bigeye, yellowfin, and south Pacific albacore tuna

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Executive Summary

This paper responds to the SC8 request for the development of fishing mortality limit reference points (F LRP) based on spawning potential per recruit ($Fx\%SPR_0$). These are requested for 'Level 2' species (bigeye, yellowfin, and south Pacific albacore tunas) under the "Tiered" approach for limit reference points adopted by WCPFC.

We used the most recent stock assessments – updated with relevant methodological changes – and stochastic projections to find levels of fishing mortality which reduced the stocks down below the spawning biomass limit reference point (SB LRP) ($20\%SB_{F=0,2001\text{-}2010}$) with a probability of either 5 or 10%. We then translated this fishing mortality to give the depletion level "x" in $Fx\%SPR_0$ and thus found the F-based LRP that matched the spawning biomass LRP.

For each stock we repeated this analysis across a range of existing alternative assessment model runs – particularly those with different productivity assumptions (e.g. steepness or growth). We also examined two approaches for defining the spawning biomass LRP as described in SC9-MI-WP-02.

While results for both 5 and 10% risk are provided in the paper, we primarily focus on the 5% results here for simplicity. It can be noted that for a higher risk (e.g. 10%) a higher level of fishing mortality is permissible and the stock is reduced to a lower level on average.

We found that the SB LRP varied across species, among assessment model runs examined for each species, and by the method applied to calculate SB LRP. Assuming the absolute method (ABS) for determining the SB LRP, the SB LRP relative to SB_{MSY} ranged from 0.45-0.70 for yellowfin tuna; from 0.63-0.91 for south Pacific albacore; and 0.62-1.18 for bigeye tuna. Some of the differences could be attributed to recent recruitment deviates, which were mostly negative for yellowfin and south Pacific albacore tuna, but other differences require further examination to identify the cause.

In general, the "x" in $Fx\%SPR_0$ ranged from 0.2-0.3 across the three species (yellowfin ranging from 0.19-0.28 with a mean of 0.23; south Pacific albacore ranging from 0.23-0.31 with a mean of 0.26; and bigeye ranging from 0.25-0.36 with a mean of 0.29). Lower values were often associated with higher assumed steepness values. Overall, $Fx\%SPR_0$ ranged from $0.83F_{MSY}$ (a bigeye run) to $2.30F_{MSY}$ (an albacore run), but most were in excess of F_{MSY}.

Alternatively, when the SRR approach was used to determine the SB LRP, the SB LRP was much closer to SB_{MSY} for bigeye and south Pacific albacore, but still well below SB_{MSY} for yellowfin tuna (range of 0.54-0.71). The $Fx\%SPR_0$ levels were higher than when using the ABS method, indicating lower levels of fishing mortality for the LRP, with many more model runs giving estimates in the range 0.25-0.35.

5% RISK	$\%SPR_0$ (range)		F/F_{MSY} (range)		SB/SB_{MSY} (range)	
SB LRP calculation:	ABS	SRR	ABS	SRR	ABS	SRR
Bigeye	0.26 - 0.36	0.29 - 0.41	0.83 - 1.24	0.82 - 1.09	0.76 - 1.58	0.95 - 1.60
SP Albacore	0.23 - 0.31	0.23 - 0.36	0.83 - 2.30	0.62 - 2.14	0.76 - 1.12	0.78 - 1.29
Yellowfin	0.19 - 0.28	0.19 - 0.31	1.16 - 1.44	1.08 - 1.33	0.64 - 0.90	0.71 - 0.91

In some cases, simply avoiding a limit reference point with a high probability can result in average biomass levels that might be suitable target reference points. However, given the levels of uncertainty included in the projections, avoiding the SB LRP with 95% probability gave expected biomass levels (across model runs) of $0.74SB_{MSY}$ for yellowfin to $1.14SB_{MSY}$ for bigeye tuna which is likely to be lower than practical target reference points that may not meet specified management objectives.

There are several important issues for the SC to consider in terms of these results. The first thing to note is that we did not calculate an F-based LRP that 'should be avoided with high probability', rather we calculated the level of fishing mortality that would result in an 'acceptable' risk of breaching the SB LRP. The second thing to note is that resulting high levels of fishing mortality are unlikely to be breached until the stock is close to breaching the SB LRP, so they are unlikely to act as an early warning system against overcapacity (e.g. it would allow for levels of catch well in excess of MSY at stock levels only slightly above SB_{MSY}). However, this needs to be tested thoroughly within a management strategy evaluation framework with the inclusion of harvest control rules which may themselves limit fishing mortality, but it is possible that there are alternative ways to develop F-based LRPs depending on management goals (e.g. to complement the SB LRP or to act as an early warning of potential overcapacity).

The variation in the $Fx\%SPR_0$ LRP level across species and among models for each species is significant, and there is value in a better understanding of what might be responsible for this. It could relate to variation in current levels of recruitment relative to spawner recruitment predictions (after SC9-MI-WP-02).

Finally, we note that the actual levels of allowable risk will be determined by the Commission.

Introduction

At SC8 it was noted that WCPFC8 adopted a hierarchical approach to identifying the key limit reference points (LRP) for the key target species as follows, where levels are based upon the biological knowledge available for the stock in question (Preece et. al. 2011; Harley et al. 2012):

Level	LRPs	Application
Level 1	F_{MSY} and B_{MSY}	
Level 2	$F_{X\%SPR0}$ and $20\%SB_{current,F=0}$	Bigeye, South Pacific albacore and Yellowfin tuna
Level 3	$20\%SB_{current,F=0}$	Other key target species

The hierarchy of biomass-based LRPs was subsequently adopted at WCPFC9, with further considerations for explicitly defining the SB LRP (time-window and unfished biomass calculations) being discussed at SC9 (SC9-MI-WP-02). For the fishing mortality-based limit reference point (F LRP) ($Fx\%SPR_0$), SC8 requested that, using the most recent stock assessment models for south Pacific albacore, bigeye tuna, and yellowfin tuna, analyses be undertaken to identify the appropriate values of '*X*' (depletion level; Figure 1) for each 'Level 2' species, for consideration at SC9.

This paper:

- highlights the approach used to define candidate fishing mortality-based LRPs;
- compares resulting $x\%SPR_0$ depletion levels, fishing mortality and spawning biomass indicators across a set of bigeye, south Pacific albacore, and yellowfin assessment models and two options for calculating unfished spawning biomass levels; and
- identifies key considerations for discussion.

Fishing mortality-based LRPs are used to specify a maximum fishing mortality rate to 1) avoid overfishing, 2) avoid fishing the stock down to levels that endanger stock renewal, 3) avoid vessel (effort) overcapacity (noting this may also be the role of a target reference point, dependent on management objectives), and 4) aid in the recovery of excessively depleted stocks. The $Fx\%SPR_0$ LRP is interpreted as the fishing rate that depletes the spawning potential per recruit (SPR) by *x*% of unfished levels (Figure 1), where SPR refers to the lifetime reproductive output of an individual recruit. The UN Fish Stocks Agreement provides some guidance for establishing F LRPs.

> *"The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that the biomass does not fall below a predefined threshold. For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target."*

The performance of LRPs should be explicitly tested in harvest control rule management simulations under realistic management system uncertainties to ensure they perform as intended (e.g., to ensure long-term stock sustainability).

Methods

Approach

A common approach was undertaken for bigeye, south Pacific albacore and yellowfin to identify an appropriate range of limit depletion levels ('X') for the F LRP (Fx%SPR_0). For each species, a set of model runs were evaluated to assess how robust x%SPR_0 was to assessment model uncertainty, thereby giving a range of plausible depletion levels. Projections were used to estimate x%SPR_0 (and corresponding fishing mortality and stock status indicators) for each model by iteratively searching for the scalar that resulted in a 5% and 10% risk of exceeding the SB LRP (20%$SB_{F=0,2001\text{-}2010}$) by the end of the projection period. In this way, we 'matched' the F LRP with the SB LRP by searching for the equilibrium fishing mortality rate that resulted in exceeding 20%$SB_{F=0,2001\text{-}2010}$ according to two candidate risk tolerance levels. Model selection procedures and projection details are outlined further below.

This general approach was agreed to at the pre-assessment workshop held at SPC from 8-12 April 2013 in Noumea (OFP, 2013). Specific recommendations from workshop participants were incorporated into the analysis and included:

- use of stochastic projections in the analysis to characterize recruitment uncertainty;
- select no more than 10 key models from the structural uncertainty grid for each species (bigeye, SP albacore, and yellowfin) that span the productivity and stock status 'space' of the grid;
- assess a 'run21' scenario as a sensitivity for bigeye; and
- evaluate 5% and 10% risk levels for the analyses until manager's advice otherwise.

Selected assessment models were rerun to account for stock recruitment bias-corrections (recent update to MULTIFAN-CL; see WCPFC-sC9/SA-IP-07) and to explore two options for calculating unfished biomass levels (Figure 1). Unfished biomass levels were calculated using 1) absolute recruitment (ABS) or 2) scaled recruitment according to the stock-recruitment relationship (SRR). In the ABS case, it was assumed that recruitment levels for the unfished stock were equivalent to the estimated (exploited) recruitment levels. In the SRR case, it was assumed that recruitment levels for the unfished stock were rescaled estimates [upwards] according to the stock-recruitment relationship (i.e., the estimated recruitment deviates were added to R_0 (the estimated recruitment level at carrying capacity). The absolute value of 20%$SB_{F=0,t1\text{-}t2}$ differed depending on the option used to calculate unfished spawning biomass levels (SC9-MI-WP-02). Accordingly, the F LRPs will also be sensitive to this option as they were iteratively 'tuned' to match the unfished SB LRP. The selection of an approach to calculate unfished biomass levels is a philosophical decision and warrants further discussion at SC9.

Selection of key assessment model runs

A set of assessment model runs were selected from the structural uncertainty grid for bigeye, yellowfin, and south Pacific albacore to assess how robust estimated spawning potential per recruit depletion levels (x%SPR_0) and resulting candidate F LRPs (Fx%SPR_0) were to model uncertainty (Table 1; Figure A1).

- For bigeye tuna, the reference case model and 8 key one-off sensitivity models from the most recent stock assessment (Davies et al. 2011, page 44) were evaluated. The model 'run21' scenario for bigeye – where the stock recruitment curve was estimated from a subset of recent historic recruitment levels (1989-2008) to capture more recent [higher] levels of estimated recruitment – was also evaluated.

- Model runs for yellowfin tuna used in this analysis included the reference case and 5 key one-off sensitivity models (Langley et al. 2011, page 44).
- For SP albacore, a single model ('run93') was chosen from the structural uncertainty grid that best approximated the overall grid median (SC8 provision for management advice for this species) according to several management quantities (MSY, $F_{current}/F_{MSY}$, $SB_{current}/SB_{MSY}$, and $SB_{current}/SB_{current,F=0}$). Nine additional one-off sensitivity models (from 'run93') were identified from the most recent stock assessment (Hoyle et al. 2012; Figure A2).

Projections

Two-hundred stochastic projections[2], selecting future recruitments from the stock-recruitment relationship with a stochastic deviate, to the year 2030 (SP albacore) or 2040 (bigeye and yellowfin) were performed for each assessment model. Projecting out to the year 2030 was sufficient to allow the population to reach some equilibrium with the projected level of fishing. The projection period for bigeye and yellowfin went to 2040 simply as a matter of convenience as time-consumptive hessian calculations for deriving stochastic inputs had previously been completed. Projections were based on 2010 effort conditions (all fisheries) and run in an iterative search sequence to find the scalar associated with having a 5% and 10% risk of exceeding the SB LRP $20\%SB_{F=0,2001-2010}$. We note that the choice of base year is not critical for the projections. Once 'tuned', outputs were calculated as the median (across 200 simulations) from the last year in the projection. Outputs included $x\%SPR_0$, F/F_{MSY}, F_{MSY}, and SB/SB_{MSY} for each model, risk scenario (5 or 10%) and option for calculating unfished biomass levels (ABS or SRR) scenario.

Results

The median $\%SPR_0$ depletion level, and both fishing mortality and spawning biomass indicators are presented in Table 2 (ABS assumption) and Table 3 (SRR assumption) for each model evaluated. 'Tuned' $\%SPR_0$ depletion levels resulted in median spawning biomass estimates generally greater than SB_{MSY} for bigeye, about equal to SB_{MSY} for SP albacore, and less than SB_{MSY} for yellowfin (Figure 2). They also resulted in a median limit fishing mortality rate close to or greater than F_{MSY} for all species (Figure 3). The F LRP and the perceived risk of falling below the F LRP depended on the specified approach for calculating unfished biomass levels (ABS or SRR), so this will be an important consideration for defining limit reference points. In general, tuning to a 5% candidate risk resulted in higher $x\%SPR_0$ and SB/SB_{MSY} levels compared to tuning to a 10% candidate risk. Below we describe the results tuned for a 5% risk, for simplicity.

The SB LRP (relative to SB_{MSY}; see column 1 of Tables 2 and 3) varied across species, among assessment model runs examined for each species, and by the method applied to calculate the SB LRP. The $\%SPR_0$

[2] One-hundred stochastic projections were run for 'tuning' $x\%SPR_0$ under the SRR option for calculating unfished biomass levels due to time limitations. Results were unaffected by this change.

depletion level was moderately sensitive to these in a similar way (coefficients of variation ranged from 0.08 – 0.15; Figure 3). The ABS approach consistently led to a less conservative estimate of stock status relative to the limit reference point and consequently a lower $x\%SPR_0$ limit depletion level, when compared to the SRR approach.

Using the ABS method for determining the SB LRP, the SB LRP relative to SB_{MSY} ranged from 0.45-0.70 for yellowfin tuna; from 0.63-0.91 for south Pacific albacore; and 0.62-1.18 for bigeye tuna. Some of the differences could be attributed to recent recruitment deviates, which were mostly negative for yellowfin and south Pacific albacore tuna, but other differences require further examination. In general, the "x" in $Fx\%SPR_0$ ranged from 0.2-0.3 across the three species (yellowfin ranging from 0.19-0.28 with a mean of 0.23; south Pacific albacore ranging from 0.23-0.31 with a mean of 0.26; and bigeye ranging from 0.25-0.36 with a mean of 0.29). Lower values were often associated with higher assumed steepness values. Overall, $Fx\%SPR_0$ ranged from $0.83F_{MSY}$ (a bigeye run) to $2.30F_{MSY}$ (an albacore run), but most were in excess of F_{MSY}.

Using the SRR method for determining the SB LRP, the SB LRP was much closer to SB_{MSY} for bigeye and south Pacific albacore, but still well below 1.0 for yellowfin tuna (range of 0.55-0.71). The $Fx\%SPR_0$ levels were higher than when using the ABS method, indicating lower levels of fishing mortality for the LRP, with many more model runs giving estimates in the range 0.25-0.35. Tuning the level of risk to this approach for calculating the SB LRP led to lower $Fx\%SPR_0/F_{MSY}$ ratios in comparison to the ABS approach.

Considerations

There are several considerations that warrant discussion at SC9.

1. The approach used to examine F LRPs
    - calculate using an iterative search to 'match' the $Fx\%SPR_0$ with $20\%SB_{F=0,t1-t2}$
    - testing of F LRPs within harvest control rule framework through management strategy simulations

We calculated the spawning potential per recruit depletion level ($x\%SPR_0$) that corresponded to exceeding the SB LRP ($20\%SB_{F=0,2001-2010}$) with a probability of 5% and 10% to examine F LRPs ($Fx\%SPR_0$). We did not calculate an F-based LRP that 'should be avoided with high probability'. The use of $Fx\%SPR_0$ was recommended for Level 2 species by WCPFC9. However, this should be tested thoroughly within a management strategy evaluation framework. It is also noted that there are alternative ways to develop F-based LRPs that achieve specified management objectives (e.g. to complement the SB LRP or to act as an early warning of potential overcapacity). Fishing mortality-based LRPs can be examined and adapted (where necessary) through the use of management strategy simulations, which has been indicated as a best practice approach (Hilborn 2002, Sainsbury 2008). Testing of the overall management framework for WCPFC fisheries, including the performance of operational biomass and fishing mortality-based reference points within a well defined set of harvest control rules, will be instructive for refining F LRPs according to acceptable levels of risk defined by managers.

At a recent international workshop on tuna RFMO reference points and harvest control rules (Anonymous 2013), it was noted that the level of risk of exceeding specified F-based limit reference points may need to be different from those specified for biomass-based limits. The appropriate level of risk tolerance should be discussed further at the next WCPFC Management Objectives Workshop just prior to WCPFC10 in Cairns, Australia.

The approach used here to examine F LRPs resulted in median fishing mortality rates often greater than F_{MSY} (above the level indicated as a minimum standard by UNFSA). In practice, high levels of fishing mortality are unlikely to be breached until the stock is close to breaching the SB LRP, so they are unlikely to act as an early warning system against overcapacity (e.g. it would allow for levels of catch well in excess of MSY at stock levels only slightly above SB_{MSY}). Further, the variation in the $Fx\%SPR_0$ LRP level across species and among models for each species was significant, and there is value in a better understanding of what might be responsible for this.

2. Concurrent decisions and the sensitivity of results
    - time window for calculating depletion based LRPs
    - approaches for describing uncertainty
    - calculation of unfished biomass levels
    - management objectives and the characterization of acceptable risk

We acknowledge that the results presented in this paper will be influenced by other management decisions, preferences for risk tolerance, and biological assumptions associated with stock assessment. Decisions at SC9 on "defining an appropriate time window" (SC9-MI-WP-02) and "approaches for describing uncertainty" (SC9-MI-WP-04) will affect the settings used in these projections. Calculations of $x\%SPR_0$ depletion levels were sensitive to the assumption of an appropriate level of risk tolerance and to the option used to calculate unfished biomass levels. In fact, the approach selected to calculate unfished biomass levels is an important topic for consideration at SC9 as it will influence biomass and fishing mortality LRPs, perceptions of risk in management decisions, and the development of harvest management strategies. In addition, the assumed (or estimated) value of steepness and the deviates around the stock-recruitment relationship (size and temporal trends) will also influence the LRP, as will changes in selectivity.

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Figures and Tables

Table 1. Description of key model runs used to evaluate candidate fishing mortality-based limit reference points for bigeye, south Pacific albacore, and yellowfin tuna. For each species, a reference case model (bolded) and several key one-off sensitivity models were chosen from the structural uncertainty grid. Run 93 for south Pacific albacore was selected as the 'reference model' to best represent the median performance across the grid according to several key management parameters (see Figure A2). Sensitivity to alternative recruitment periods for estimating MSY was also examined for bigeye (the 'run21' scenario).

Species	Model	Description
Bigeye[1] (2011)	**run3j**	**reference case**
	run4	uncorrected PS catch and size frequency
	run5	exclude JP pre-1975 CPUE
	run10	aggregate CPUE
	run11	low weight on some length data
	run12	exclude PTTP
	run13	lower steepness
	run14	higher steepness
	run17	high juvenile mortality
	run21	1989-2008 levels of recruitment to estimate MSY
SP Albacore[2] (2012)	**run93**	**best grid median approximating model**
	run21	lower steepness
	run105	higher natural mortality
	run129	alternative growth2
	run165	higher steepness
	run273	alternative growth3
	run489	alternative growth4
	run525	alternative growth5
	run561	alternative growth6
	run597	alternative growth7
Yellowfin[3] (2011)	**run_ref**	**reference case**
	run_PSold	uncorrected PS catch
	run_JPSize	high weight JP data
	run_dwtSize50	low weight distant water size data
	run_h95	high steepness
	run_h65	low steepness

[1] WCPFC-SC7-2011/SA-WP-02 (Davies et. al. 2011); [2] WCPFC-SC8-2012/SA-WP-04 (Hoyle et al. 2012);

[3] WCPFC-SC7-2011/SA-WP-03 Rev. 1 (Langley et al. 2011)

Table 2. Indicators resulting from each model being iteratively tuned to have 5% and 10% risk levels of falling below the biomass-based limit reference point $20\%SB_{F=0,\ 2001\text{-}2010}$ at the end of the projection period, where unfished levels of spawning biomass were calculated using the ABS approach. The $\%SPR_0$ refers to the median '*X*' (across stochastic simulations) in $Fx\%SPR_0$, signifying the spawning potential per recruit depletion level that is equivalent to the 20% spawning biomass depletion level. Corresponding median levels of fishing mortality and spawning biomass indicators are also reported. The ratio of the SB LRP to SB_{MSY} indicates where the stock would currently be according to estimates from the most recent stock assessments. Note that model runs are species and stock assessment specific.

			Risk = 5%				**Risk = 10%**			
Species	**Model**	**$SBLRP/SB_{MSY}$**	**$\%SPR_0$**	**F/F_{MSY}**	**F_{MSY}**	**SB/SB_{MSY}**	**$\%SPR_0$**	**F/F_{MSY}**	**F_{MSY}**	**SB/SB_{MSY}**
Bigeye[1]	**run3j**	**0.930**	**0.318**	**0.950**	**0.049**	**1.253**	**0.294**	**1.015**	**0.049**	**1.165**
(2011)	run4	0.860	0.277	1.112	0.044	1.138	0.255	1.184	0.044	1.056
	run5	0.772	0.247	1.218	0.044	0.973	0.234	1.265	0.044	0.922
	run10	0.949	0.363	0.874	0.046	1.157	0.250	1.205	0.046	0.749
	run11	0.910	0.284	1.080	0.047	1.192	0.263	1.140	0.047	1.111
	run12	0.936	0.293	1.054	0.043	1.167	0.280	1.100	0.043	1.114
	run13	0.730	0.317	1.240	0.035	0.922	0.300	1.300	0.035	0.863
	run14	1.178	0.285	0.830	0.062	1.582	0.266	0.877	0.061	1.493
	run17	1.003	0.284	1.010	0.052	1.269	0.264	1.070	0.051	1.185
	run21	0.622	0.260	1.163	0.046	0.763	0.240	1.233	0.046	0.701
SP Albacore[2]	**run93**	**0.776**	**0.229**	**1.420**	**0.159**	**0.931**	**0.222**	**1.480**	**0.159**	**0.902**
(2012)	run21	0.626	0.229	2.304	0.220	0.755	0.220	2.427	0.220	0.726
	run105	0.858	0.238	1.190	0.153	1.091	0.220	1.330	0.153	1.016
	run129	0.892	0.314	0.826	0.169	1.109	0.305	0.877	0.169	1.073
	run165	0.626	0.230	2.280	0.126	0.760	0.222	2.395	0.126	0.733
	run273	0.908	0.297	0.964	0.165	1.081	0.288	1.019	0.165	1.047
	run489	0.913	0.305	0.899	0.166	1.116	0.295	0.956	0.166	1.081
	run525	0.898	0.283	1.054	0.163	1.066	0.274	1.115	0.163	1.028
	run561	0.767	0.232	1.374	0.158	0.941	0.219	1.475	0.158	0.889
	run597	0.749	0.227	1.405	0.159	0.930	0.216	1.495	0.159	0.886
Yellowfin[3]	**run_ref**	**0.542**	**0.228**	**1.308**	**0.094**	**0.747**	**0.213**	**1.372**	**0.094**	**0.689**
(2011)	run_PSold	0.517	0.236	1.320	0.097	0.702	0.226	1.363	0.096	0.664
	run_JPSize	0.447	0.244	1.290	0.096	0.753	0.228	1.354	0.095	0.698
	run_dwtSize50	0.701	0.222	1.330	0.093	0.689	0.210	1.380	0.092	0.639
	run_h95	0.560	0.186	1.157	0.120	0.904	0.174	1.205	0.119	0.851
	run_h65	0.516	0.281	1.435	0.075	0.641	0.264	1.509	0.075	0.579

[1] WCPFC-SC7-2011/SA-WP-02 (Davies et. al. 2011); [2] WCPFC-SC8-2012/SA-WP-04 (Hoyle et al. 2012); [3] WCPFC-SC7-2011/SA-WP-03 Rev. 1 (Langley et al. 2011)

Table 3. Indicators resulting from each model being iteratively tuned to have 5% and 10% risk levels of falling below the biomass-based limit reference point $20\%SB_{F=0,\ 2001\text{-}2010}$ at the end of the projection period, where unfished levels of spawning biomass were calculated using the SRR approach. The $\%SPR_0$ refers to the median '*X*' (across stochastic simulations) in $Fx\%SPR_0$, signifying the spawning potential per recruit depletion level that is equivalent to the 20% spawning biomass depletion level. Corresponding median levels of fishing mortality and spawning biomass indicators are also reported. The ratio of the SB LRP to SB_{MSY} indicates where the stock would currently be according to estimates from the most recent stock assessments. Note that model runs are species and stock assessment specific.

			Risk = 5%				**Risk = 10%**			
Species	**Model**	**$SBLRP/SB_{MSY}$**	**$\%SPR_0$**	**F/F_{MSY}**	**F_{MSY}**	**SB/SB_{MSY}**	**$\%SPR_0$**	**F/F_{MSY}**	**F_{MSY}**	**SB/SB_{MSY}**
Bigeye[1]	**run3j**	**1.061**	**0.353**	**0.862**	**0.049**	**1.374**	**0.335**	**0.905**	**0.049**	**1.309**
(2011)	run4	0.952	0.300	1.042	0.044	1.225	0.279	1.105	0.044	1.148
	run5	0.888	0.285	1.086	0.044	1.125	0.267	1.144	0.044	1.053
	run10	1.086	0.295	0.980	0.062	1.455	0.286	1.007	0.062	1.404
	run11	1.027	0.325	0.954	0.048	1.354	0.292	1.048	0.048	1.218
	run12	1.059	0.336	0.936	0.044	1.323	0.325	0.954	0.048	1.354
	run13	0.963	0.405	0.971	0.036	1.222	0.381	1.037	0.036	1.140
	run14	1.209	0.289	0.823	0.062	1.600	0.271	0.866	0.061	1.509
	run17	1.132	0.325	0.904	0.052	1.446	0.299	0.970	0.052	1.336
	run21	0.787	0.324	0.967	0.046	0.954	0.298	1.039	0.046	0.877
SP Albacore[2]	**run93**	**0.793**	**0.235**	**1.364**	**0.159**	**0.944**	**0.226**	**1.442**	**0.159**	**0.907**
(2012)	run21	0.658	0.241	2.144	0.126	0.783	0.231	2.276	0.126	0.750
	run105	0.869	0.245	1.141	0.153	1.123	0.229	1.259	0.153	1.052
	run129	1.039	0.364	0.615	0.169	1.289	0.354	0.652	0.169	1.256
	run165	0.658	0.241	2.144	0.126	0.783	0.230	2.281	0.126	0.749
	run273	1.000	0.334	0.776	0.165	1.213	0.319	0.849	0.165	1.156
	run489	1.019	0.339	0.729	0.166	1.246	0.331	0.766	0.166	1.214
	run525	0.968	0.309	0.907	0.163	1.157	0.293	0.997	0.163	1.097
	run561	0.781	0.234	1.358	0.158	0.944	0.227	1.408	0.158	0.918
	run597	0.760	0.227	1.404	0.159	0.925	0.218	1.479	0.159	0.887
Yellowfin[3]	**run_ref**	**0.589**	**0.236**	**1.272**	**0.095**	**0.785**	**0.222**	**1.332**	**0.094**	**0.727**
(2011)	run_PSold	0.553	0.305	1.082	0.099	0.862	0.282	1.156	0.098	0.789
	run_JPSize	0.537	0.272	1.187	0.097	0.881	0.243	1.291	0.096	0.779
	run_dwtSize50	0.713	0.229	1.302	0.093	0.714	0.217	1.349	0.093	0.671
	run_h95	0.615	0.186	1.156	0.120	0.907	0.175	1.202	0.119	0.855
	run_h65	0.565	0.308	1.325	0.076	0.742	0.293	1.382	0.076	0.691

[1] WCPFC-SC7-2011/SA-WP-02 (Davies et. al. 2011); [2] WCPFC-SC8-2012/SA-WP-04 (Hoyle et al. 2012); [3] WCPFC-SC7-2011/SA-WP-03 Rev. 1 (Langley et al. 2011)

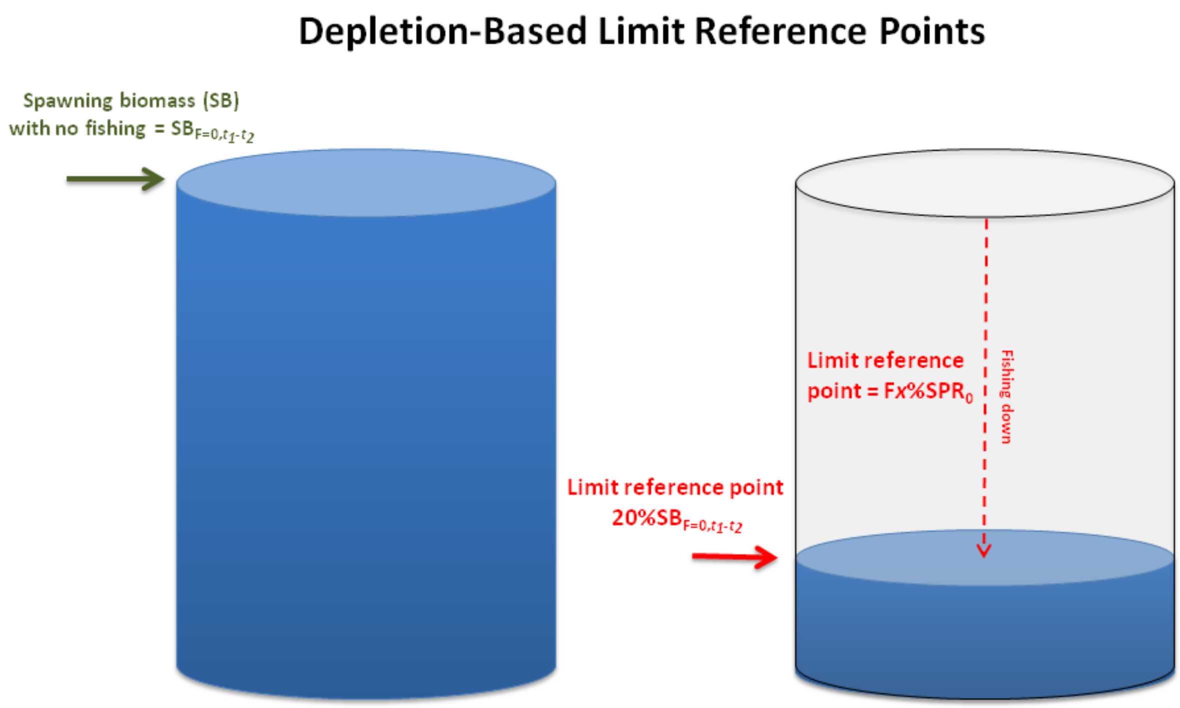

Figure 1. Schematic illustrating the relationship between unfished spawning biomass and both biomass and fishing mortality depletion-based limit reference points.

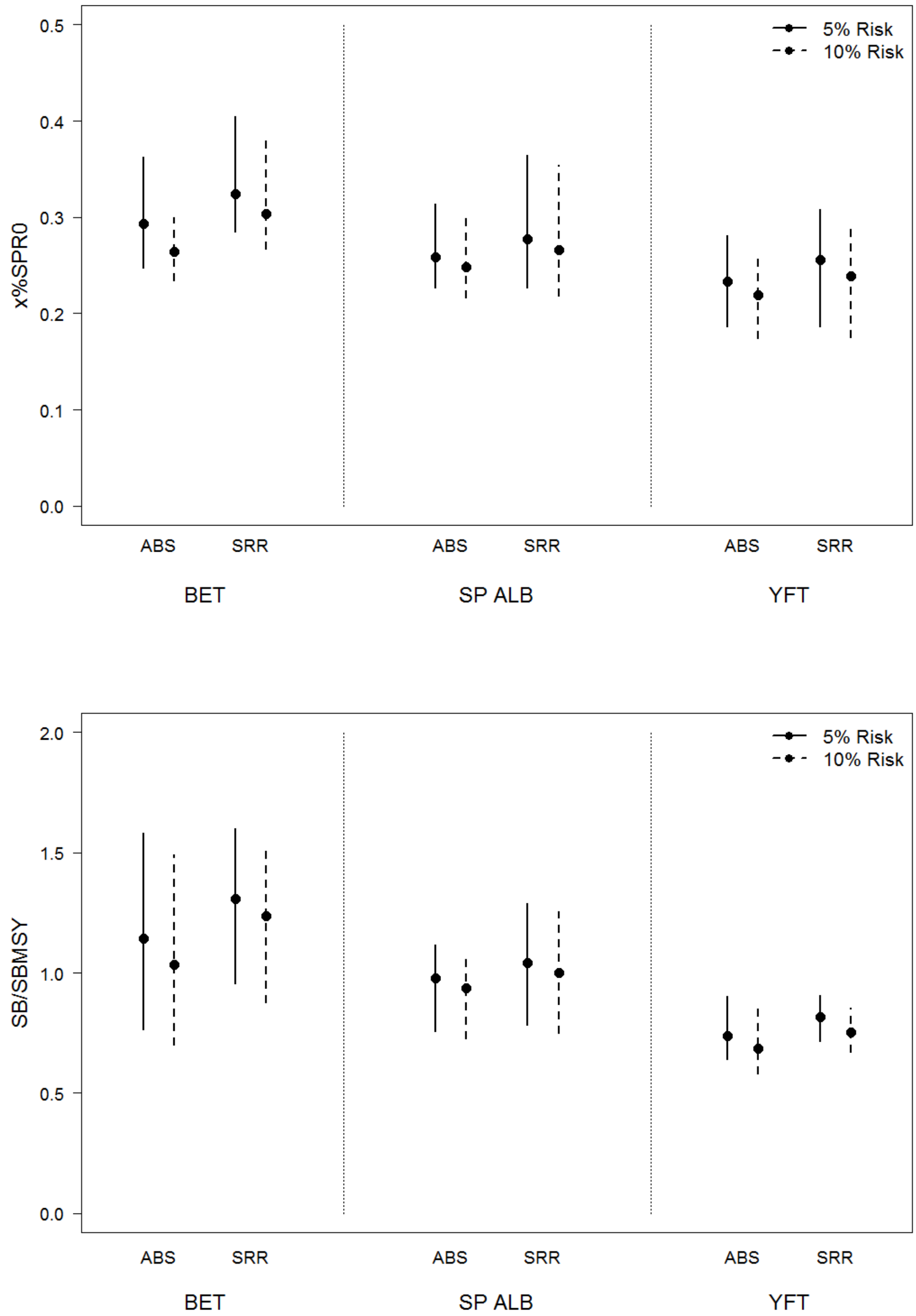

Figure 2. The average (circle) and range (lines) of x%SPR0 (top) and SB/SB_{MSY} (bottom) from models tuned to 5% and 10% risk levels of exceeding the biomass-based limit reference point $20\%SB_{F=0,\ 2001\text{-}2010}$ for the two options of calculating unfished spawning biomass levels (ABS and SRR).

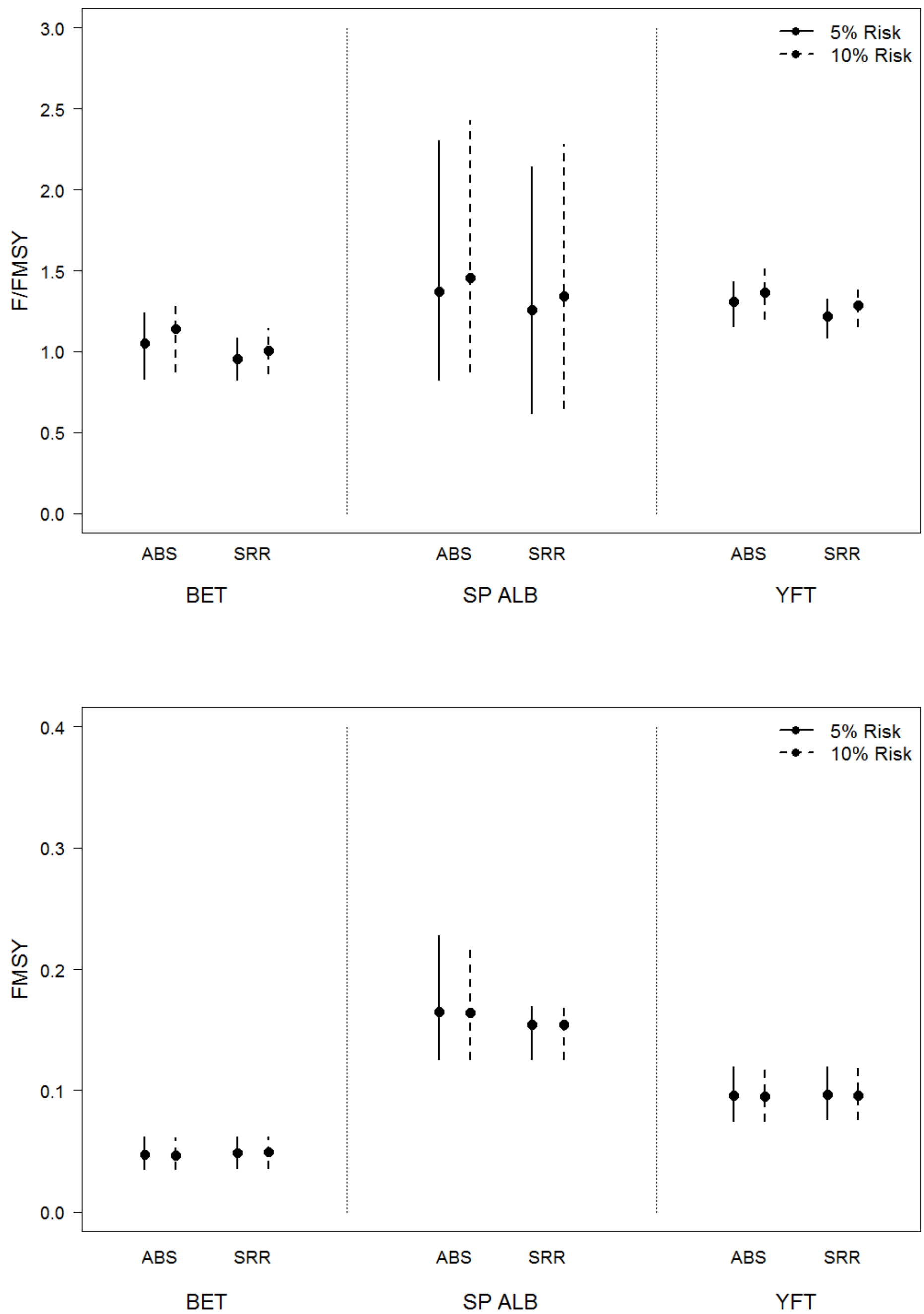

Figure 3. The average (circle) and range (lines) of F/F_{MSY} (top) and F_{MSY} (bottom) from models tuned to 5% and 10% risk levels of exceeding the biomass-based limit reference point $20\%SB_{F=0,\ 2001\text{-}2010}$ for the two options of calculating unfished spawning biomass levels (ABS and SRR).

Appendix

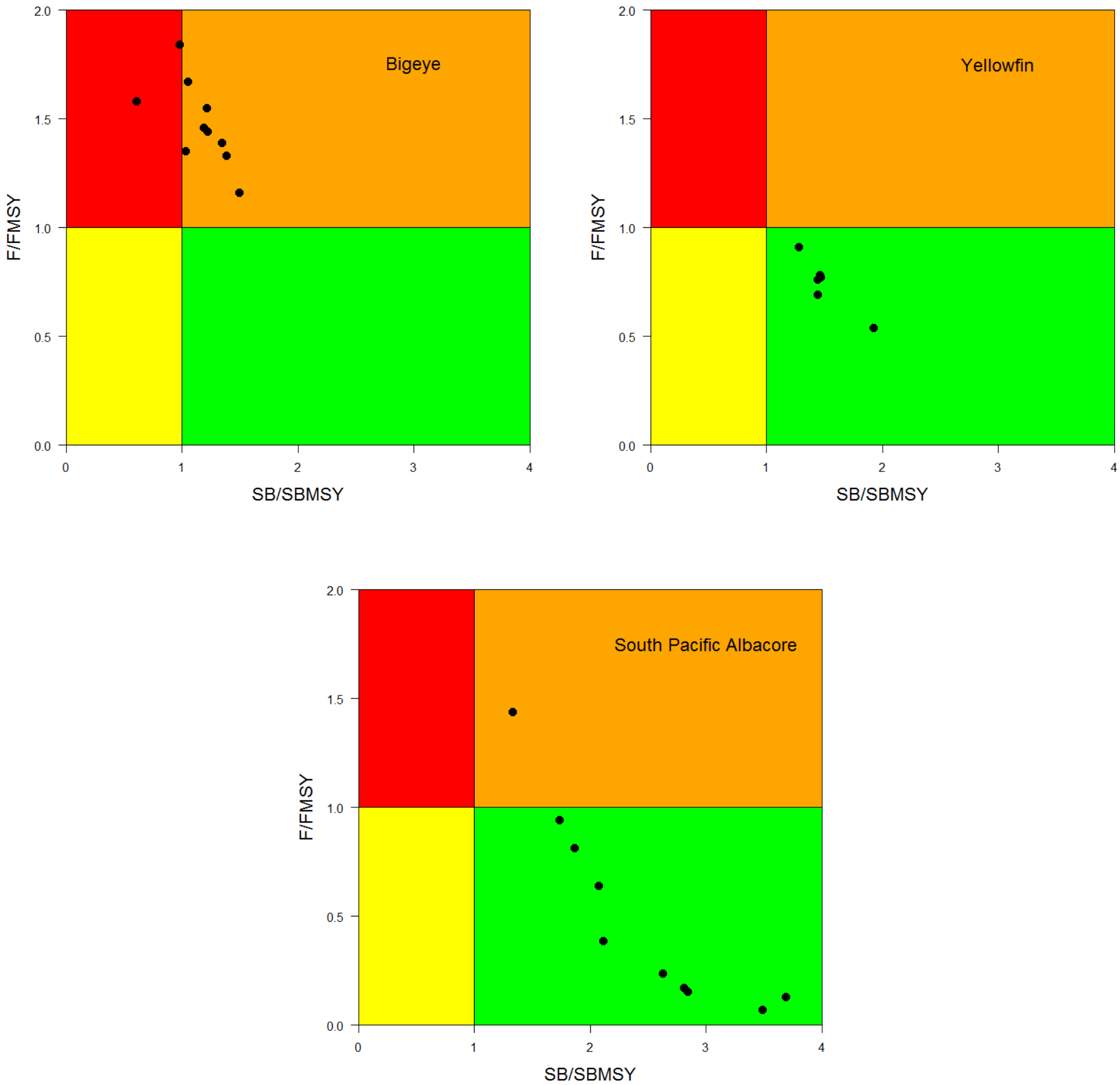

Figure A1. Kobe plot representation of the key model runs (dots) for bigeye (2011), yellowfin (2011), and south Pacific albacore (2012) used in this paper. These models are a subset of the entire grid of models examined in each of these assessments.

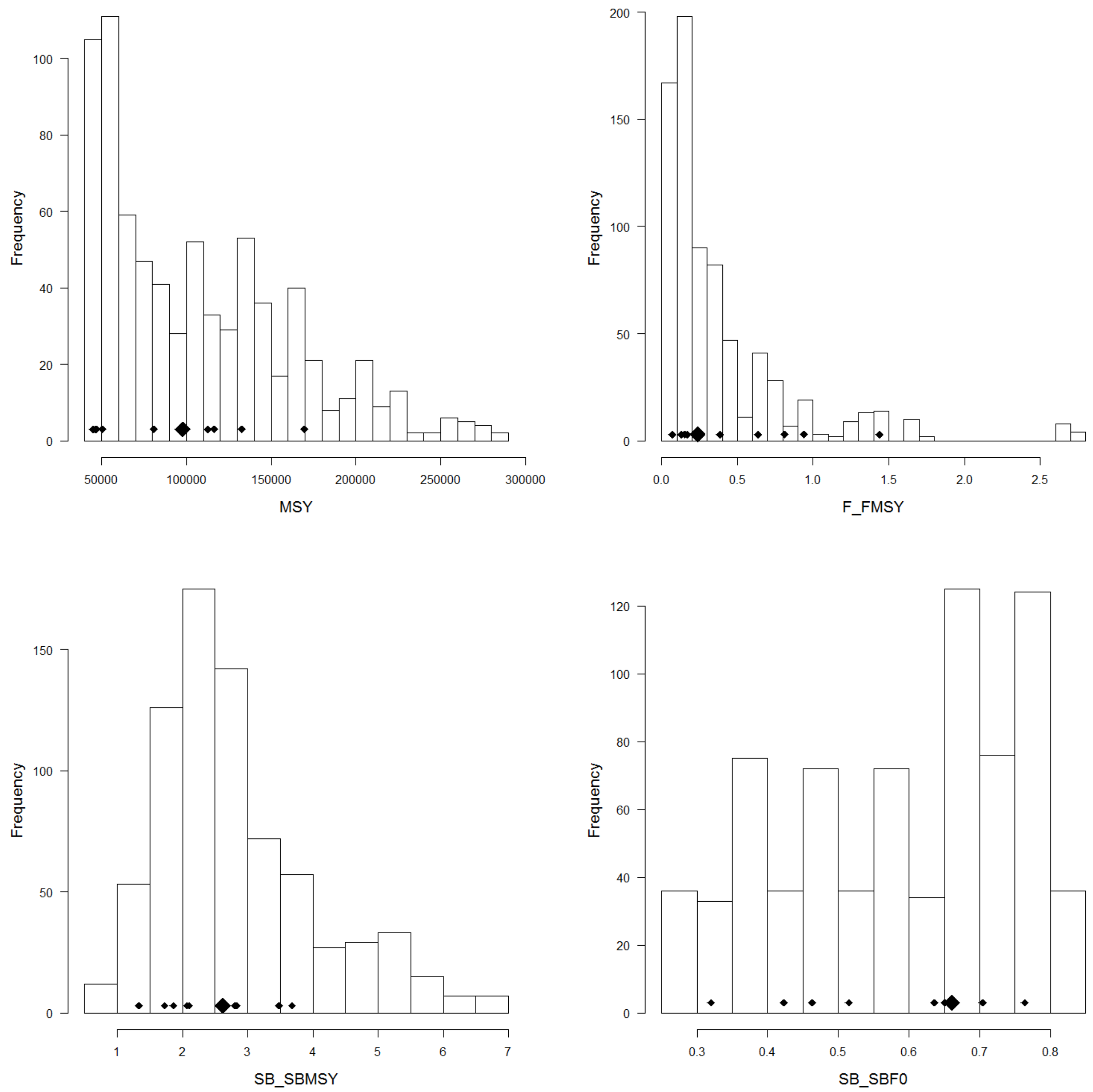

Figure A2. Distributions of key management parameters across the 2012 structural uncertainty grid for south Pacific albacore. Black dots indicate the relative location of the subset of models used in the analysis. Run 93 results have been enlarged.