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Evaluation of risks of exceeding limit reference points for south Pacific albacore, bigeye, yellowfin and skipjack tunas with implications for target reference points: a case study using south Pacific albacore

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Abstract

The aim of this work was to evaluate, as a proof of concept, the implications of alternative levels of permissible risk of falling below the agreed biomass Limit Reference Point for south Pacific albacore (20%$SB_{F=0,\ 2001\text{-}2010}$). The ultimate aim is to provide analyses of the implications of alternative risk levels in a format easily understood by managers, as requested by WCPFC10.

Stochastic projections were performed for south Pacific albacore, capturing structural uncertainty by using eighteen alternative assessment runs from the 2012 south Pacific albacore stock assessment, and future stochasticity in recruitment. Future longline fishing levels were identified so that the proportion of future projections that fell below the Limit Reference Point matched four different levels of risk, being 5%, 10%, 15% and 20% of runs. Resulting median stock conditions were examined.

Results showed that under the level of uncertainty examined, the lower the permissible level of risk of falling below the LRP, the further the stock biomass must be on average from that LRP and the lower the median level of fishing mortality permissible. The calculated median $SB_{2030}/SB_{F=0,2001\text{-}2010}$ levels (0.59 (5% risk) to 0.46 (20% risk)) can be considered as the 'minimum distance' between the LRP and any TRP consistent with a given level of risk. For south Pacific albacore, these levels implied median permissible fishing mortality levels well below F_{MSY}, and spawning biomass levels over double those at SB_{MSY}. They also related to longline vulnerable biomass (CPUE) levels similar to or notably greater than levels estimated for 2010, dependent on the permissible risk level.

The risk and corresponding median levels were strongly impacted by the stock assessment runs selected for the analysis; for south Pacific albacore a key influence on the calculated risk level was the uncertainty in growth. When selecting model runs for use for each tuna species, or when

considering the weighting to be placed on each run, the biological plausibility of those runs should be considered. The number of selected runs also needs to be computationally realistic.

For this analysis we have interpreted 'very low' as a range of risks between 5% and 20%. As noted by SC9, the permissible risk is a decision to be made by managers. However, some discussion on this issue by SC10 would be beneficial.

Particular guidance is sought from SC10 on:

- the proposed approach and any improvements;
- the appropriate assessment runs to be used within evaluations of the tropical tunas (and SPA if required);
- any relative weighting of those runs when calculating risk;
- confirmation that the range of risks presented in this paper is consistent with the recommendation that the level of risk should be 'very low'.

Following the provision of SC10 guidance, the analysis will be repeated for the tropical tuna stocks (skipjack, yellowfin, bigeye) and the consequences of a range of levels of risk of exceeding the LRPs will be presented to WCPFC11 and/or the associated Management Objectives Workshop 3.

Introduction

The UN Fish Stocks Agreement (Anon. 1995) discusses reference points in the context of international fisheries within the annex '*Guidelines for application of precautionary reference points in conservation and management of straddling fish stocks and highly migratory fish stocks*'. Two important concepts provided within that annex are (with emphasis added):

a) Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points.
b) Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low.

At the 9th meeting of the Commission (WCPFC9, 2012; para 269) biomass Limit Reference Points (LRPs) for skipjack, yellowfin, bigeye and south Pacific albacore were agreed, consistent with the hierarchical structure that defines the appropriate LRP for a stock based on the biological knowledge available (WCPFC SC7, 2011). The 9th Scientific Committee meeting further refined approaches to calculate the biomass LRPs (time window, calculation of unfished biomass levels) and discussed the incorporation of uncertainty within stock projections. That meeting also noted that the identification of an acceptable level of risk for the stock to breach an LRP was a management issue (WCPFC SC9, 2013a), and recommended that WCPFC10 identify those levels. However, WCPFC10 requested further clarification of the implications of different levels of risk from the Scientific Committee (WCPFC10, 2013b, para 190).

Under Project 57 (Research related to development of limit reference points (LRP)) analyses have been defined to provide recommendations on the implications of alternative risk levels in a format easily understood by managers. The analyses include:

1. For bigeye, skipjack, south Pacific albacore, and yellowfin tunas: undertake stochastic projections using one or more model runs (as recommended by SC10) at a

range of effort multipliers that give a range of risks (e.g., 5%, 10%, 15%, 20%, etc.) of exceeding the agreed limit reference points. Calculation of risk could be across single or multiple model runs as appropriate.

2. Key quantities from the analysis will include the average biomass (of the projections) that is associated with a given risk of exceeding the limit reference point to emphasize the link between limits, risks, and inform discussions on minimum standards for target reference points.
3. Other quantities from the analyses could include comparison of the biomass levels above to MSY-related quantities, vulnerable biomass (proxy for CPUE), and fishing mortality rates.

We provide a 'proof of concept' progress report on this work for discussion by SC10, using south Pacific albacore as a test case. Following endorsement of an approach by SC10, analyses will be repeated using the latest stock assessments for the three tropical tuna species. Decisions by SC10 are also sought on the potential range of assessment models to be used for each stock, and if necessary the relative weighting of those runs when calculating risk. Advice on the appropriateness of the range of risk levels examined here, consistent with the risk being 'very low', is also sought. Following the provision of SC10 guidance, the consequences of a range of levels of risk of exceeding the LRPs will be presented to WCPFC11 and/or the associated Management Objectives Workshop 3.

Methodology

Stochastic projections were performed for south Pacific albacore, incorporating SC9's recommendations on capturing uncertainty (WCPFC, 2013a). The main assumptions made within the projections were:

- Eighteen alternative assessment runs from the 2012 south Pacific albacore stock assessment uncertainty grid (Hoyle et al., 2012) were used to capture uncertainty in 'current' stock status and biological characteristics (Table 1);
- Variability in future recruitment was modelled around the stock-recruitment relationship; Berger et al., 2013a), with future deviates from the stock-recruitment relationship sampled from those calculated for the whole of the historical assessment time period;
- Catchability (which can have a trend in the historical component of the model) was assumed to remain constant in the projection period at the level estimated in the terminal year of the assessment model.
- Projections were run for twenty years from 2010, but actual effort data were modelled for the most recent years (2011, 2012);
- Scalars for future fishing levels were applied on the level of effort within the longline fishery (rather than catch);
- Levels of activity in the troll fishery were kept constant at 2010 levels;
- Two hundred projections were performed for each assessment run under a given effort scalar.

As noted by Berger et al. (2013a), the approach used to describe uncertainty will influence perceptions of management risks. Therefore an important part of the analysis is the selection of a feasible number of assessment runs that best captured the key uncertainties present within the

South Pacific albacore stock assessment 'uncertainty grid' (Hoyle et al., 2012). For this 'proof of concept' analysis, the decision was taken to concentrate upon the key biological parameters that comprised 3 'axes of uncertainty', being:

- the steepness of the stock recruitment relationship (*h*=0.65, 0.8 or 0.95);
- the natural mortality rate (M=0.3, 0.4 or 0.5); and
- growth (2 alternative growth models used within the stock assessment, representing that used within the base case model run, and an alternative growth model).

The aim was to ensure that all unique combinations of values along each uncertainty axis were included. The two selected growth settings aimed to bracket the range of uncertainty in growth examined, while maintaining a computationally tractable analysis, and resulted in a sub-set of 18 stock assessment runs (Table 1). When examining the results, each run within this sub-set was given equally weighting.

The unfished biomass level ($SB_{F=0,2001-2010}$, the time period recommended by SC9) was calculated within each of the eighteen assessment model runs to ensure consistency with the underlying biological assumptions. The agreed Limit Reference Point was 20% of that unfished level. For each longline effort scalar tested, the risk of the stock falling below that LRP was calculated as the proportion of the 3600 projection runs (200 iterations * 18 assessment runs) where the spawning biomass in 2030 was below the LRP. The scalars used on future longline effort were iteratively adjusted to achieve alternative levels of LRP risk by 2030, where that risk was 5%, 10%, 15% and 20% of runs.

Following identification of future longline fishing levels that led to the specified LRP risk levels, summary metrics related to the median population biomass and consequences for longline CPUE were calculated.

The impact of the selection of assessment runs on the results of the analysis is examined in Appendix 1.

Results

Figure 1 presents the range of future stock trajectories under longline effort scalars that achieved each of the four alternative levels of risk. The resulting 'risk' levels for each of the 18 stock assessment runs, which when combined made up the overall level of risk, is presented in Appendix 2.

Table 2 presents the corresponding median spawning biomass levels in 2030 relative to both the unfished spawning biomass (calculated consistent with the limit reference point) and SB_{MSY}, the median fishing mortality relative to F_{MSY}, and consequences for longline vulnerable biomass (as a proxy for CPUE) in 2030 relative to 2010 levels.

The lower the level of permissible risk, the further away the median $SB_{2030}/SB_{F=0,2001-2010}$ level must be from the Limit Reference Point. For example, if an acceptable LRP risk level of 5% risk (one in 20 chance) is selected, the minimum median adult stock size ($SB_{2030}/SB_{F=0,2001-2010}$) needs to be 28% greater than the minimum median adult stock size permissible if a 20% (one in five chance) risk is allowed. The median level of fishing mortality 'allowable' within a fishery at a 5% risk level is accordingly lower; a 5% level of risk equates to a median F/F_{MSY} of 0.36, while the median at a 20% level of risk is 0.57 F/F_{MSY}.

Given the range of uncertainties examined within the analysis, the median fishing mortality levels consistent with the 'minimum' $SB_{2030}/SB_{F=0,2001\text{-}2010}$ values are well below F_{MSY} levels, and the corresponding spawning biomass levels are over double that at MSY. In turn, the minimum stock levels permissible to achieve the defined levels of risk all equate to an increase in the vulnerable biomass levels in 2030, relative to those calculated in 2010. At a 5% level of risk, a 28% median increase in vulnerable biomass is estimated.

Discussion

The aim of this work was to evaluate, as a proof of concept, the implications of alternative levels of permissible risk of falling below the agreed biomass Limit Reference Point for south Pacific albacore ($20\%SB_{F=0,\ 2001\text{-}2010}$).

The lower the permissible level of risk of falling below an LRP, for a given level of uncertainty examined within the projections, the further the stock biomass must be on average from that LRP, and correspondingly the lower the median level of fishing mortality permissible.

In this sense, the analysis informs discussions on minimum standards for target reference points. The calculated median $SB_{2030}/SB_{0,2001\text{-}2010}$ levels (0.59 (5% risk) to 0.46 (20% risk)) under the assumed level of uncertainty within the system defined by the future recruitments and range of stock assessment runs used within the evaluation, can be considered to be the minimum levels for a Target Reference Point that is consistent with the level of risk; i.e. they reflect the 'minimum distance' between the LRP and any TRP consistent with a given level of risk. For south Pacific albacore, these levels implied median permissible fishing mortality levels well below F_{MSY}, and spawning biomass levels over double those at SB_{MSY}. They also related to longline vulnerable biomass (CPUE) levels similar to or notably greater than levels estimated for 2010, dependent on the permissible risk level.

We note that the level of permissible risk of breaching a Limit Reference Point, and the 'minimum distance' defined by that risk level (and included uncertainty) provides information only on the lowest level that a TRP should be set consistent with a risk-based Management Objective. A TRP consistent with achieving a range of pre-defined Management Objectives set by managers, and taking account of the trade-offs between them, may well imply a higher TRP level.

The risk and corresponding median levels were strongly impacted by the stock assessment runs selected for use within the analysis; for south Pacific albacore a key influence on the calculated risk level was the uncertainty in growth. For all runs where the estimated growth function was assumed, there was zero risk of the stock falling below the LRP (Table A2.1). The level of risk calculated here, therefore, was strongly influenced by the inclusion of the alternative growth assumption runs. Indeed, the fact that the probability of exceeding the limit falls to one model factor (the alternative growth assumption) in this analysis is not ideal and reflects the significant effect the choice of model runs can have on the results. Under the runs with that growth assumption, risk levels were further influenced by the level of natural mortality assumed, as well as by the steepness of the stock-recruitment relationship. When selecting model runs for use within the analysis, or when considering the weighting to be placed on each run, the biological plausibility of runs should be considered. For the particular axes of uncertainty selected here, it would be possible to compute the relative probability of each alternative model in each axis using the likelihood statistics for the model fits (see Table 1). Use of model-based weights computed in this way, if considered realistic, would contract the projection uncertainty to some extent and moderate the risk statistics accordingly. Note however that it may not be possible to determine relative model weights in this way for all models in a particular structural uncertainty grid, while some model runs may be included as reasonable alternatives despite their likelihood statistics indicating they were of lower probability.

There is a trade off between the level of uncertainty captured (the number and range of assessment runs selected), the desire to obtain a 'balanced' set of runs to explore each axis of uncertainty, and the increasing computational demand required to run stochastic projections across those runs. For example, for south Pacific albacore if all 7 candidate growth models were to be examined, this would lead to a computationally challenging 63 separate assessment runs being considered. There is therefore a need for SC10 to identify a computationally realistic number of stock assessment runs from the uncertainty grid for use in this analysis for bigeye, skipjack and yellowfin tuna. While 200 stochastic projections were used in the current analysis, the computational trade-off between the number of model runs and the number of stochastic projection runs performed can be investigated.

We note that the UN FSA Guidelines indicate that the risk of exceeding Limit Reference Points should be 'very low', but that those Guidelines provide no definition on what 'very low' is. As noted by SC9, the permissible risk is a decision to be made by managers. For this analysis we have interpreted 'very low' as a range of risks between 5% and 20%, but some discussion on this issue by SC10 would be beneficial.

In summary, particular guidance is sought from SC10 on:

- the proposed approach and any improvements;
- the appropriate assessment runs to be used within evaluations of the tropical tunas (and SPA if required);
- any relative weighting of those runs when calculating risk;
- confirmation that the range of risks presented in this paper is with the recommendation that the level of risk should be 'very low'.

Following SC agreement on the approach to be used, and their identification of the suite of assessment model runs to be used to capture the relevant uncertainty, the analysis will be repeated for the tropical tuna stocks (skipjack, yellowfin, bigeye) and the consequences of a range of levels of risk of exceeding the LRPs will be presented to WCPFC11 and/or the associated Management Objectives Workshop 3.

Acknowledgements

We would like to acknowledge funding for this work from the WCPFC and from the Australian Aid (AusAID) Fisheries for Food Security programme.

References

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Tables and Figures

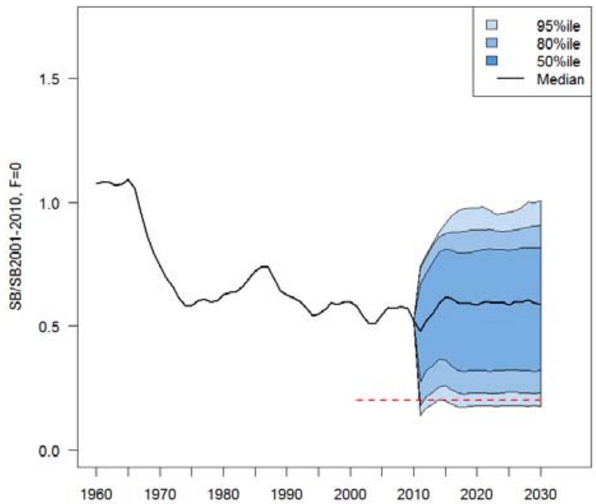
Table 1. Biological parameter settings within the stock assessment runs selected to capture uncertainty as a 'balanced' set of runs.

Stock assessment run	Settings			Model objective function
	Steepness	Growth model	Natural mortality	
1	0.65	Estimated	0.3	138170.3
2	0.80	Estimated	0.3	138170.2
3	0.95	Estimated	0.3	138170.3
4	0.65	Estimated	0.4	138166.9
5	0.80	Estimated	0.4	138168.4
6	0.95	Estimated	0.4	138168.3
7	0.65	Estimated	0.5	138166.1
8	0.80	Estimated	0.5	138165.8
9	0.95	Estimated	0.5	138165.9
10	0.65	Alt1	0.3	138139.8
11	0.80	Alt1	0.3	138139.0
12	0.95	Alt1	0.3	138139.1
13	0.65	Alt1	0.4	138142.3
14	0.80	Alt1	0.4	138142.4
15	0.95	Alt1	0.4	138142.6
16	0.65	Alt1	0.5	138145.2
17	0.80	Alt1	0.5	138145.5
18	0.95	Alt1	0.5	138145.7

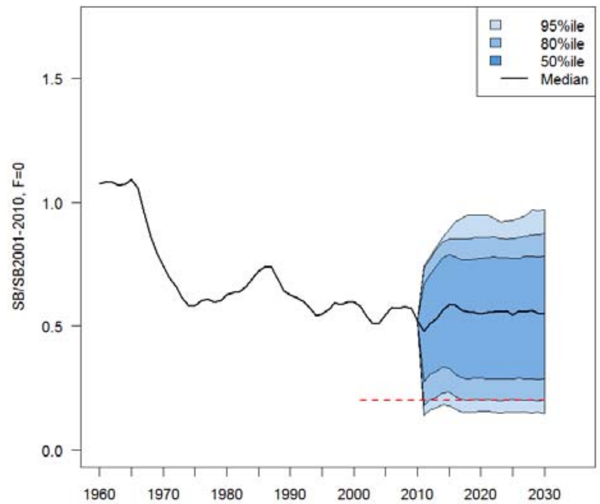
Table 2. Median quantities calculated across the 3600 projections of spawning biomass in 2030 relative to the unfished level averaged over 2001-2010 and to SB_{MSY}, the fishing mortality in 2030 relative to F_{MSY}, and the vulnerable biomass in 2030 relative to that in 2010.

Risk level ($P(SB_{2030} < 0.2SB_{0,2001-2010})$)	Corresponding LL effort scalar	Median $SB_{2030}/SB_{F=0,2001-2010}$	Median F_{2030}/F_{MSY}	Median SB_{2030}/SB_{MSY}	Longline VB_{2030}/VB_{2010}
0.05 (5%)	0.39	0.59	0.36	2.54	+28%
0.10 (10%)	0.49	0.55	0.42	2.40	+20%
0.15 (15%)	0.62	0.51	0.49	2.22	+11%
0.20 (20%)	0.78	0.46	0.57	2.04	+2%

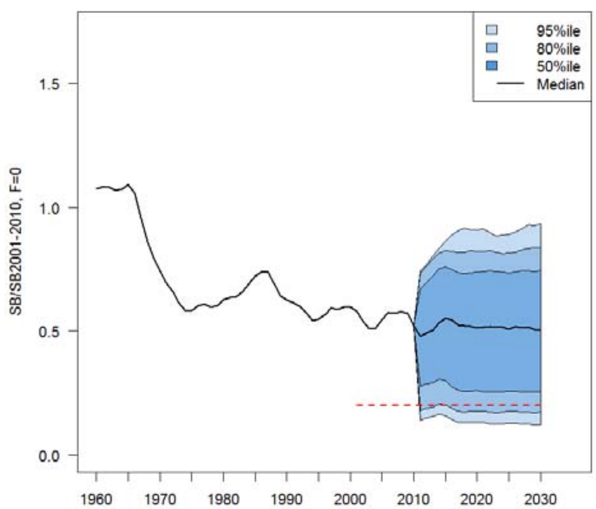
P=0.05 (5%)



P=0.10 (10%)



P=0.15 (15%)



P=0.20 (20%)

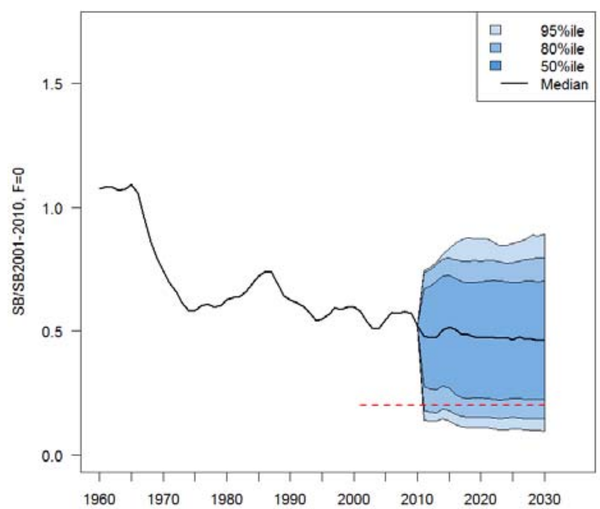


Figure 1. Stochastic projections of future adult stock status under effort levels that achieved different probabilities of the spawning biomass falling below the biomass Limit Reference Point (20% $SB_{F=0,\ 2001\text{-}2010}$, indicated by horizontal dashed red line). The historical median status from 1960 up to 2010 inclusive represents that across the 18 assessment model runs (structural uncertainty only). Uncertainty after 2010 represents both structural uncertainty and stochastic recruitment (3600 simulation runs).

Appendix 1. Evaluating the impact of the selection of assessment runs

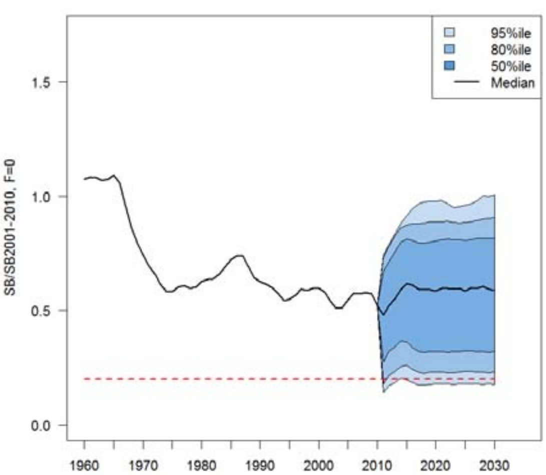
The selection of assessment runs for the analysis is a critical step. To illustrate the impact of this selection on the results, analyses were repeated using a second selected group of model runs. That group covered the same axes of biological uncertainty (steepness, natural mortality, growth), but in an 'unbalanced' way (Table A1.1). These alternative 10 models did not cover all options within each axis of uncertainty, nor all individual combinations of the parameters.

Table A1.1. Biological parameter settings within stock assessment runs selected to capture greater uncertainty but in an 'unbalanced' set of runs.

Stock assessment run	Settings		
	Steepness	Growth model	Natural mortality
1	0.65	1	0.3
2	0.80	1	0.3
3	0.80	1	0.5
4	0.95	2	0.3
5	0.80	1	0.3
6	0.80	3	0.3
7	0.80	4	0.3
8	0.80	5	0.3
9	0.80	6	0.3
10	0.80	7	0.3

The outcomes of the analysis based upon the two selections of underlying alternative stock assessment runs are compared for the 5% risk level (Figure A1.1, Table A1.2). It should be noted that the results compare the median from 3600 projection runs ('balanced' model runs; Table 1) with 2000 projection runs ('unbalanced' model runs; Table A1.1).

'Balanced' 18 assessment runs



'Unbalanced' 10 assessment runs

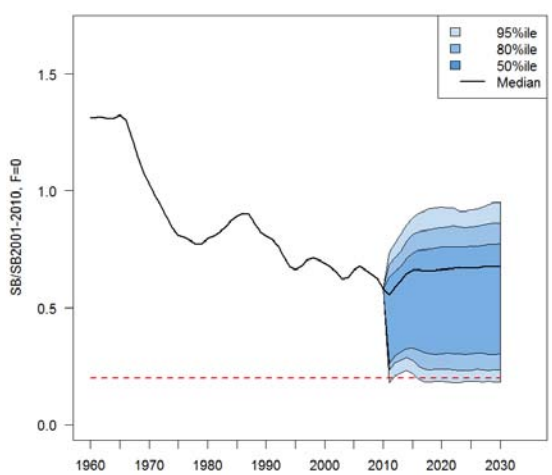


Figure A1.1. Comparison of stochastic projections of future adult stock status under effort levels that are consistent with a 5% risk of spawning biomass falling below the biomass LRP by 2030, under two different selections of underlying assessment runs.

Table A1.2. Table of median quantities across the projections of spawning biomass in 2030 relative to the unfished level averaged over 2001-2010 and to SB_{MSY}, fishing mortality in 2030 relative to F_{MSY}, and the vulnerable biomass in 2030 relative to that in 2010; at a 5% risk level ($P(SB_{2030} < 0.2SB_{F=0,2001-2010}) = 0.05$).

Selected stock assessment runs	Median $SB_{2030}/SB_{F=0,2001-2010}$	Median F_{2030}/F_{MSY}	Median SB_{2030}/SB_{MSY}	Longline VB_{2030}/VB_{2010}
'Balanced'	0.59	0.36	2.54	+28%
'Unbalanced'	0.67	0.38	2.26	+21%

While the overall range of uncertainty in future conditions was similar between the two sets of runs (Figure A1.1), the consequences for the median values were very different. This is a result of the 'skew' in the future status levels, where the median conditions were higher than seen in the 'balanced' set of model runs; compare the median line in the right hand plot of Figure A1.1 with that on the left. The median $SB_{2030}/SB_{F=0,2001-2010}$ in the 'unbalanced' 10 run analysis is 14% higher than that in the 'balanced' 18 run analysis, and might therefore be viewed as more precautionary (the 'minimum standard' for the TRP would therefore be a higher level of biomass). However, the unbalanced nature of the runs, and the alternative combined biological assumptions, implies that this can be achieved overall under slightly higher levels of median fishing mortality and lower spawning biomass, when related to MSY levels. Forecast gains in CPUE are also lower.

Appendix 2. Risk levels for each of the 'balanced' 18 assessment model runs used in the main analysis.

Table A2.1. Risk levels for each of the 18 assessment model runs used in the main analysis, for each of the overall risk levels examined.

Stock assessment run	Settings			$P(SB_{2030} < 0.2SB_{F=0,2001\text{-}2010})$			
	Steepness	Growth model	Natural mortality	0.05	0.10	0.15	0.20
1	0.65	Estimated	0.3	0	0	0	0
2	0.80	Estimated	0.3	0	0	0	0
3	0.95	Estimated	0.3	0	0	0	0
4	0.65	Estimated	0.4	0	0	0	0
5	0.80	Estimated	0.4	0	0	0	0
6	0.95	Estimated	0.4	0	0	0	0
7	0.65	Estimated	0.5	0	0	0	0
8	0.80	Estimated	0.5	0	0	0	0
9	0.95	Estimated	0.5	0	0	0	0
10	0.65	Alt1	0.3	0.62	0.93	1.00	1.00
11	0.80	Alt1	0.3	0.24	0.58	0.86	0.97
12	0.95	Alt1	0.3	0.03	0.23	0.55	0.78
13	0.65	Alt1	0.4	0	0.04	0.32	0.68
14	0.80	Alt1	0.4	0	0	0.01	0.15
15	0.95	Alt1	0.4	0	0	0	0.01
16	0.65	Alt1	0.5	0	0	0	0
17	0.80	Alt1	0.5	0	0	0	0
18	0.95	Alt1	0.5	0	0	0	0