Oceans & Atmosphere
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Performance of a revised candidate MP using all 3 input data sources

Rich Hillary, Ann Preece, Campbell Davies

CCSBT-ESC/1909/16

CSIRO Oceans & Atmosphere
Battery Point, Hobart 7000, Tasmania, Australia.

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Important disclaimer

Contents

1 Background

This paper details the revised structure and performance of a candidate MP using all three of the input data sources (gene-tagging, close-kin, and LL CPUE). The revised MP is very similar to the one presented at the OMMP10 [1], but with some alterations to the CPUE part of the HCR. From the OMMP summary it was clear the previous version of the MP was prone to high probabilities of increasing the TAC in the first 2 decisions, then decreasing it again. This is one of the performance statistics that has been outlined as something we want to minimise for an MP tuned to the reference set of OMs [2].

The candidate MPs are tuned to the agreed reference set of OMs [2] for the current two tuning objectives:

1. Attain a TRO depletion level of 30% of the unfished level by 2035 and with probability 0.5
2. Attain a TRO depletion level of 35% of the unfished level by 2040 and with probability 0.5

and we assumed a tuning tolerance of $\pm 1\%$.

2 Revised MP structure

As noted, the previous **rh12** [1] CMP had a propensity to result in higher probabilities of two initial TAC increases then a decrease in the first three decision years [2]. Given this has been considered undesirable behaviour for CMPs - at least for the reference set of OMs - we needed to determine what was causing the behaviour, then redesign the CMP in a manner that addressed the issue.

The cause of this behaviour was clear: in the **rh12** HCR there was a trend term for the CPUE data and, as the strong year classes of recent years moved through the CPUE in the first 5–10 years of the projections a strong “up then down” trend is apparent in the CPUE. With a trend term, and the time-frame over which this “up then down” trend moves through the data (basically coincidental with the TAC decision years with the lag accounted for), the trend term in the HCR basically hard-wired in the “2 up then 1 down” TAC behaviour.

To fix the problem we modified the CPUE part of the HCR, by replacing the trend term with a functional response more like that used for the gene tagging part of the HCR. That is, within a threshold range of recent mean CPUE do not change the TAC, and when below/above the threshold range decrease/increase the TAC (with an asymmetric response allowed). The main difference between the CPUE implementation and the gene tagging component is that we attach a weighting to the functional response for the CPUE, as we want it to be more subtle than the gene tagging part of the HCR. The mathematical specification of the revised MP - **rh13** - is given in the Appendix.

Below we provide a high-level (relatively) explanation of the operation of the revised MP (**rh13**):

- **CPUE**: as described above, if the recent average CPUE is within a specified range it does nothing; above/below this range it tries to increase/decrease the TAC. The reactivity of this part of the HCR is directly linked to how close we are to the estimated rebuilding level (as estimated by the CKMR population model in the CMP). Prior to attaining the target rebuilding level, the CPUE part of the HCR is *more* reactive than when close to the target and after it has been achieved.

- **CKMR**: below the rebuilding objective level the HCR enforces a minimum rate of TRO rebuilding; for values above/below this rate it tries to increase/decrease the TAC. As the stock is estimated (from the CKMR model within the CMP) to approach the target rebuilding level the minimum increase rate is effectively reduced to to zero; this encourages TAC changes to keep the TRO at the rebuilding level
- **Gene tagging**: similar to the CPUE part of the HCR, there is a target range for the average 2 year old absolute abundance over recent years from the gene tagging. Below this specified range the HCR reduces the TAC strongly; above this range it is increases the TAC more slowly. The main difference for this part of the HCR, relative to the CPUE implementation, is there is no weighting on the reactivity. This is to allow the MP to respond rapidly enough to poor (or very good) recruitments detected in the gene tagging data.

3 Robustness tests

The priority robustness tests as agreed at OMMP10 were [2]:

1. **lowR5** (reclow5): reduce future recruitment by half during the first n years. For 2018, n was set to 5 (H)
2. **h=0.55** (h55): reduced grid with steepness of 0.55 *only* (and the two highest M_0 values in the full grid are also excluded) (M)
3. **IS20** (fis20): Indonesian selectivity flat from age 20+ (M)
4. **Upq2008** (cpueupq): permanent 25% increase in LL1 catchability from 2008 (H)
5. **Omega75** (cpueom75): power function for biomass-CPUE relationship with power set at 0.75 (i.e. hyper-stable) (H)
6. **Var sq. CPUE** (cpuew0): variable squares (L)
7. **Aerial2016** (as2016): remove 2016 aerial survey data point (H)
8. **CPUE2018** (cpue18): remove 2018 LL1 abundance index data point (M)

The first terms in brackets are their respective codes; the second terms are their relative ranking: high (H), medium (M), or low (L). This covers the individual robustness tests but a number of “crossed” tests were also recommended: reclow5as2016 (H), reclow5cpuew0 (L), as2016cpue18 (H).

While not strictly robustness tests, the OMMP also agreed that developers tune their respective MPs to the 30% by 2035 objective *but* for a 2,000 and 4,000 maximum TAC change to investigate the impact of changing the maximum TAC increase/decrease on CMP performance as requested by the SFMWG5. This was to be done only for the reference set of OMs, and these tuned MPs were not to be run on the suite of robustness tests outlined above. This was considered sufficient to explore the likely impact of these alternative relative to the 3,000 maximum TAC change, which is the specification of the Bali Procedure, and used as the default in CMP testing to date. We also tuned the MP to the 30% by 2040 tuning option that, while not included in the main tuning objectives, has not yet actually been ruled out.

4 Results

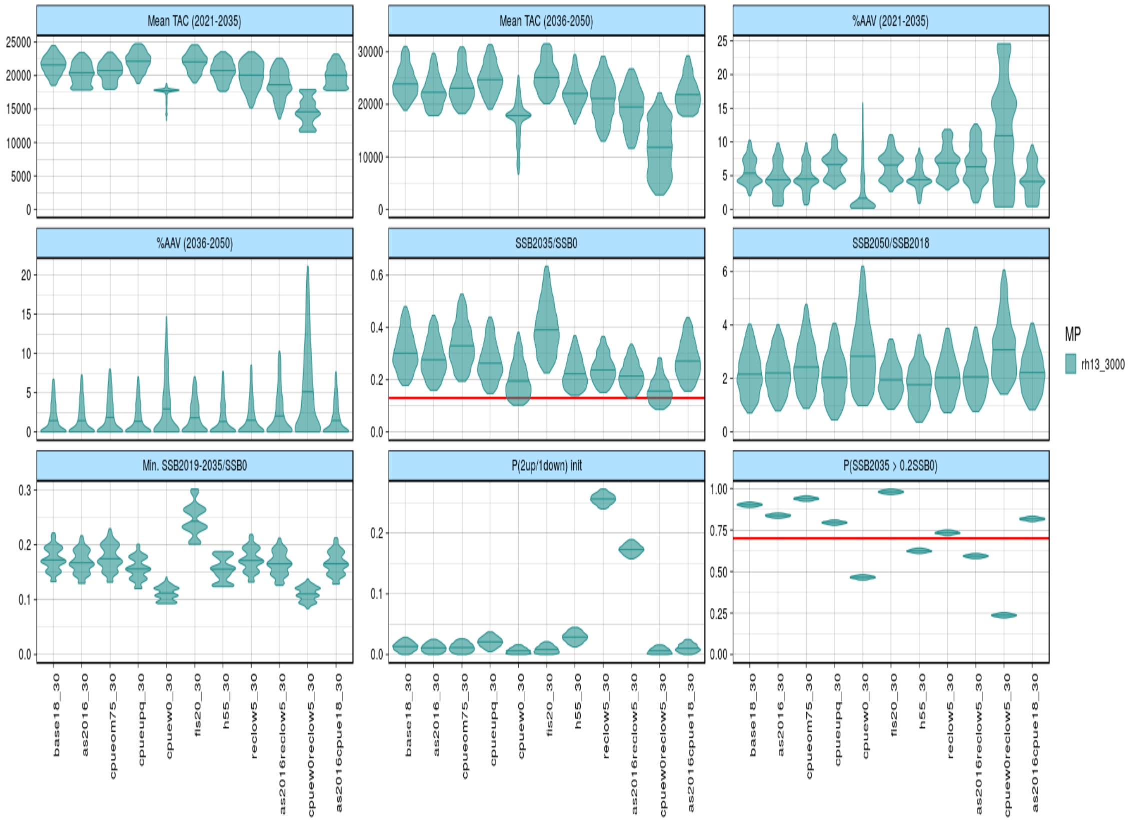

Figure 4.1: *Performance summary for the 30% by 2035 tuning objective.*

4.1 30% by 2035 tuning level

Figure 4.1 shows the SBT shiny app violin plot performance summary for this tuning level. Figure 4.2 shows the associated TAC and TRO worm plots for the reference grid. For the base tuning average TACs (for the 2021–2035 period) range from 19,000 to 24,000t; AAV is low (median of 5%) and never seems to exceed 11%; for the period after the tuning the AAV is even lower as build into the MP structure; the probability of 2 TAC increases then a decrease is very low; and the probability of being above 20% of the unfished level in 2035 is just above 0.9 (so well above the previous 0.7 tuning objective).

For the **as2016** robustness test, this generally results in slightly lower average TACs over the tuning period, slightly lower AAV (as big 2013 recruitment is reduced in influence in projections), and just misses the actual tuning objective getting to around 28% with probability 0.5. The original tuning objective is still exceeded (around 0.85). The crossed **as2016cpue18** test appears *very* similar to the **as2016** test. The mean TACs are marginally smaller, and the 2035 median depletion level is a little higher. The reason is that removing the 2018 CPUE point, as well as the 2016 survey, does not change the reduction in the size of the estimated 2013 year-class (as a result of removing the 2016 aerial survey data point). All it really does is make the mean average CPUE at the start of the projection period somewhat smaller, which results in slightly lower TACs in the first decision year.

For the **reclow5** robustness test, this results in lower TACs over the tuning period and specifically an asymmetric distribution in the average TAC to levels down to around 15,000t at the lowest given the limit-type nature of the gene tagging part of the HCR. The median value of depletion

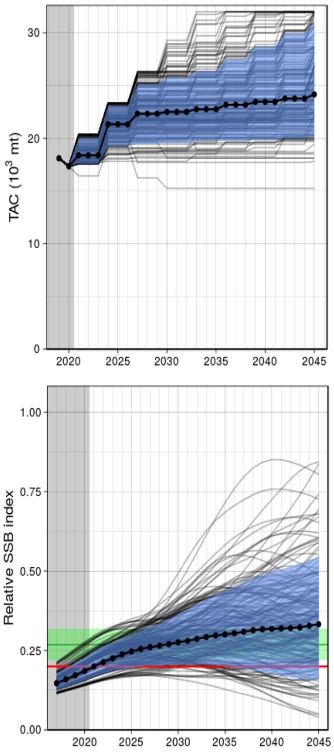

Figure 4.2: *Worms plots for the base UAM1 grid (tuned to 30% by 2035) for TAC (top) and TRO (bottom) and 20 random worms are shown.*

by 2035 is around 0.24 and the original tuning objective is still achieved.

For the **as2016reclow5** combination robustness test this results in the most pessimistic projections, as one might expect. Average TAC levels are similar but a little lower than the **reclow5** case, wIth median TRO levels of around 0.21 by 2035 - so it misses the original tuning objective but does get the relative TRO to 20% with a greater than 50% probability by 2035.

For the **cpueom75** test we actually see slightly lower average TACs over the tuning period and a greater than 50% probability of being above 30% by 2035. This might seem odd for what is, ostensibly, a pessimistic robustness test (hyperstable CPUE). The reasons are twofold: (i) the starting conditions for this test are actually very similar to the reference case, and (ii) the hyperstable relationship means CPUE increases *slower* than true abundance and results in a more conservative MP (lower TACs) and, as a result, a higher level of relative TRO by the target year. For the **cpueupq** test we see higher than average catches, given the step-shift change in q from 2008 onwards, and a resultant median depletion level of around 0.27 by 2035. The MP still easily meets the previous tuning objective (probability of 0.78). The **cpuew0** and **cpue0reclow5** tests are by far the most pessimistic in terms of rebuilding relative to the current and previous objectives and average catch levels. This is because this scenario is *very* pessimistic in terms of current (2019) depletion levels (below 0.1 TRO).In terms of relative level of rebuilding for these two robustness test, the CMP actually increases the TRO by almost a factor of 3 between 2019 and 2050. So, while the MP does very poorly in terms of the the tuning objectives (current and previous), it does act to rebuild the stock - and does increase it substantially in relative terms.

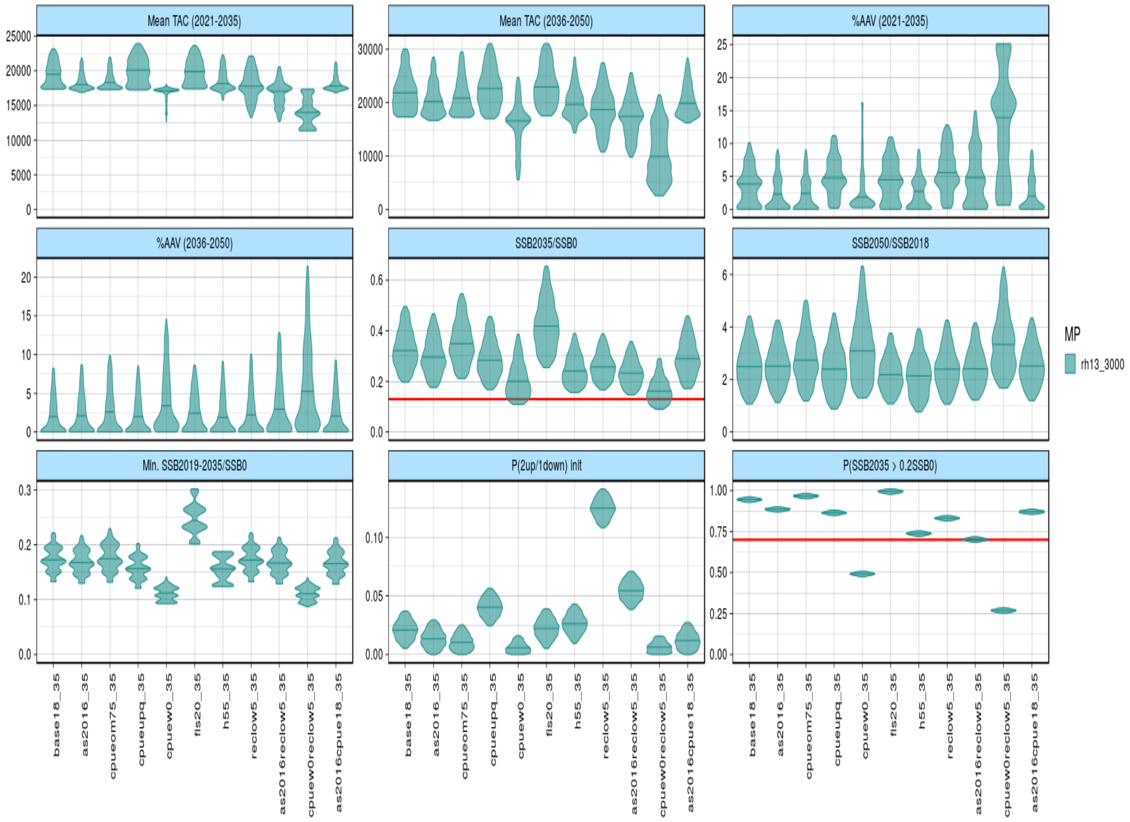

Figure 4.3: *Performance summary for the 35% by 2040 tuning objective.*

4.2 35% by 2040 tuning level

Figure 4.3 shows the SBT shiny app violin plot performance summary for this tuning level. Figure 4.4 shows the associated TAC and TRO worm plots for the **base2018** grid. For the base tuning average TACs (for 2021–2035 period) range from 17,500 to 22,000t; AAV is low (median of 4%) and never seems to exceed 10%; for the period after the tuning year the AAV is even lower, which reflects the reduced level of reactivity built into the MP; the probability of 2 TAC increases then a decrease is low (0.06); and the probability of being above 20% of the unfished level in 2035 is around 0.95 (so well above the 0.7 probability specified for the interim rebuilding objective).

For the **as2016** robustness test, this generally results in slightly lower average TACs over the tuning period, slightly lower AAV (as big 2013 recruitment is reduced in influence in projections), and just misses the actual tuning objective getting to around 32% with probability 0.5 by 2040. The original tuning objective is still exceeded (just over 0.87).

For the **reclow5** robustness test, this results in lower TACs over the tuning period and specifically an asymmetric distribution in the average TAC to levels down to around 13,000t at the lowest given the limit-type nature of the gene tagging part of the HCR. The median value of depletion by 2035 is around 0.26 and the original tuning objective is still easily achieved.

For the **as2016reclow5** combination robustness test this results in the most pessimistic projections, as one might expect. Average TAC levels are similar but a little lower than the **reclow5** case, wth median TRO levels of around 0.23 by 2035 but still *just* meets the original tuning objective. The qualitative features of the performance of the MP tuned to the 35% by 2040 objective

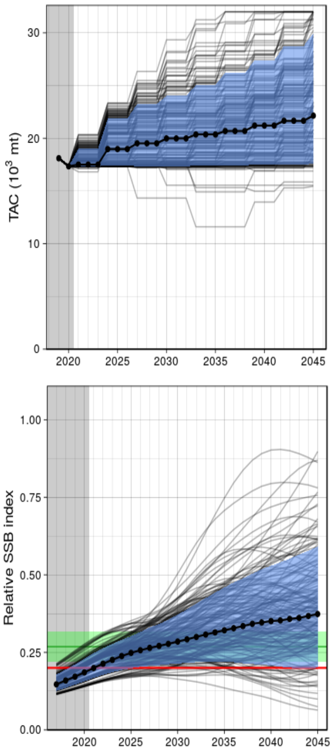

Figure 4.4: *Worms plots for the base UAM1 grid (tuned to 35% by 2040) for TAC (top) and TRO (bottom) and 200 random worms are shown.*

on the CPUE-related robustness tests are basically the same as those of the MP tuned to the 30% by 2035 objective.

4.3 Alternative maximum TAC change levels

Figure 4.5 summarises the effect of the 2,000t and 4,000t maximum TAC change levels, relative to the current 3,000t maximum change. Average TACs between 2021–2035 are around 500t less for the 2,000t, relative to the 3,000, but the same for the 4,000t. As might expected, there is an increasing trend in AAV as the maximum TAC change increases though it still never exceeding 13% even for 4,000t. Minimum TRO levels are basically the same across the three levels, and there is an increasing trend in the 2-up/1-down statistic as the maximum change increases but it never exceeds 0.05 for the levels examined.

4.4 30% by 2040 tuning objective

We tuned the MP described herein to the 30% by 2040 tuning objective because this variant has not been ruled out by the Commission, and to see if it really differs at all to the 30% by 2035 objective. Figure 4.6 shows the reference set performance for all three tuning objectives, and Figure 4.7 shows the TAC and TRO worms for this tuning objective. Basically, this tuning objective is *very* similar to the 30% by 2035 tuning objective. The average catch over the 2021–2035 period is around 400-500t higher, AAV is fractionally higher, the 2-up/1-down probabilities are basically the same, and the median level fo relative TRO by 2035 in this case is 0.29 (which is why they are so similar). In terms of short-term differences, looking at the TAC worms all one can really say is that, in median terms, the first TAC decision is a slightly larger increase and the

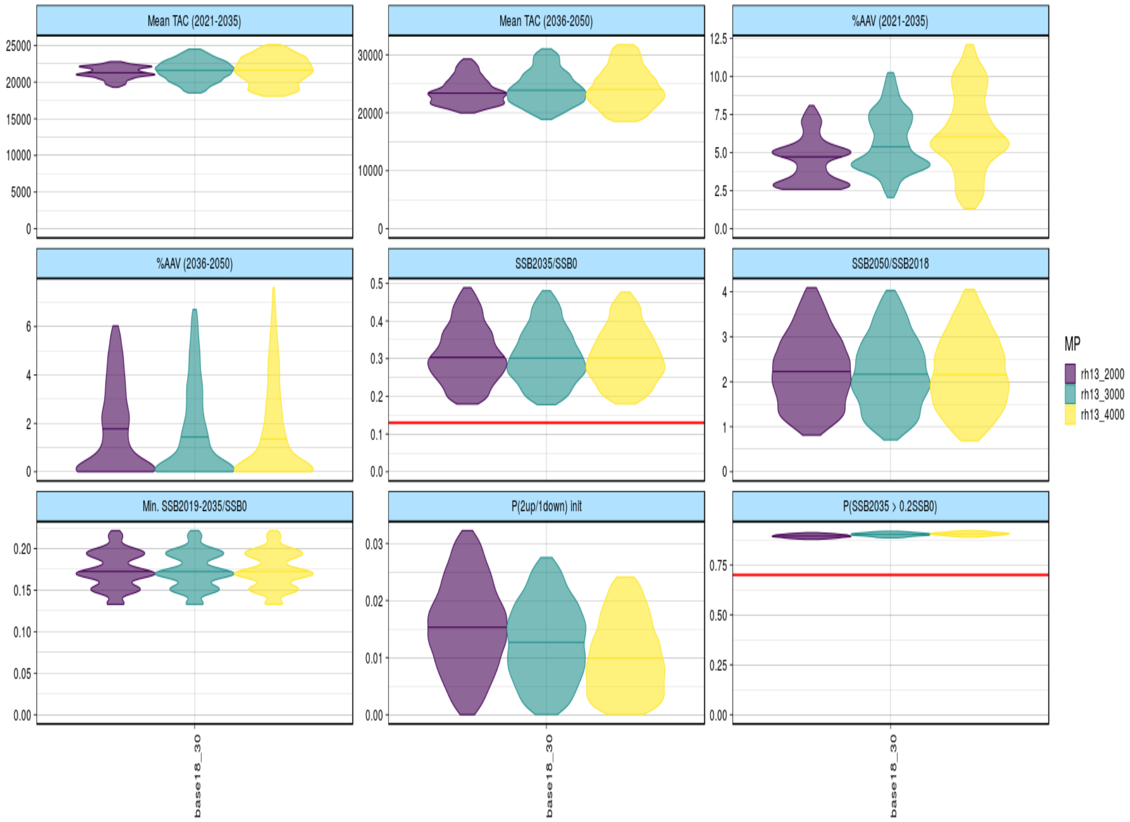

Figure 4.5: *Performance summary for the 30% by 2035 tuning objective and with the 2,000t (purple) and 4,000t (yellow) maximum TAC changes alongside the base 3,000t level.*

second a slightly smaller increase, relative to the 30% by 2035 tuning objective.

5 Discussion

The candidate MP presented at OMMP10 (**rh12** [1]) - which used the gene tagging, CPUE and CKMR data - was revised based on the feedback received from the meeting [2]. The main change to the CMP's HCR was to remove the trend-driven CPUE component and replace it with something similar to the gene tagging functional response. This includes an "OK" zone for mean CPUE within which the TAC does not change, and "good" and "bad" threshold levels which, when breached, result in (potentially asymmetric) increases and decreases in TAC, respectively (see Appendix for details). The modification was implemented to address the higher probability of this CMP, relative to the others, of two initial increases in TAC then a decrease in the third [2]. The revised MP was tuned to the two tuning levels and run on all the key robustness trials. It was also tuned to the 30% by 2035 objective with maximum TAC changes of 2,000t and 4,000t to explore the potential effect of changing from the current default of 3,000t maximum TAC change. For tuning objective completeness, we also included the 30% by 2040 option but only for the reference set of OMs (no robustness trials).

For the 30% by 2035 tuning objective average TACs over the 2021–2035 period had a median of 22,000t and a range of around 19,000-24,000t. AAV levels over the same period were low: median values of 5% and very rarely exceeding 10%. The probability of a 2-up/1-down dynamic

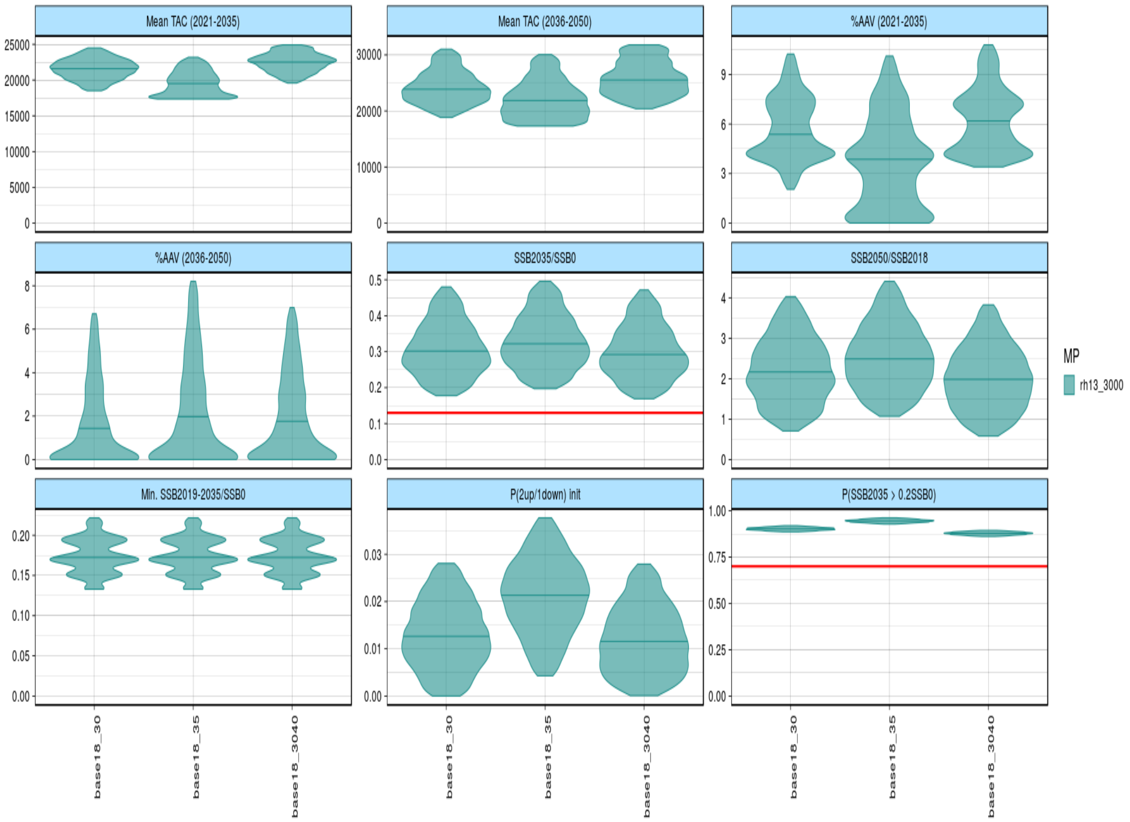

Figure 4.6: *Performance summary on the reference set for the three tuning objectives.*

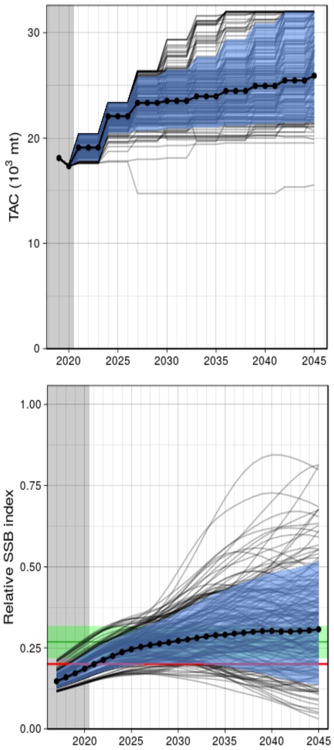

Figure 4.7: *Worms plots for the base UAM1 grid (tuned to 30% by 2040) for TAC (top) and TRO (bottom) and 200 random worms are shown.*

in the first three TACs was very low (0.02) so the modified HCR seems to have addressed the poorer performance of the previous version of the CMP for this statistic. The probability of achieving the interim rebulding objective was 0.94, so well above the 0.7 required level. The MP performs satisfactorily on the high-ranking robustness tests (low recruitment, removing the 2016 aerial survey and 2018 CPUE data points), as well as the Upq2008 and Omega75 CPUE tests. By far the worst performance was on the **cpuew0** because of the very low starting relative TRO level (below 0.1). Notwithstanding this performance against the specified rebuilding objective, the MP does rebuild (in relative terms) the TRO by a factor of almost 3 (relative to a factor of 2 for the more optimistic grids).

For the 35% by 2040 tuning objective the average TACs had a median value of 19,000t (17,500–23,000t range). The AAVs are low - median value of 4% and never exceeding 10% - and a little lower than for the MP tuned to the 30% by 2035 tuning objective. The qualitative performance of this MP tuned to this objective on the robustness tests is the same as for the MP tuned to the 30% by 2035 objective, just slightly more conservative across the board.

Changing the maximum TAC increase/decrease to 2,000 or 4,000t didn't strongly change the behaviour of the MP, at least when tuned to the 30% by 2035 objective. For the 2,000t limit the average TACs (2021–2035) were at most 500t lower than the other two options; and there was no obvious difference in mean TACs for the 3,000t and 4,000t options, just higher variability in the latter. There were small but clear trends in both AAV and the 2-up/1-down TAC probability statistics - increasing with increasing size of maximum TAC - but still at good performance levels. At most, and without running the variants on the robustness test, one could conclude that increasing the maximum TAC change to 4,000t would not be expected to result in higher TACs on average.

When looking at the 30% by 2040 tuning objective, the performance of the MP on the reference set of OMs was *very* similar to that of the MP tuned to the same depletion level but by 2035. This is not necessarily surprising, given how the TRO flattens out after 2035 for this tuning year. At most, there is a 400-500t higher average catch over the 2021–2035 period and a slightly higher TAC increase then slightly lower TAC increase (relative to the 30% by 2035 objective) for the first two TAC decisions.

The revised structure of the CMP presented at the OMMP10 [1] appears to have improved the poor performance on the 2-up/1-down TAC statistic. Given no change to the rest of the structure or major parametric changes in the MP itself, it is perhaps not a major surprise that it performs similarly to before on the other performance statistics. It performs satisfactorily on the high priority robustness tests, and does so with good AAV and other catch related performance criteria. The alternative maximum TAC changes (2,000 and 4,000t) did not appear to have a major effect - in particular there was no obvious significant increase in average TACs for the between the 3000t and 4000t values, but there was a small associated increase in catch variability.

6 Acknowledgements

This work was funded by CSIRO, the Department of Agriculture and the Australian Fisheries Management Authority.

References

[1] R. M. Hillary, A. Preece, C. R. Davies (2019) Updated candidate MP performance summary on reconditioned grid. *CCSBT–OMMP/1906/4*.

[2] Anonymous. Report of the 10th Operating Model and Management Procedure workshop. CCSBT, Canberra, Australia.

[3] R. M. Hillary, A. Preece, C. R. Davies (2019) Updates to the SBT OM. *CCSBT–OMMP/1909/17*.

Appendix

We explored a modified version of the original adult-focused age-structured population model, now with auto-correlated “recruitment” deviations:

$$
\begin{aligned}
N_{y_{\min},a_{\min}} &= \bar{R}\exp\left(\xi_{y_{\min}} - \sigma_R^2/2\right),\\
N_{y,a_{\min}} &= \bar{R}\exp\left(\epsilon_y - \sigma_R^2/2\right),\\
\epsilon_y &= \rho\epsilon_{y-1} + \sqrt{1-\rho^2}\xi_y,\\
\xi_y &\sim N(0,\sigma_R^2),\\
N_{y+1,a+1} &= N_{y,a}\exp\left(-Z_{y,a}\right) \qquad a \in (a_{\min}, a_{\max}),\\
N_{y+1,a_{\max}} &= N_{y,a_{\max}-1}\exp\left(-Z_{y,a_{\max}-1}\right) + N_{y,a_{\max}}\exp\left(-Z_{y,a_{\max}}\right),\\
Z_{y,a} &= Z_y \qquad a \le 25,\\
Z_{y,a} &= Z_y + \frac{a-25}{a_{\max}-25}\left(Z_{a_{\max}} - Z_y\right) \qquad a \in [26, a_{\max}],\\
Z_y &= \frac{Z_{\max}e^{\chi_y} + Z_{\min}}{1+e^{\chi_y}},\\
\chi_{y+1} &= \chi_y + \zeta_y,\\
\zeta_y &\sim N(0,\sigma_\chi^2),\\
TRO_y &= \sum_a N_{y,a}\varphi_a
\end{aligned}
$$

The estimate parameters of this model are:

1. The mean adult recruitment, $\bar{R}$
2. The adult recruitment deviations, ϵ_y
3. The initial value, χ_{init}, that ”starts” the random walk for Z_y (with an associated normal prior mean and SD)
4. The random walk deviations ζ_y

This is similar to the number of parameters estimated in the Bali Procedure population model. There are not a large number of model parameters, and many of them are going to be constrained deviation parameters. The likelihood model for the POP and HSP data are basically the same as those used in the SBT OM, but where M_a and the harvest rates are replaced by $Z_{y,a}$ to estimate cumulative survival in the HSP likelihood. The assumed settings for the CKMR MP population model are detailed in Table 8.1.

The general structure of the revised MP is as follows:

$$
TAC_{y+1} = TAC_y\left(1 + \Delta_y^{\text{cpue}} + \omega^{\text{ck}}\left(\Delta_y^{\text{ck}} - 1\right)\right) \times \Delta_y^{\text{gt}},
$$

where the inertial terms for the CPUE and CKMR parts of the HCR are now additive, not multiplicative as previously explored. This avoids the quadratic term in the multiplicative case where both trends are consistently positive consistently making the TAC increases larger than for the additive case, despite the trends being the same in both cases.

Before detailing the changed form of the HCR we recap some useful variables:

Parameter	Value
$a_{\min}$	6
$a_{\max}$	30
σ_R	0.25
ρ	0.5
σ_χ	0.1
$Z_{\min}$	0.05
$Z_{\max}$	0.4
$Z_{a_{\max}}$	0.5
$\mu_{\chi_{\text{init}}}$	-1.38
$\sigma_{\chi_{\text{init}}}$	0.15
q_{hsp}	0.9

Table 6.1: Settings for CKMR MP population model

- I_y^{ck}: moving average of the estimated TRO from the MP population model (now pushed forward to the current year using the model to project forward for 4 years to avoid too much intertia in the signal when you need it)
- $\tilde{I}$: average estimated TRO from 2003 to 2012 (reference period w.r.t. relative rebuilding criterion)
- γ: proportional amount of TRO rebuilding we wish to achieve

We are interested in the following ratio: $\delta = I_y^{\text{ck}}/(\gamma\tilde{I})$. To get from the current average level of TRO to the 30% level we would consider $\gamma \approx 2$; for the 35% level $\gamma \approx 2.5$. As the ratio δ approaches 1 (i.e. we *think* we are at or close to the target TRO), we would like to have the potential to morph (continuously and possibly smoothly) the behaviour of the MP. It seems that MPs need to be fairly reactive in the first 10–15 years (3–4 TAC decisions) of the projections to be able to tune to the 30% target by 2035, but afterwards that embedded reactivity might be giving rise to continued TAC increases to levels likely to cause the TRO to come back down again post-target year. For the CPUE trend part of the HCR we explore a density-dependent gain parameter:

$$k^{\text{cpue}}(\eta) = w_1^{\text{cpue}}\left(1-\left(1+e^{-2\kappa\eta}\right)^{-1}\right) + w_2^{\text{cpue}}\left(1+e^{-2\kappa\eta}\right)^{-1}$$

where $\eta = \delta - 1$. This is using the logistic function approximation to the Heaviside step function $H[\eta]$ ($H[\eta < 0] = 0$, $H[\eta \geq 0] = 1$). We set $\kappa = 20$ so the transition between the two gain parameters, given η, happens within $\pm 5\%$ of $\delta = 1$. The CPUE multiplier is then just defined as follows:

$$\Delta_y^{\text{cpue}} = k^{\text{cpue}}(\eta)\left(\delta_y^{\text{cpue}} - 1\right)$$

and δ_y^{cpue} is actually very similar in form to the gene tagging part of the HCR

$$\begin{aligned}
\delta_y^{\text{cpue}} &= \left(\frac{\bar{I}_{\text{cpue}}}{I_{\text{low}}}\right)^{\alpha_1} && \forall \bar{I}_{\text{cpue}} \leq I_{\text{low}}, \\
\delta_y^{\text{cpue}} &= 1 && \forall \bar{I}_{\text{cpue}} \in \left(I_{\text{low}}, I_{\text{high}}\right), \\
\delta_y^{\text{cpue}} &= \left(\frac{\bar{I}_{\text{cpue}}}{I_{\text{low}}}\right)^{\beta_1} && \forall \bar{I}_{\text{cpue}} \geq I_{\text{high}},
\end{aligned}$$

where $\bar{I}_{\text{cpue}}$ is the (4 year) moving average LL1 CPUE, $\bar{I}_{\text{low}}$ and $\bar{I}_{\text{high}}$ are upper and lower threshold CPUE values, and α_1 and β_1 allow for an asymmetric response above or below the threshold zone.

For the CKMR part of the HCR we try to preserve the main elements of the previous candidate MP (**rh12**): ensure a minimum rate of increase in the TRO *beneath* the target level, and once it is achieved we would like to maintain the TRO at that level. To include this kind of behaviour in the HCR we also include some density-dependence in the log-linear growth rate at which the HCR moves from a TAC increase to a TAC decrease:

$$\begin{aligned}
\Delta_y^{\mathrm{ck}} &= 1 + k^{\mathrm{ck}}(\eta)\left(\tilde{\lambda}(\eta) - \lambda^{\mathrm{ck}}\right), \\
k^{\mathrm{ck}}(\eta) &= k_1^{\mathrm{ck}}\left(1 - \left(1 + e^{-2\kappa\eta}\right)^{-1}\right) + k_2^{\mathrm{ck}}\left(1 + e^{-2\kappa\eta}\right)^{-1}, \\
\tilde{\lambda}(\eta) &= \lambda_{\min}\left(1 - \left(1 + e^{-2\kappa\eta}\right)^{-1}\right)
\end{aligned}$$

The threshold level at which a trend goes from a TAC decrease to an increase essentially begins at $\lambda_{\min} > 0$ and, as the estimated TRO approaches the target level, this rapidly dercreases to zero (in a similar way to the CPUE trend term). This is to ensure that a minimum level of rebuilding is encouraged for **all** trajectories below the target, and where above the target the *status quo* is preferred.

In the last several incarnations of this MP we use the absolute nature of the GT data then the general principles would be something like:

- Below the limit level the HCR should act strongly to reduce the TAC
- Above the limit level and up to some pre-specified upper level the GT part of the HCR maintains the TAC where it is
- If recent mean recruitment has been suitably elevated (i.e. above a pre-specified level) then the HCR should act to increase the TAC

To calculate the recent mean age 2 abundance from the GT data consider a weighted moving average approach:

$$\bar{N}_{y,2} = \sum_{i=y-1-\tau}^{y-2} \omega_i \widehat{N}_{i,2}$$

where ω_i is a weighting proportional to the number of matches used to produce the GT estimate $\widehat{N}_{i,2}$ (basically inverse variance weighting). The 2 year delay between having the estimate and what year it actually refers to is factored into the calculation. The multiplier for the GT part of the HCR would then be:

$$\begin{aligned}
\Delta_y^{\mathrm{gt}} &= \left(\frac{\bar{N}_{y,2}}{N_{\mathrm{low}}}\right)^{\alpha} \quad \text{if} \quad \bar{N}_{y,2} \leq N_{\mathrm{low}}, \\
\Delta_y^{\mathrm{gt}} &= 1 \qquad\qquad \text{if} \quad \bar{N}_{y,2} \in (N_{\mathrm{low}}, N_{\mathrm{high}}), \\
\Delta_y^{\mathrm{gt}} &= \left(\frac{\bar{N}_{y,2}}{N_{\mathrm{high}}}\right)^{\beta} \quad \text{if} \quad \bar{N}_{y,2} \geq N_{\mathrm{high}}
\end{aligned}$$

with N_{low} the limit level and N_{high} the upper level at where TAC inrceases are permitted. The exponents α and β are to allow for differential responses depending on the situation: we might expect $\alpha > 1$ as we would want to act strongly on poor recruitment levels; alternatively we might have $\beta < 1$ so that TAC inreases based on increased recruitment are more modest, given increased recruitment does not guarantee the TRO will increase (especically if we increase the Fs they experience as they mature).

Along with embedding a kind of switching mechanism in both **rh11** and **rh12**, in terms of behaviour once the target is met, we also continue with the idea of a maximum TAC value. This is again to avoid short-term increases to levels of TAC (and, hence, total catch including UAM) that are not sustainable in the long-term, even for the most optimistic grid combinations and future trajectories, and will definitely require large TAC decreases in the future. The value chosen for the maximum TAC was 32,000t. Including UAM (which is approximately and consistently 20% of the TAC) this value would be a total catch of around 36,000t.

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au