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EVALUATION OF STOCK STATUS OF BIGEYE, SKIPJACK, AND YELLOWFIN TUNAS AGAINST POTENTIAL LIMIT REFERENCE POINTS

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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).

This paper addresses parts 2 and 3 above and evaluates the historical, and projected future, stock status of bigeye, skipjack and yellowfin tuna against the limit reference points proposed in SC7-MI-WP-03, namely:

- Bigeye and yellowfin tuna: $F_{SPR40\%}$ and $20\%SB_0$
- Skipjack tuna: $20\%SB_0$[2]

The request to use the 2011 stock assessments for the evaluation dictated that it was not possible to undertake the full analysis with stochastic projections that was provided by Davies and Harley (2010), but Attachment 2 includes some preliminary results of some stochastic projections.

Traditionally the evaluation of stock status has been based on MSY-related reference points. For comparative purposes, therefore, we have included F/F_{MSY} and SB/SB_{MSY} in the analysis simply so that readers can compare the levels of these MSY-related reference points to those proposed by Preece et al. (2011).

[2] although results under the limit reference point $F_{SPR40\%}$ are also presented

Building on previous considerations of the different approaches for characterizing uncertainty in relation to reference points (Harley et al. 2009; Davies and Harley 2010), there is a need to estimate the probability that reference points have been exceeded in the past, and might be exceeded in the future. This was examined using the structural uncertainty grid developed for the 2011 bigeye, skipjack, and yellowfin tuna assessments to define a range of potential historical stock trajectories. These were projected forward using deterministic projections with current levels of catch and effort. The results are therefore predicated on the species-specific assessment model outputs for 2011.

With respect to the reference points proposed by Preece et al. (2011) we found that:

- Bigeye tuna: the fishing mortality limit reference point ($F_{SPR40\%}$) has been exceeded with high probability for the past 20 years and will continue to be exceeded with high probability into the future under current levels of fishing. The spawning biomass limit reference point (20%SB_0) will only be exceeded with very low probability in the future unless recruitment declines to the mean level predicted by the SRR; then that limit reference point will be exceeded with relatively high probability (0.48 in 2021). It is important to note that under the assumption of recent average recruitment, the estimate of SB_0 based on historical recruitment will underestimate the average unfished biomass in the projection period;
- Skipjack tuna: historical and projected future biomass far exceed the spawning biomass limit reference point;
- Yellowfin tuna: the fishing mortality limit reference point has been exceeded with high probability for the past 10 years and the probability that it will be exceeded in the future was very sensitive to future recruitment assumptions. While yellowfin is much closer to the spawning biomass limit reference point than skipjack tuna, none of the historical estimates or future projections of spawning biomass declined below this level.

These results suggest that adoption of limit reference points is important for bigeye and yellowfin tuna as these stocks are at the levels (biomass and/or fishing mortality) where limit reference points are likely to impact on future fishing management strategies. For skipjack tuna, we are likely to be at a much higher level so instead the focus must be on determining management objectives and setting target reference points to maximize fishery performance.

Methods

A key aspect to evaluating the probability of exceeding reference points is the approach used to characterize uncertainty in the knowledge of stock status – both in the past and in the future. In this paper we use a structural uncertainty approach to characterize uncertainty as commonly structural uncertainty is greater than the statistical uncertainty that exists within a single model run (Harley et al. 2009). We used the model runs contained within the structural uncertainty grid developed for the 2011 bigeye, skipjack, and yellowfin tuna assessments[3] to define a range of potential historical stock

[3] See SA-WP-2 (bigeye), SA-WP-03 (yellowfin), and SA-WP-04 (skipjack) for further information of the factors included in the grid

trajectories. These were projected forward to the year 2021 under 2010 of catch (longline fisheries) and effort (all other fisheries).

As with the grid of generic projections provided in OFP (2011), two alternative assumptions were assumed for recruitment 1) at the average of the level estimated over the last ten years of the model and 2) the levels predicted by the spawner recruitment relationship (SRR).

As the spawning biomass per recruit calculations are not done within MULTIFAN-CL, we decided to instead undertake the calculations outside the model using the statistical modeling package R. The code is provided in Attachment 1.

Results

Figures 1-3 provide estimates of the range (across the grid runs) of annual stock status and fishing mortality levels in relation to the candidate limit reference points, and with respect to F_{MSY} and SB_{MSY} (the latter is only presented for the SRR runs) for comparative purposes, for the recent historical period (from 1975) and through the projection period. The probability of exceeding these reference points is provided graphically in Figure 4 and summarized for some important time periods in Table 1.

For bigeye tuna the $F_{SPR40\%}$ limit reference point was exceeded with high[4] probability since 1990 and continues to be exceeded into the future with very high probability under status quo fishing for both recruitment scenarios (Figure 4). Bigeye was estimated to be above the $20\%SB_0$ level during the historical period and predicted to have only a very low probability of declining below this level under recent average recruitment levels (4-7%), but this increases to 48% by 2021 under projections with the SRR option (Table 1). SB_{MSY} is typically at a higher level than $20\%SB_0$, so the probability of exceeding it is higher. Across the range of steepness values in the grid, F_{MSY} is typically higher than $F_{SPR40\%}$ so the probability of exceeding it is lower.

For skipjack tuna there was zero probability of falling below $20\%SB_0$ during either the historical or projection periods. We also include an evaluation against the other reference points (but note that these were not recommended for evaluation by Preece et al 2011) and none of these are approached.

For yellowfin tuna the results with respect to $F_{SPR40\%}$ were very sensitive to the recruitment option used within the projection, as fishing mortality levels were very close to that threshold level and the uncertainty (range across models in the grid) was low (see Figure 3). Since 2000, fishing mortality levels have been at or above the $F_{SPR40\%}$ level, with a probability of 0.83 of exceeding this reference point in 2010. In the projected period the probability drops to 0.67 by 2012 if assuming recent average recruitment, but it drops to 0.22 under the SRR assumption due to the higher level of recruitment predicted. Yellowfin spawning biomass does not fall below $20\%SB_0$ during either the historical or projection periods.

[4] Noting that for a limit reference point the aim is to avoid exceeding it with high probability, i.e., accept only a very small probability of exceeding it.

Discussion

Limit reference points define regions (typically in terms of either fishing mortality or spawning biomass) that we want to avoid with a high probability.

The purpose of this paper was to evaluate historical and projected future stock conditions in relation to the limit reference point proposed by Preece et al. (2011). We now comment briefly on three important matters, firstly the limit reference points proposed, next some different approaches for characterizing uncertainty in the historical and projected time periods, and finally, how we can combine limit reference points with the projection approaches described here to evaluate potential management options in a way consistent with the proposed approach outlined for the Kobe II strategy matrix.

Comments on the candidate reference points

$F_{SPRx\%}$ is a proxy (or substitute) for F_{MSY} and for a given value of steepness one can determine the value of x such that $F_{SPRx\%} = F_{MSY}$. For example in the simulation studies undertaken by Preece et al. (2011 – Figure 8) if steepness is ~0.65 then $F_{SPR40\%} = F_{MSY}$ and if steepness is ~0.78 then $F_{MSY} = F_{SPR30\%}$. Provided that assumed values of steepness do not impact on stock dynamics (e.g. recruitment is estimated with weak constraints) then a similar approach to assuming that $F_{SPR40\%}$ is a suitable proxy for F_{MSY} would be to simply fix steepness at 0.65.

Clearly whether $F_{SPR40\%}$ is a suitable proxy for F_{MSY} depends on the unknown true level of steepness. While noting that it is very difficult to estimate steepness reliably within an assessment (Harley 2011), based on the estimated values of steepness obtained for bigeye and yellowfin tuna in the 2011 assessments, $F_{SPR40\%}$ would be a conservative proxy for bigeye tuna, but overly optimistic one for yellowfin tuna.

Preece et al. (2011) note that $20\%SB_0$ is a commonly used reference point in many fisheries management arrangements. In situations where stock dynamics are not in equilibrium (e.g. medium to long-term trends in either strong negative or positive deviations from the spawner recruitment relationship) this reference point might not be as suitable as one which takes into account the non-equilibrium conditions. Harley et al. (2009) described alternative depletion based references points, currently implemented in MULTIFAN-CL, which attempt to estimate the level of biomass that would exist at any point in the past if fishing had not occurred (e.g. $20\%SB_{current_{F=0}}$). This 'no-fishing' based reference point will perform the same as that proposed by Preece et al. (2011) when conditions are close to equilibrium, but might be considered to perform better in non-equilibrium conditions like are estimated for bigeye tuna in the WCPO. For example, SC6 decided that the recent average level of bigeye tuna recruitment provides a more realistic basis for stock projections than the average values that would be predicted to occur from the stock recruitment relationship fitted to the full time series. If we accept this premise, then quantities such as SB_0 and SB_{MSY} should be computed for the recent average level of recruitment for the purpose of comparison with projected SB.

Methods for characterizing uncertainty

Previously we have described the different approaches that might be used for describing uncertainty in the historical and projected time periods (Harley et al. 2009; Davies and Harley 2010). In this paper we have focused on uncertainty across different structural models for both time periods as structural uncertainty is typically larger than statistical uncertainty within a model and there was insufficient time (computational resources) to run full stochastic projections using the 2011 assessments prior to SC7 (see Attachment 2 for some preliminary results).

In using the runs from the grid we have not attempted to provide differential weight to any of the runs, i.e. they were all given equal weight. It is not necessary to make this assumption and model individual runs from the grid could be weighted either based on some prior knowledge (or expert opinion) or based on the likelihoods where these are directly comparable. It is important that such decisions be made objectively (i.e. think about the relatively plausibility of the different factors rather than the results that they give) and collectively. We have not attempted to do this in the current analysis.

Ideally one would like to incorporate stochasticity in future conditions, uncertainty in current conditions, and uncertainty in model structure. This could be done by running stochastic projections for runs in the grid. Currently the stochastic projections, as implemented in MULTIFAN-CL, can incorporate uncertainty in both future recruitment and current stock status but this requires calculation of the variance-covariance matrices for both estimated and many derived parameters, which is quite time consuming. It might be possible to do such calculations in the future, but likely not at the same time as the stock assessments are being undertaken.

Evaluating management options

As noted by Davies and Harley (2010) the types of analyses described here can be easily extended to provide advice to managers on the implications of different potential management options. Currently, to evaluate alternative management option we undertake deterministic projections for different catch and effort levels across a small number of models (typically one) for each species (e.g. OFP 2011).

Once the Commission had adopted some reference points (target or limit), and the allowable risks of exceeding them, it will be useful to incorporate uncertainty in stock status into the evaluation of management options and extend the type of work described in OFP (2011). To do this it will first be necessary to decide an approach for characterizing uncertainty and some thoughts on this were provided in the preceding section. The advice that could be provided to the Commission from these analyses would be the probabilities of exceeding its chosen reference points for particular management options. This general approach is consistent with the Kobe II strategy matrix and the principles of management strategy evaluation[5].

Also, using the types of algorithms described in Davies and Harley (2010) it would be possible to find the strategy (e.g. scalar of catch and effort levels) that achieves a given level of acceptable risk (as determined by managers). However, when multiple reference points are considered (e.g. the two limit

[5] However, given the computational demands of incorporating uncertainty it would be useful for the Commission to specify a smaller number of management measures to be considered than has typically been done in the past. In OFP (2011) we considered 125 different management options (combinations of catch and effort for different fleets) and each run took one minute. In the analysis of uncertainty here, the grid for bigeye tuna comprised 144 model runs. If we included the same source of uncertainty for each management option the total required computing time would be 18,000 minutes (12.5 days).

reference points proposed for bigeye and yellowfin tuna) it is not unusual to have conflict whereby a particular management strategy can satisfy one reference point, but exceeds the threshold risk level for another (e.g. the status quo fishing strategy for bigeye tuna under recent average recruitment satisfies 20%SB_0 by not $F_{SPR40\%}$).

In undertaking these types of analyses it will be important to provide advice to managers relating to fishery performance – rather than simply stock status in relation to some levels of biomass or fishing mortality that could have undesirable biological impacts. In these projections it is possible to calculate metric of interest including: average annual catch, year-to-year variability in catch, average catch rates, and proportion of time that catch or catch rates drop below some threshold. These types of quantities could form the basis for defining target reference points.

Acknowledgements

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Preece, A., R. Hillary, and C. Davies. 2011. Identification of candidate limit reference points for the key target species in the WCPFC. WCPFC-SC7-2011/MI-WP-03.

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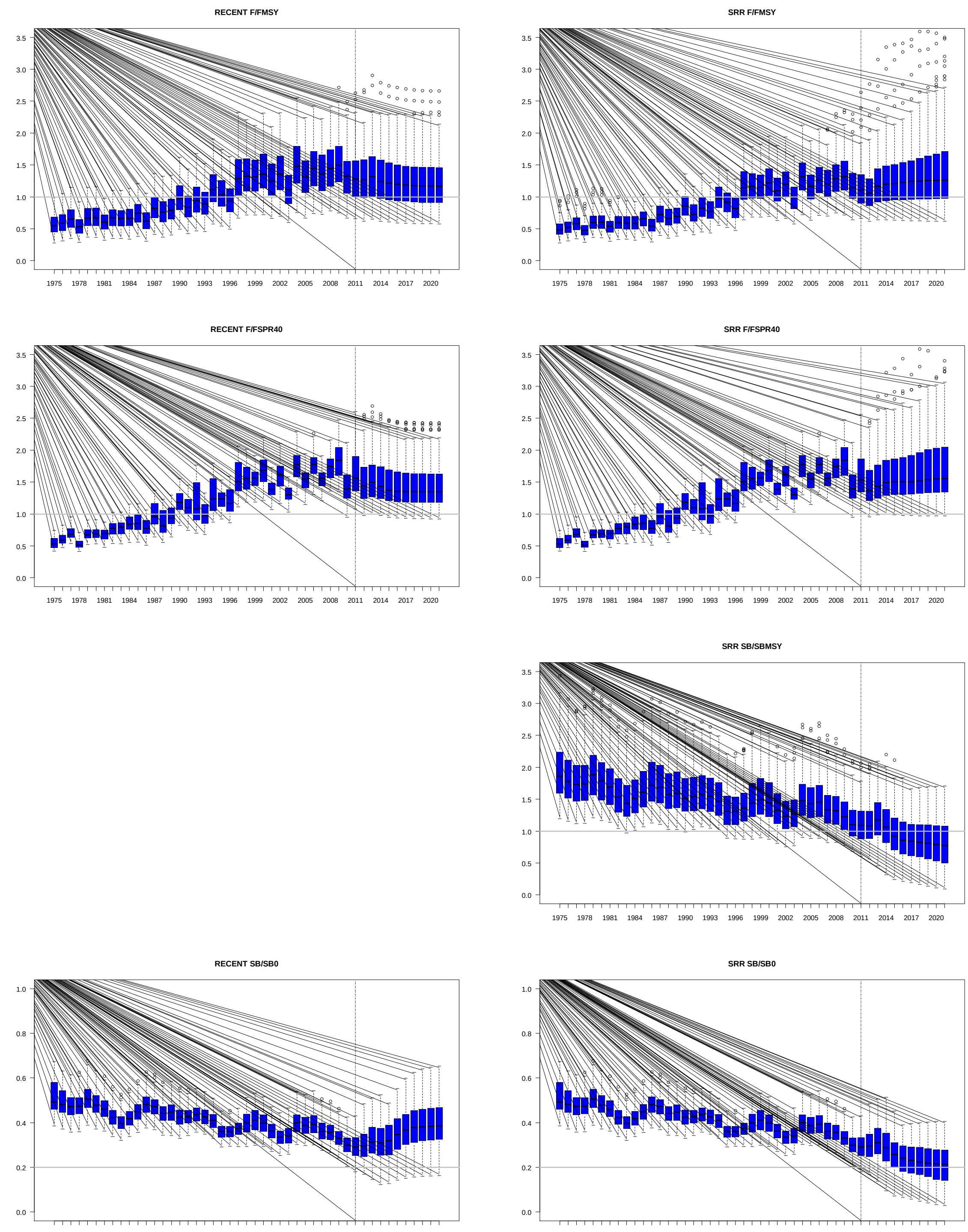

Figure 1: Boxplots of annual status of bigeye tuna against four reference points based on deterministic projections for each model in the grid under recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

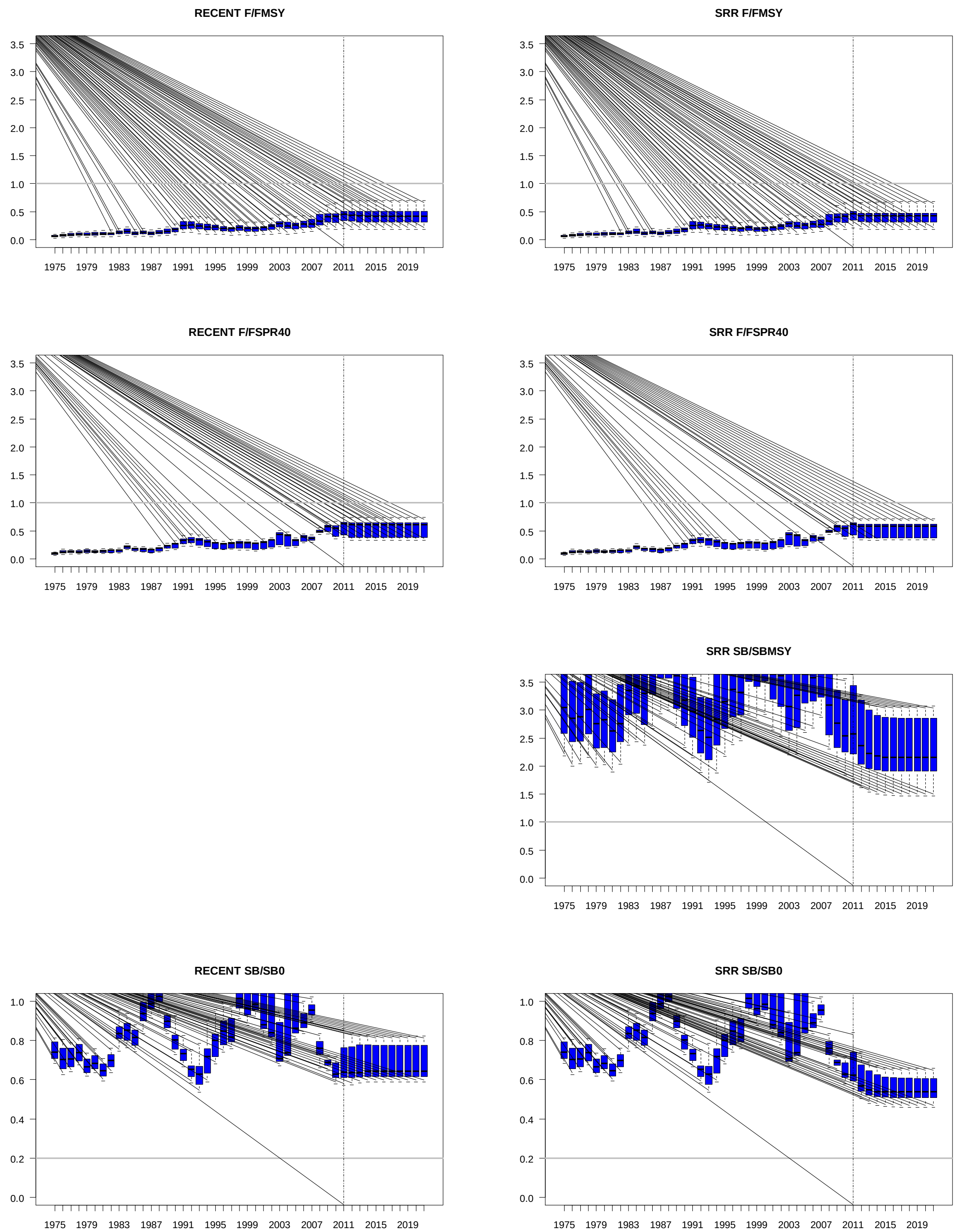

Figure 2: Boxplots of annual status of skipjack tuna against four reference points based on deterministic projections for each model in the grid under recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right). Note that we have used the same y-limits for all three species for ease of comparison.

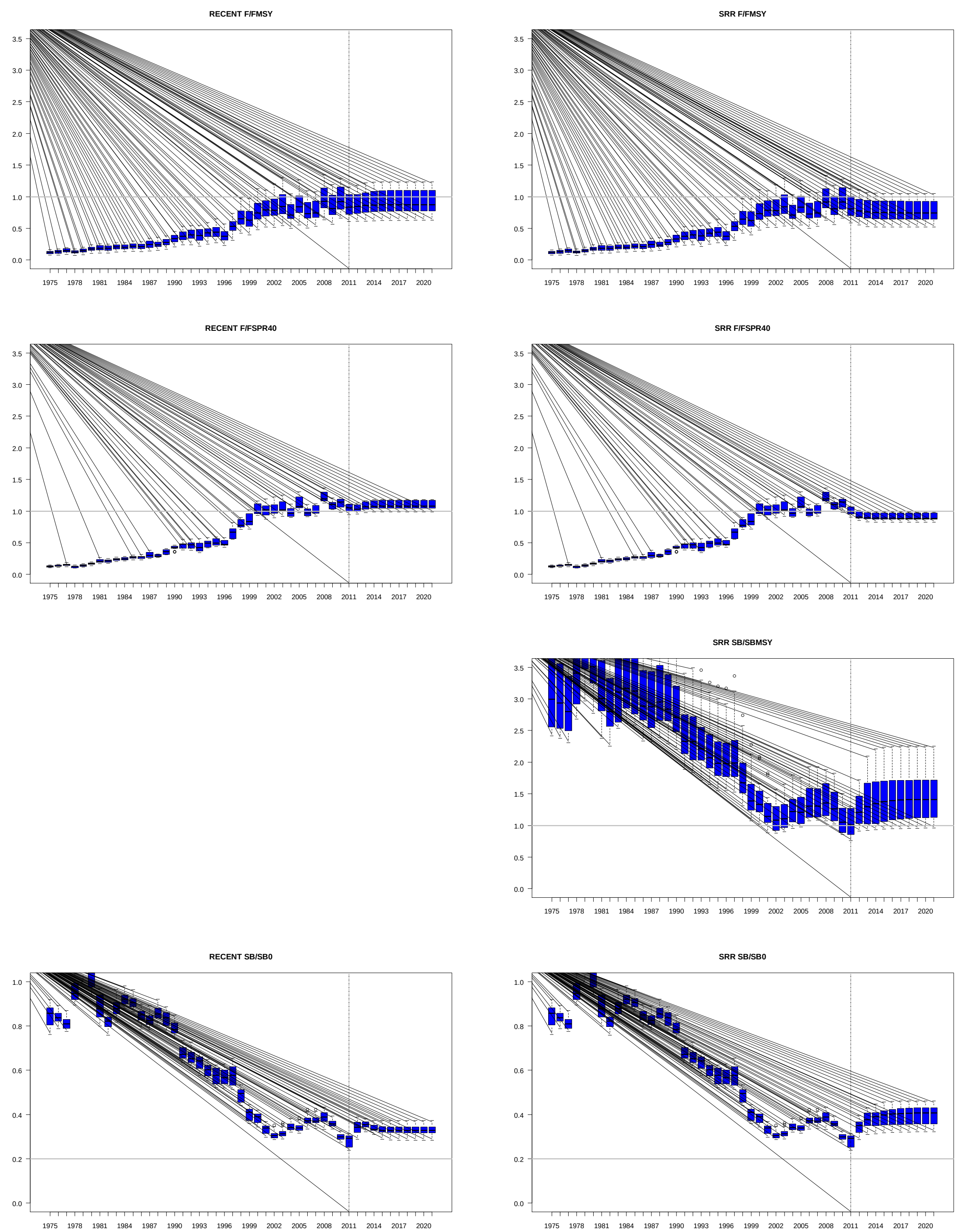

Figure 3: Boxplots of annual status of yellowfin tuna against four reference points based on deterministic projections for each model in the grid under recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

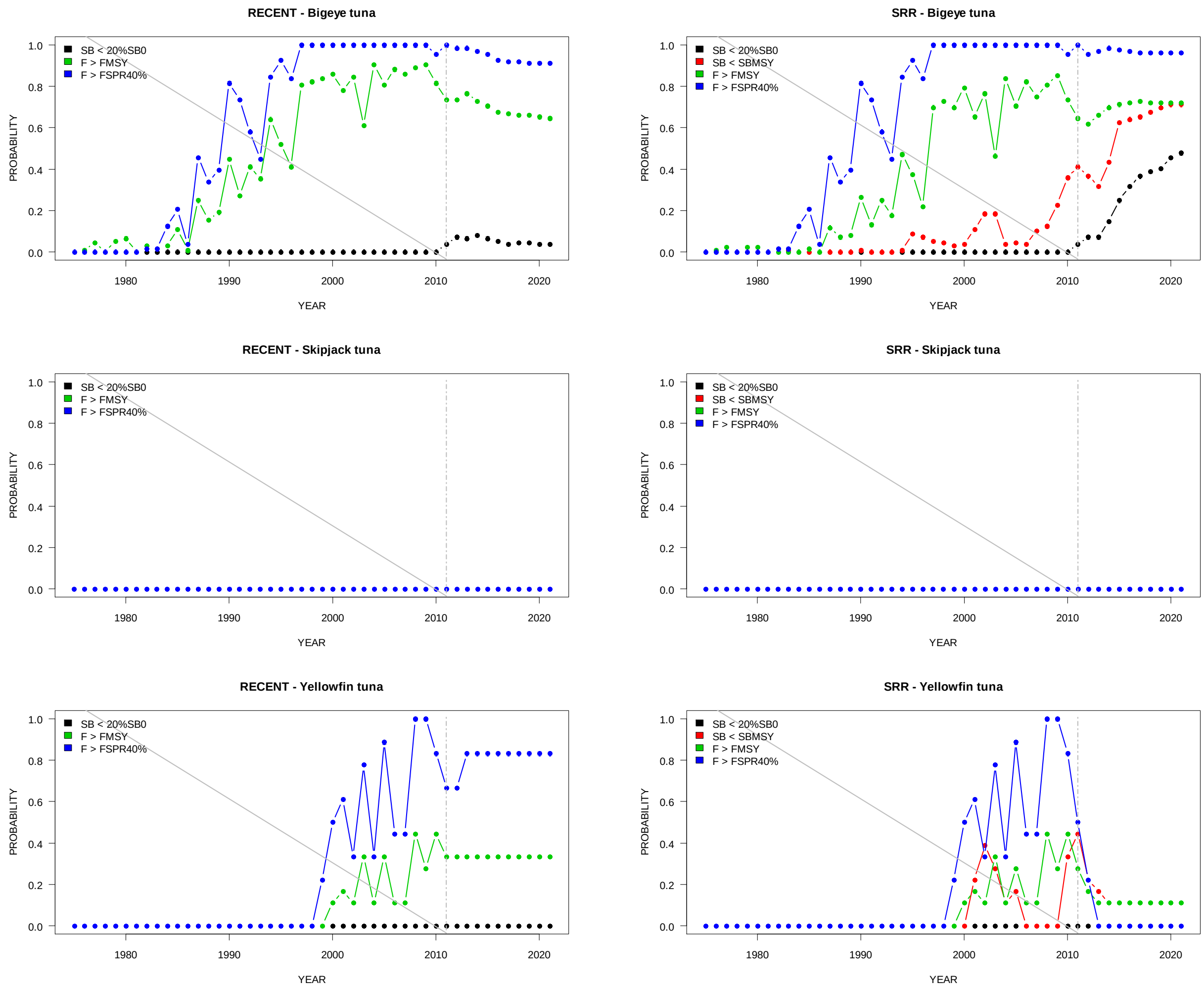

Figure 4: Graphs of annual probability of each species exceeding alternative limit reference point levels based upon deterministic projections for each model in the grid under recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

Table 1: Probability of exceeding reference points in 2010, 2012, and 2021 based on the uncertainty in the grid of structural model runs.

	Recent average recruitment			Spawner recruitment relationship		
Bigeye tuna	2010	2012	2021	2010	2012	2021
$SB_y < 20\%SB_0$	0.00	0.07	0.04	0.00	0.07	0.48
$SB_y < SB_{MSY}$	--	--	--	0.36	0.37	0.71
$F_y > F_{MSY}$	0.82	0.74	0.65	0.74	0.62	0.72
$F_y > F_{SPR40\%}$	0.96	0.99	0.91	0.96	0.96	0.96
Skipjack tuna						
$SB_y < 20\%SB_0$	0.00	0.00	0.00	0.00	0.00	0.00
$SB_y < SB_{MSY}$	--	--	--	0.00	0.00	0.00
$F_y > F_{MSY}$	0.00	0.00	0.00	0.00	0.00	0.00
$F_y > F_{SPR40\%}$	0.00	0.00	0.00	0.00	0.00	0.00
Yellowfin tuna						
$SB_y < 20\%SB_0$	0.00	0.00	0.00	0.00	0.00	0.00
$SB_y < SB_{MSY}$	--	--	--	0.33	0.22	0.11
$F_y > F_{MSY}$	0.44	0.33	0.33	0.44	0.17	0.11
$F_y > F_{SPR40\%}$	0.83	0.67	0.83	0.83	0.22	0.00

Attachment 1: Spawning biomass per recruit code

```
for(run in 1:length(reslist))
{
        jnk <- read.rep(reslist[run])
        tmp <- apply(jnk$AdultBiomass,1,sum)/jnk$SB0
        results[run,,1] <- round(as.vector(tapply(tmp,years,mean)),3)
        results[run,,2] <- round(as.vector(tapply(jnk$Eq.SB.SBmsy,years,mean)),3)
        results[run,,3] <- round(as.vector(tapply(jnk$Eq.F.Fmsy,years,mean)),3)

        # the SPR stuff ....
        # biological inputs
        outputs <- data.frame(ages=seq(1,jnk$nAges),matage=jnk$MatAge,watage = jnk$mean.WatAge, fecatage=jnk2$maturity)
        # fishing mortaltiy
        FFF <- jnk$FbyAgeYr
        #aggregate
        Fatage.yr <- round(aggregate(FFF,by=list(years),mean),4)[,-1]
        SPR.F0 <- get.spr(biol=outputs,Fatage=rep(0,length=ncol(Fatage.yr)))

          for(j in 1:length(unique(years)))
          {
          tmp <- get.spr(biol=outputs,Fatage=as.numeric(Fatage.yr[j,]))
          results[run,j,4] <- round(tmp/SPR.F0,3)
          results[run,j,5] <- round(1/nlminb(1,get.sprscalar,FATAGE=as.numeric(Fatage.yr[j,]),SPRtarg=0.4)$par,3)
          }
}

# Function that gets SRR
get.spr <- function(biol=outputs,Fatage=Fatage.yr[1,])
{
# SJH 10/7/2011 # Calculated spawning biomass per recruit from biol params and F-at-age
popmat <- matrix(NA,nrow=nrow(biol),ncol=3,dimnames=list(1:nrow(biol),c("N","B","SB")))
popmat[1,1] <- 1
    for(i in 2:(nrow(popmat)-1))
    {
    popmat[i,1] <- popmat[i-1,1]*exp(-(biol$matage[i-1]+Fatage[i-1]))
    }
# Plus group
popmat[nrow(popmat),1] <- popmat[i,1]*exp(-(biol$matage[i-1]+Fatage[i-1]))/(1-exp(-(outputs$matage[i]+Fatage[i])))
#now multiple to get B and SB
popmat[,2] <- popmat[,1]*biol$watage
popmat[,3] <- popmat[,2]*biol$fecatage
return(sum(popmat[,3]))
}
```

```
get.sprscalar <- function(Fscale,BIOL=outputs,FATAGE=as.numeric(Fatage.yr[50,]),SPRtarg=0.4)
{
a <- get.spr(biol=BIOL,Fatage=FATAGE*0)
b <- get.spr(biol=BIOL,Fatage=FATAGE*Fscale)
diff <- ((b/a)-SPRtarg)^2
return(diff)
}
```

Attachment 2: Stochastic projections

The standard methodology for undertaking stochastic projection in MULTIFAN-CL is provided in Davies and Harley (2010). Here we used stochastic projections for the bigeye and yellowfin tuna reference case models. 200 projections were run with uncertainty in the future recruitment. Recruitment was sampled from the recruitment deviates around the spawner recruitment curve.

While the uncertainty only occurs in the future we have used the same presentation format as for the deterministic projections from the grid – so the focus should be on comparing the uncertainty in the future conditions. A comparison of the stochastic and deterministic projections are provided below.

In each case the stochastic projections are more optimistic – primarily due to the inclusion of only a single level of steepness. Therefore, it is recommended that where possible that both process error (as in the stochastic projections) and structural undertainty (from the grid) be incorporated into such evaluations.

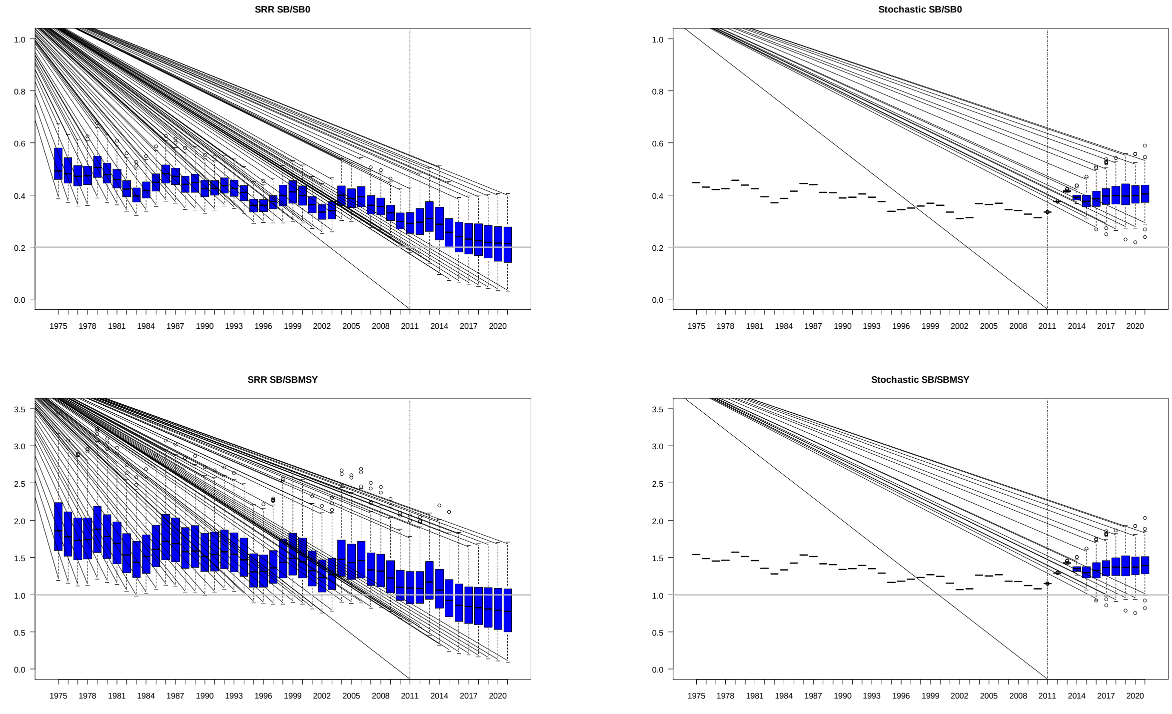

Figure A 1: Comparison of stock status in relation to spawning biomass reference points for bigeye tuna from the deterministic projections (left) and stochastic projections from the reference case model (right).

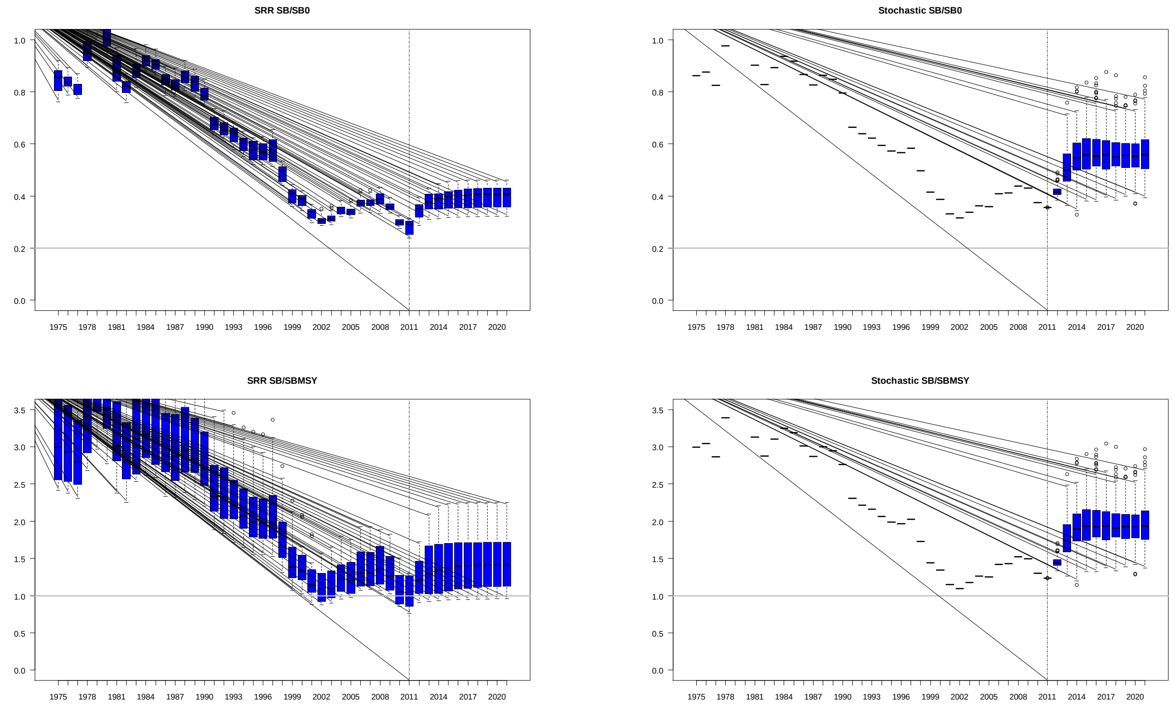

Figure A 2: Comparison of stock status in relation to spawning biomass reference points for yellowfin tuna from the deterministic projections (left) and stochastic projections from the reference case model (right).