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STOCHASTIC AND DETERMINISTIC PROJECTIONS: A FRAMEWORK TO EVALUATE THE POTENTIAL IMPACTS OF LIMIT REFERENCE POINTS, INCLUDING MULTI-SPECIES CONSIDERATIONS

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N. Davies and S. J. Harley

Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea, New Caledonia

STOCHASTIC AND DETERMINISTIC PROJECTIONS: A FRAMEWORK TO EVALUATE THE POTENTIAL IMPACTS OF LIMIT REFERENCE POINTS, INCLUDING MULTI-SPECIES CONSIDERATIONS

NICK DAVIES AND SHELTON J. HARLEY

SUMMARY

At SC5 the Scientific Committee proposed four steps to further the development of reference points in the WCPFC:

1. Identify candidate indicators (e.g. $B_{current}/B_0$, SB/SB_{MSY}) and related limit reference points (LRPs) (e.g. $B_{current}/B_0$=X, SB/SB_{MSY} =Y), the specific information needs they meet, the data and information required to estimate them, the associated uncertainty of these estimates, and the relative strengths and weaknesses of using each type within a management framework.
2. Using past assessments, evaluate the probabilities that related performance indictors exceed the values associated with candidate reference points.
3. Evaluation of the consequences of adopting particular LRPs based on stochastic projections using the stock assessment models.
4. Undertake a literature review and meta-analyses to provide insights into levels of depletion that may serve as appropriate LRPs and other uncertain assessment parameters (e.g. steepness).

In this paper we describe alternative approaches to addressing (3) above. We briefly overview some of the theoretical basis for LRPs and then describe how this question of the consequences of adopting particular LRPs can be addressed using stochastic projections. We then apply this approach to bigeye tuna using run 14 from the 2009 bigeye tuna stock assessment (Harley et al. 2010). This example involves some hypothetical LRPs since the outcomes from activities 1 and 4 above were not available at the time of writing. Finally, using the results of the bigeye tuna example we take the estimates of the effort reductions required to achieve the hypothetical LRPs and apply these reductions to yellowfin and skipjack tuna to determine the potential multi-species implications of adopting particular LRPs for bigeye tuna. In this paper the focus is on the theoretical and methodological aspects of the analysis rather than the LRPs themselves.

Subject to the approval of this approach by the SC, and the selection of some candidate LRPs, it would be possible to apply this methodology to the latest assessments of bigeye, yellowfin, and skipjack tuna. This information could assist the WCPFC in its consideration of reference points.

METHODS

LIMIT REFERENCE POINTS

Much of the necessary background on LRPs can be found in Annex II of the UNFSA (Anon. 1995).

Sections relevant to our analysis here are:

- *Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. (from paragraph 2)*
- *Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty (from paragraph 3)*
- *Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. (from paragraph 5)*

In the absence of guidance for selecting potential LRPs, for the evaluations here we have used two potential limit references points:

- $0.5SB_{MSY}$ – half the level of spawning biomass necessary to support the MSY; and
- $0.2S_0$ – 20% of the virgin spawning biomass

The first relates to the concept of MSY while the second is commonly used in New Zealand stock assessments (Francis 1992).

The next consideration relates to the third bullet point above, namely the “very low risk” of exceeding the LRP that is considered in evaluating fishing management strategies. In our analysis we consider two risk levels: 5% and 10%, e.g. a strategy is acceptable if biomass is only predicted to fall below the LRP by no more than 5% or 10% of the time. Further details of how this was implemented are provided later in the paper.

STOCHASTIC PROJECTIONS

In 2009 the ability to undertake deterministic projections that included effort for some fisheries and catch for others was implemented in MULTFAN-CL to allow the evaluation of complex management measures such as CMM2008-01 (Hampton and Harley 2009). Based on the need to evaluate the consequences of adopting reference points, further enhancements were made to MULTIFAN-CL to incorporate important sources of uncertainty and variability into projections. MULTIFAN-CL now has the capability to have stochastic recruitment in the projections, e.g. you can have multiple projections and each will have a different time series of recruitments; and additional sources of variability, namely incorporation of the uncertainty in the age structure of the population in the final year of the assessment model; and incorporate variability in catchability around the mean catchability value (e.g. the effort deviates) are in the testing / development stage.

MODELLING APPROACH

For this example we focused on bigeye tuna as it is the stock for which LRPs are most relevant due to its relatively poorer stock status. We first describe general steps of the analysis and then go through them in greater detail. The general steps were:

1. To identify fishery management strategies that were consistent with the particular LRP and risk level (four combinations); and
2. Apply those strategies to yellowfin and skipjack tuna to determine the potential impact of stock status and catches for these species.

For the bigeye tuna analysis we used run 14 from the 2009 assessment (Harley et al. 2009b) as was used in the analytical assessments of CMM2008-01 (Hampton and Harley 2009). For skipjack tuna we used the equatorial model from the 2008 assessment (Langley et al. 2008) and for yellowfin tuna we used the base case from the 2009 assessment[1] (Langley et al. 2009).

We undertook 200 stochastic simulations projected 10 years (2009-2018) into the future for the bigeye tuna with fishing effort for all fisheries set equal to their 2004 levels. Recruitment trajectories for five of the simulations are presented in Figure 1. We then estimated the probability that the two reference points were exceeded based on the number of 200 simulations where the biomass in any one quarter of the final three years of the projections was below the LRP. We then scaled fishing effort for all fisheries **except** for the unassociated set purse seine fisheries and the domestic fisheries of Indonesia and the Philippines to the value that meet the criteria for the four LRP / risk level combinations. The determination of the effort scalar was determined using a numerical hill climb algorithm.

Once the four effort scalars had been estimated, we then applied these to the yellowfin and skipjack assessment models for deterministic projections ten years into the future. Recent average recruitment was used for skipjack while long-term average recruitment was assumed for yellowfin. In future analyses, projections should be undertaken under both assumptions. As with the bigeye case, we excluded the unassociated set purse seine fisheries and the domestic fisheries of Indonesia and the Philippines. We then calculated the total catches that were predicted by the model for each species under the status quo effort and the four scenarios. This provides some information of the potential impacts of adopting fisheries management strategies to meet LRPs for bigeye tuna on skipjack and yellowfin tuna.

RESULTS

With 2004 levels of effort spawning biomass was predicted to be below both LRPs for all projections by 2018 so substantial reductions in fishing effort were necessary to achieve the four LRP / risk level combinations (Table 1). Effort was reduced to 65-68% of its 2004 levels in order to achieve the two risk levels for the 50%SB_{MSY} LRP and 34-37% of the 2004 levels in order to achieve the two risk levels for the 20%SB_0 LRP. The biomass trajectories are presented in Figure 2. The small difference in the effort scalars between the 5% and 10% risk levels can be attributed to the tight distributions on projected biomass. This small difference may not occur if more variation is

[1] The "CPUE low, LL sample high, LL q incr" model

included into the projections (e.g. uncertainty in the population age structure at the start of the projection period and effort deviates).

The mean spawning biomass levels that resulted when meeting the two risk criteria for the $50\%SB_{MSY}$ LRP was estimated to be 67-69% of SB_{MSY}. This suggests that if a **target** reference point was set at SB_{MSY} or higher, the LRP is unlikely to be a factor in restricting levels of fishing effort, i.e. avoiding this LRP with low probability is likely to result in biomass levels below the target which therefore would not be acceptable. Fishing strategies that met the target reference point on average (as recommended by Anon. (1995)) would result in very low risks (much lower than 5%) or exceeding an LRP of $50\%SB_{MSY}$. This conclusion should be revaluated with greater levels of variability included in the projections.

Because $20\%SB_0$ is very close to the SB_{MSY} level, avoiding this LRP with low probability results in average biomasses greater than SB_{MSY} (113-119% SB_{MSY}). In this case it would not be possible to achieve a target reference point of SB_{MSY} on average without breeching the risk threshold of the LRP.

Ten year deterministic projections for skipjack and yellowfin tuna under the four effort scalars are presented in Figure 3. Under all cases the biomass is predicted to lead to modest increases in spawning biomass above the levels predicted under status quo effort. As both stocks are currently estimated to be above their SB_{MSY}-level this increased biomass was associated with decreased catches. The reduction is catches that could be expected from fishing strategies based on the four combinations of LRP and risk level are provided in Table 2. The results were similar for both skipjack and yellowfin tuna. Catches were predicted to be reduced to 84-85% of the levels under the status quo effort in the scenarios where the $20\%SB_0$ LRP was assumed and 93-94% of the levels under the status quo effort in the scenarios where the 50% SB_{MSY} LRP was assumed.

Discussion

The approach of using stochastic projections to evaluate performance of management strategies in relation to risk, is consistent with that of the "Kobe Strategy Matrix" that is progressively being applied for tuna fisheries management by RFMOs. The specific method described here focuses on the sources of uncertainty / variability within a single population model. This does not take into account the uncertainty in the structure of the model itself or the key data uncertainties, which are now commonly examined within the stock assessments, i.e. the structural uncertainty analysis or 'grid' (Harley et al. 2009a; 2009b). An alternative approach to that of stochastic projections could be to base the projection on a large number of model runs and then undertake either deterministic or stochastic projections with each. Evaluation of the probability of exceeding particular LRPs would be similar to the approach used here, but with this alternative approach the values for the particular LRPs could differ across models. This approach is similar to that used in the Management Strategy Evaluation work undertaken in CCSBT and probably provides a more robust assessment against uncertainty, which is typically greater between models of alternative structures than within a single model. The fuller incorporation of major sources of uncertainty into this approach impacts upon the estimated risk levels, i.e. will increase with more uncertainty for any given strategy. The specification of the sources of uncertainty incorporated, complete or partial, may best be consistent among assessments and should be carefully considered when deciding what an acceptable level of risk be.

The simulations here only incorporated uncertainty in the predicted recruitment, but there are other sources of uncertainty that could be included to get more accurate estimates of the risks of exceeding reference points. Within the MULTFAN-CL framework it will be possible to include uncertainty in the population structure at the start of the projection period and the relationship between catchability and fishing mortality as modeled by the effort deviates. Inclusion of these sources of variation should lead to wider confidence intervals in projected biomass.

There are also different methods for calculating the risk of exceeding a given reference point. In the example here we calculated the risk as the proportion of the 200 simulations where the biomass in any one quarter of the final three years of the projections was below the LRP. Alternative approaches for calculating the probability that a LRP may be exceeded include:

- proportion of time steps across all simulations in which the LRP is exceeded over the entire projection period;
- as above, but only for a particular part of the projection time series (e.g. last three years);
- number of simulations in which SB goes below the LRP at any stage in projection period.

CONCLUSIONS

Methodological framework described in this paper is practical and not unduly computationally intensive and is consistent with approaches used to estimate risk and exceeding reference points elsewhere. We recommend that the basic approach described here be applied to the updated stock assessments for bigeye and skipjack tuna, and considering a wider range of sources of uncertainty and methods for calculating risk, and a range of plausible LRPs.

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Table 1: Effort scalars and the average SB_{2018}/SB_{MSY} over the 200 projections for bigeye tuna for the four LRP / risk level combinations.

		5%		10%	
	LRP (mt)	SB_{2018}/SB_{MSY}	Effort scalar	SB_{2018}/SB_{MSY}	Effort scalar
50%SB_{MSY}	54,750	0.69	0.65	0.67	0.68
20%SB_0	96,180	1.20	0.34	1.13	0.37

Table 2: Relative catches of skipjack and yellowfin tuna under the effort scalars necessary to meet the four LRP / risk level combinations for bigeye tuna.

		% of status quo catches	
LRP	Risk level	Skipjack tuna	Yellowfin tuna
50%SB_{MSY}	5%	92%	93%
50%SB_{MSY}	10%	93%	94%
20%SB_0	5%	84%	85%
20%SB_0	10%	85%	85%

Figure 1: Annual recruitment from five of the 200 stochastic projections undertaken for bigeye tuna. Quarterly recruitment was used in the projections.

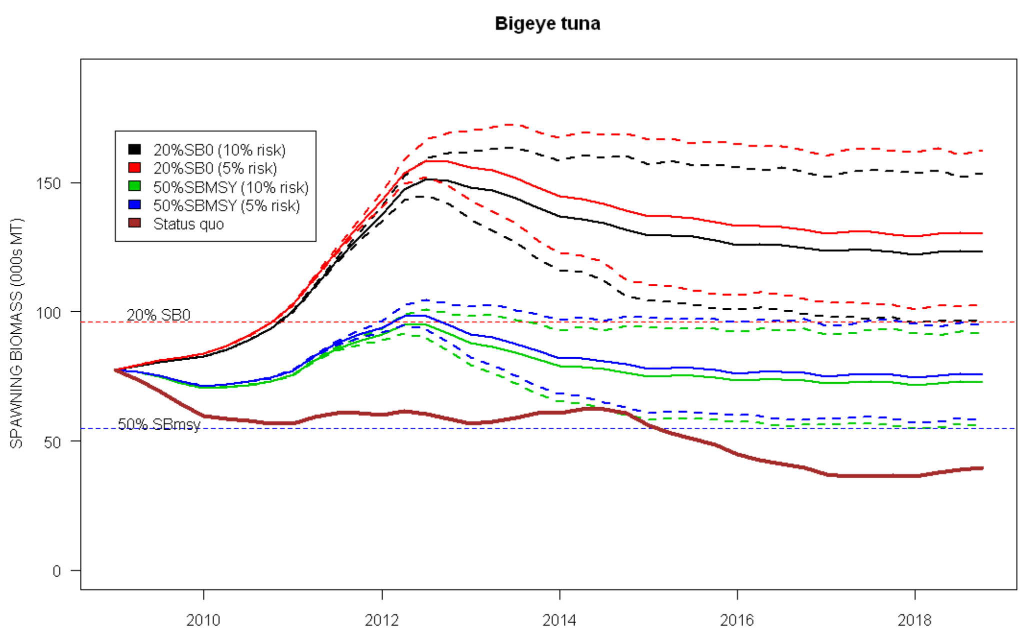
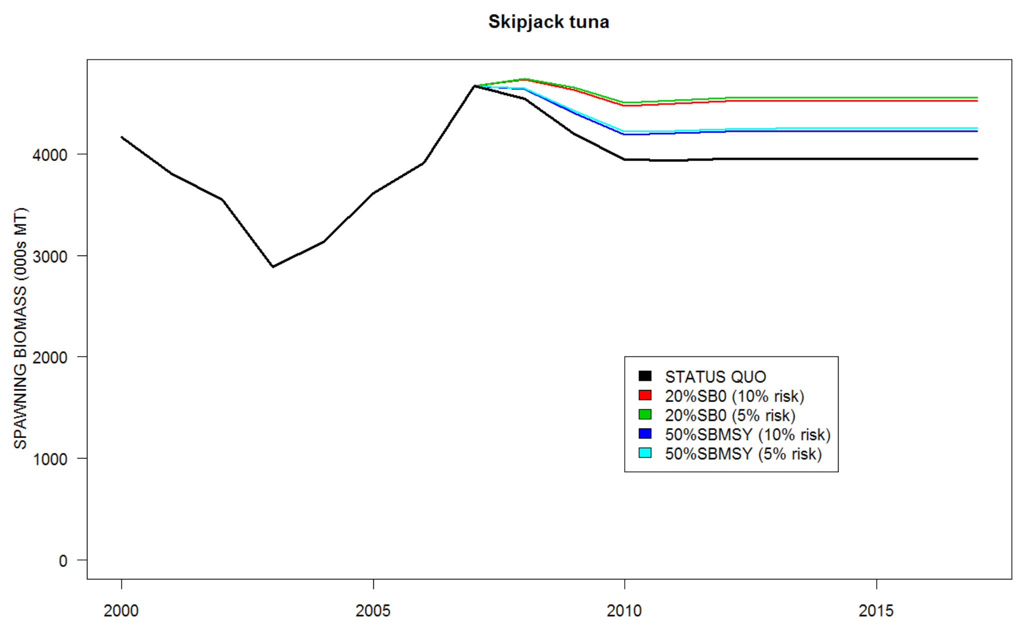


Figure 2: Mean adult biomass (solid lines) and 90th percentiles (dashed line) for the stochastic projections for the four LRP / risk level combinations. The dark brown line presents the deterministic projection adult biomass obtained for status quo levels of effort.



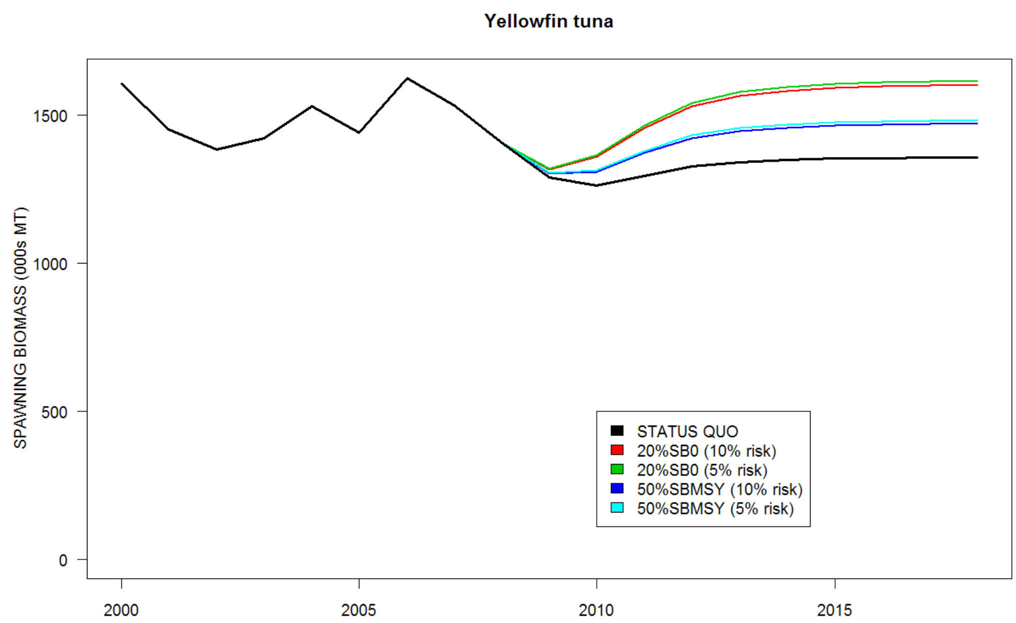


Figure 3: Predicted spawning biomass for skipjack (top) and yellowfin tuna (bottom) for the four combinations of LRP and risk level.