Results of the progression towards a proposed Management Procedure for the Toothfish (*Dissostichus eleginoides*) Resource in the Prince Edward Islands vicinity

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October 2020

ABSTRACT

Brandão and Butterworth (2019a) investigated various target-based Candidate Management Procedures (CMPs) for the Prince Edward Islands toothfish resource; however, their performances under some operating models were not satisfactory so that further investigation/adjustment of these CMPs was needed. An adjusted form of CMP(mean+tag) of Brandão and Butterworth (2019a), which incorporated trends in the cumulative number of recaptured tags as well as the recent mean of the trotline CPUE, was considered to have good potential as a CMP. This paper documents the various iterations of results as this CMP was refined and the results examined by a Task Team. The "final" MP now proposed for the consideration of the Demersal Working Group considers an initial smoothing of the TAC trajectory, is tuned to a target of 40% of the median final depletion under OM10 and constrains the TAC to a maximum inter-annual change of 10%. This MP performs satisfactorily under most of the OMs, in that median catches increase for most of the projection period while catch rates keep increasing and the median final depletion remains above the specified target value under OM10. The application of an initial TAC smoothing largely eliminates the pattern of an initial increase before a later drop in TACs.

INTRODUCTION

Brandão and Butterworth (2019a) investigated several simple empirical Candidate Management Procedures (CMPs) for computing future TACs for toothfish in the Prince Edward Islands region. Of these CMPs, the performance of one showed particular potential, but further work was needed to refine it. The main difference between the formulation of the CMPs reported in this paper and that one from Brandão and Butterworth (2019a) is that previously the slope of a log-linear (rather than a linear) regression of the cumulative number of recaptured tags against time was used in the TAC computation. This change means that the CMP output becomes more sensitive to the number of tags recaptured in absolute terms, which provide a better reflection of resource status.

A Task Team has been evaluating these further refinements to this CMP, with several iterations of results examined that addressed different aspects of the specification of the MP eventually detailed below. This paper documents the various iterations in the development of this MP (with previous iteration results given in an Appendix). The results for the latest iteration which correspond to the proposed MP for consideration for recommendation for adoption by the Demersal Working Group are given in the main text. Table 1 summarises the details of particular specifications of the CMP at each iteration, and highlights the changes made from the previous iteration.

OPERATING MODELS AND PROJECTIONS

Assessment component

Brandão and Butterworth (2019b) presented the conditioning of a Reference Set (RS) of Operating Models (OMs) to be used to generate future data to test Candidate Management Procedures (CMPs). Table 2 lists the final RS and gives details of the differences between the Base case OM (OM01) and each alternative OM. The OMs developed are Age-Structure Production Models (ASPMs), and the methodology applied to fit ("condition") these models to updated data is given in Appendix A. Table 3 lists the Robustness tests (ROBs) suggested by the Task Team (see below for details), and gives details of the differences between the Base case OM (OM01) and each alternative ROB. Only ROB01 and ROB02 need to be conditioned, as the remaining ROBs affect only projections and have been run for the Base case OM only. Robustness tests ROB01 to ROB03 are alternative OMs (OM11, OM17 and OM18) that have been investigated previously but were agreed to be considered as part of the Robustness rather than the Reference set as they were deemed less plausible. Robustness tests ROB04 and ROB05 try to bound the problem of the consistent under-catching of the TAC that has been a feature of the fishery (see Figure 1). The baseline runs assume that the TAC is fully caught every year, but two sensitivities to this are considered:

a) The fishery continues forever with the proportion of under-catch equal to the average over the last five years (i.e. average over 2015 to 2019) (ROB04). A value of under-catch = 0.488 has been used.

b) That under-catch continues for five more years, but that then changes to a full catch from projection year six onwards (i.e. fully caught from 2025) (ROB05).

ROB06 and ROB07 reflect different assumptions about the future tagging rate. The baseline runs assume a constant number of tagged fish of 400 per year. Two sensitivities are considered which adjust this number depending on the TAC set for that year. These are:

a) Assume the number of tags released is $400TAC_y/TAC_{2020}$, i.e. proportional to the TAC (ROB06).

b) The number of tags released is assumed to be as in (a) until 2024, but from 2025 the number of tags released is tripled, i.e. assumed to be $1200TAC_y/TAC_{2020}$. This is to account for the possibility that the tagging rate might increase to three fish per tonne caught in the future (ROB07).

Projections component

The CMPs investigated here assume that commercial trotline CPUE data will continue to be available annually and that tag-recapture data from trotlines will be available in the future. Details on the future level of tagging assumed is discussed below under item (5). The current level of cetacean predation assumed for trotlines by each OM is also assumed to continue in the future. Furthermore, the assumption is made that no IUU catches take place in the future.

The evaluation of the CMPs require the simulation of such future CPUE and tag-recapture data from projections for the population. These projections are carried out using the following procedure.

1. Numbers-at-age ($N_{y',a}$) for the start of the year in which projections commence (i.e. y' = 2018[1]) are calculated by applying equations (A1.1)–(A1.3). To allow for initial variation in biomass projections (as the stochastic effects enter later only through variability in future recruitment which takes a

[1] Throughout this paper a year *y* refers to a "fishing"-year which is defined to be from 1 December of year *y*-1 to 30 November of year *y*.

period to propagate through to the exploitable component of the biomass), the numbers-at-age for the first seven years are allowed to vary, where these variations are simulated by generating $\varphi_{y'}$ factors distributed as $N(0,\sigma_R^2)$, where $\sigma_R = 0.5$. The reason for this is that the catch-at-length data to which the OMs are fitted provides no information on recruitment residuals $\zeta_{y'}$ for these year classes which have yet to enter the fishery, so that these $\zeta_{y'}$ are estimated to be zero in the assessments. Thus, for ages 1–7, the numbers-at-age are given by $N_{y',a}e^{\left(\varphi_{y'}-\frac{\sigma_R^2}{2}\right)}$. The future catches-at-age ($C_{y',a}$) are obtained from equations (A1.4) and (A1.5). Such future catch-at-age values are generated under the assumption that the commercial selectivity function remains the same as that for the last year of the assessment. Future recruitments are obtained from the stock-recruitment relationship given by equation (A1.35), which allows for fluctuations about this relationship. These fluctuations are computed for each future year simulated by generating $\zeta_{y'}$ factors distributed as $N(0,\sigma_R^2)$, where $\sigma_R = 0.5$.

2. Future spawning and exploitable biomasses are calculated using equations (A1.14) and (A1.23). Given the exploitable biomass for trotlines, the expected (trotline) CPUE abundance index $I_{y'}^{CPUE}$is first generated using equation (A1.24); then a log-normally distributed observation error is added to this expected value. The fits to the trotline CPUE indices by the RS OMs do not estimate the last two of these index values well; as a result, future projected CPUE indices are much higher than those observed recently. To take this into account, the projected CPUE indices have been multiplied by the ratio of the average of the last two CPUE indices observed to the fitted average for each OM (ϑ). Hence projections of the trotline CPUE (accounting for bias and cetacean depredation) are given by:

$$I_{y'}^{CPUE} = \frac{\vartheta}{\phi} q B_{y'}^{\exp} e^{\varepsilon_{y'}},$$

where $\varepsilon_{y'}$ is normally distributed with a mean zero and a standard deviation σ whose value is given by the estimate obtained for the operating model (equation (A1.26)) as is *q* (from equation (A1.25)), for the trotline fishery.

3. For the purpose of applying equation (1) below, which describes the CMP considered to calculate future TACs, the following approach has been adopted to take the actual TACs already set for 2018 to 2020 into account:

$$TAC_{y'} = \begin{cases} 575 & y' = 2018 \\ 543 & y' = 2019 \\ 502.3 & y' = 2020 \\ TAC_y & y' \geq 2021 \end{cases}.$$

For future years (i.e. 2021, 2022, etc. for year *y'*), the generated trotline CPUE abundance indices and the cumulative number of recaptured tags are used to compute future TACs $\left(TAC_{y'+1}\right)$ from the TACs for the current year $\left(TAC_{y'}\right)$, as described in the next section which specifies the CMP. Note that this does not apply to the first iteration of results, as TACs were set for 2018 and 2019 only at the time this work was carried out, so that TACs were generated from 2020 as reported in Brandão and Butterworth (2019a) (see also Table 1).

4. The true catch ($C_{y'}$) (removal from the population) is given by the sum of $TAC_{y'}$ (the legal component) and any assumed illegal component (taken to be zero at present), together with the assumed level of cetacean depredation which is taken to remain at its current level for the OM concerned. To account

for the now known catches for 2018 and 2019 and the currently allocated TAC that is set for the 2020 season, the true catch is calculated as:

$$C_{y'} = \begin{cases} \phi\left(346.1 + IUU_{y'}\right) & y' = 2018 \\ \phi\left(269.5 + +IUU_{y'}\right) & y' = 2019 \\ \phi\left(502.3 + IUU_{y'}\right) & y' = 2020' \\ \phi\left(TAC_y + IUU_{y'}\right) & y' \geq 2021 \end{cases}$$

where ϕ denotes the factor by which the catch is changed due to the cetacean depredation assumed. The previous factor τ (Brandão and Butterworth, 2019a) that denoted the proportion of the TAC that is being allocated does not apply anymore, as from 2021 onwards the full TAC is being allocated. The value for 2019 is the catch for this fishing season, while 502.3 denotes the TAC that has been set for 2020 (and which has been fully allocated). Note that again for the first iteration of results, the true catch is calculated as in Brandão and Butterworth (2019a), in which the TACs for 2019 and 2020 were not fully allocated.

The numbers-at-age for year *y'* are projected forward under this true catch (removal); the operating model is used to obtain values for $C_{y',a}$ and $N_{y'+1,a}$. The same assumptions about the commercial selectivity function and recruitment fluctuations as made in step (1) above are also made for these projections.

5. The number of tags released each year is assumed to be constant in the future (and assumed to be 400 in this paper). The age distribution of tags released in year y' $\left(R_{y',a}\right)$, given the abundance of toothfish $N_{y',a}$, is generated as:

$$R_{y',a} = 400 \frac{N_{y',a}\frac{\bar{R}_a}{\bar{N}_a}}{\sum_a\left(N_{y',a}\frac{\bar{R}_a}{\bar{N}_a}\right)},$$

where

$\bar{R}_a$ is the average number (over the period 2005 to 2017) of tags released on fish of age *a*, and

$\bar{N}_a$ is the average number (over the period 2005 to 2017) in the population of age *a*.

Given the fishing mortality for toothfish in year *y'* of age *a* for fleet *f* $\left(F^f_{y',a}\right)$, equation (A1.38) is used to compute the estimated numbers of tags recaptured from trotlines $\left(\hat{r}_{y',a}\right)$. Future age aggregated numbers of tags recaptured from trotlines $\left(r_{y'}\right)$ are then generated as realisations from a Poisson $\left(\hat{r}_{y'}\right)$ distribution, where $\hat{r}_{y'} = \sum_a r_{y',a}$. The cumulative recapture numbers are then calculated from the age aggregated generated numbers of recaptured tags.

6. Steps (2)–(4) are repeated for each future year considered.
7. This projection procedure is replicated 100 times, to provide the probability distributions for projection results arising from uncertainties in future recruitment and observation errors in CPUE (which in turn affect future catches and consequently numbers in the population and the number of recaptures).

The updated GLMM-standardised trotline CPUE estimates for 2018 and 2019 (Table 4), and the observed number of tags released together with the number of tag-recaptures observed for 2018 and 2019 are used as the starting point inputs in the projections.

THE CMP CONSIDERED

The CMP considered in this paper, where the TAC is modified in synchrony with the trends in resource abundance indices (such as CPUE and tag recapture data) is specified as:

$$\text{CMP:} \quad TAC_{y+1} = \left(TAC_y \left[1 + \lambda \left(\frac{\mu_y^{CPUE} - t*}{t*}\right)\right]\left[1 - \gamma\left(\frac{s_y^{cum(recap)} - s_t^*}{s_t^*}\right)\right]\right), \tag{1}$$

where μ_y^{CPUE} is the mean trotline CPUE for the years $y-4, y-3$ and $y-2$ to account for the fact that at the time the TAC is set in year y, complete data are only available to year $y-2$. The quantity $s_y^{cum(recap)}$ is the slope of a linear regression of the cumulative number of recaptured tags against time for the years $y-6$ to $y-2$, and $\lambda,\ \gamma,\ t*$ and s_t^* are control parameters. Previous results and those for the first iteration set of results (see Table 1) did not consider this two-year lag in the available data when projecting TACs.

This CMP also constrains TACs to a maximum inter-annual change, after which an initial smoothing of the TAC is considered by introducing the factor ψ , so that

$$TAC_{y+1} = \psi_{y+1} TAC_{y+1}$$

where:

$$\psi_{y+1} = \begin{cases} x & \text{for } y+1 \leq 2025 \\ z & \text{for } 2025 < y+1 < 2030 \\ 1 & \text{for } y+1 \geq 2030 \end{cases}$$

and x is chosen such that $1-x$ is the percentage by which the TAC is reduced initially with z reflecting the linear increase from x in 2025 to 1 in 2030. Thus, for $x=1$, there would be no initial smoothing of the TAC.

This CMP is tuned to achieve a target value for the median final depletion under OM10 (see Table 1 for the values assumed by different CMPs). OM10 was chosen for this purpose as it shows an improved fit to the recent trotline CPUE decline than OM1.

THE DEVELOPMENT OF THE CANDIDATE MANAGEMENT PROCEDURE PROPOSED

The CMP of Brandão and Butterworth (2019a) selected for further investigation for computing future TACs for toothfish in the Prince Edward Islands region incorporates trends in the cumulative number of recaptured tags as well as the recent mean of the trotline CPUE. It is referred to as CMP(mean+tag) in Brandão and Butterworth (2019a). The formulation of the CMP (given in equation (1) above) remains the same throughout this document but various specifications of this CMP are considered in the development of the "final" proposed MP together with the results assessed by the Task Team over several iterations. As some of the specifications of the CMP were tested, different references of the CMPs were used to differentiate between them. Table 1 summarises the different specifications of the CMP at different iterations of investigation, and the reference name given to that CMP in the results.

Since results were presented in Brandão and Butterworth (2019a), the following iterations have been conducted to address suggestions made by the Task Team in the process of developing a MP for toothfish:

1. **Iteration 1**: The CMP(mean+tag) of Brandão and Butterworth (2019a) was modified so that the slope of the number of cumulative tags recaptured was calculated as a linear regression of the cumulative number of recaptured tags against time, instead of as a log-linear regression. All other specifications of the CMP remained as for Brandão and Butterworth (2019a) (see Table 1).
2. **Iteration 2**: The CMP of iteration 1 was adjusted to include the following suggestions made by the Task Team:
   a) Changes to the Base case OM: It was suggested the new information with regard to the portion of the TAC that is not allocated, the now known catch in 2019 and the TAC set in 2020 be incorporated. These changes are reflected in the calculation of the true catch ($C_{y',a}$) (removals from the population) and the calculation of future TACs which are described in points (3) and (4) above. Given the availability now of the 2019 data, the standardised CPUE index for 2019 as well as the tagging data for 2019 are also input for the evaluation of the CMP. Table 4 shows the updated standardised CPUE series that incorporates data to 2019 as well as the cumulative number of recaptured tags observed to 2019.
   b) Changes to the Baseline CMP: It was proposed that the Baseline CMP constrain TACs to a maximum inter-annual change of 10% instead of 15% as previously. A two-year lag in the calculation of the CMP is applied to account for the fact that at the time the TAC is set in year y, complete data are available only to year $y-2$.

   After Iteration 1, the final RS of OMs was suggested, as was a set of Robustness tests (ROBs). Results under Iteration 2 are provided for the RS of OMs and these ROBs.

3. **Iteration 3:** The changes made in iteration 2 to the Base case OM meant that generated projections start from 2021. To continue basing performance statistics on a twenty-year projection period, the final projection year was changed from 2038 to 2040. Alternative CMPs to the Baseline CMP are also investigated to either constrain the TAC to various maximum inter-annual changes, or to tune to different median final depletions under OM10. Thus, the following CMPs were investigated:

   CMP01: constrain TAC to maximum inter-annual change of 10%.
   CMP02: constrain TAC to maximum inter-annual change of 5%.
   CMP03: constrain TAC to maximum inter-annual change of 15%.
   CMP04: Tune CMP to a target of 30% of the median final depletion under OM10.
   CMP05: Tune CMP to a target of 50% of the median final depletion under OM10.

   CMP01 to CMP03 assume the Baseline target of 40% of the median final depletion under OM10. CMP04 and CMP05 assume the Baseline constraint of the TAC to a maximum inter-annual change of 10%. The results presented for these CMPs are restricted to OM02, OM10 and OM15, where the first and last were selected as they reflected the largest positive and negative median final depletions compared to that for OM10.

   Alternative CMPs to CMP01 to CMP05 were then considered in which an initial smoothing of the TAC was applied. In this case the CMP is denoted with an "S" for example CMP01S for CMP01 with an initial TAC smoothing. The results presented for all these CMPs are again restricted to OM02, OM10 and OM15.

4. **Iteration 4:** Results in the main text are given for the complete Reference Set of Operating Models and Robustness tests for the proposed MP to be considered by the Demersal Working Group. This MP considers an initial smoothing of the TAC, is tuned to a target of 40% for the median final depletion under OM10 and constrains the TAC to a maximum inter-annual change of 10%. An alternative form of this CMP in which a non-symmetrical maximum inter-annual variation in the TAC of 5% down and 10% up is also considered. To the differentiate between these two CMPs, in this paper they will be referenced as MP10-10 (for a maximum up and down inter-annual change in TAC of 10%), and CMP5-

10 (for a maximum of 5% down and 10% up in the inter-annual change in the TAC). The results for CMP5-10 are restricted to OM02, OM10 and OM15.

Further details of how the Task Team suggestions arose at each iteration are provided below under the discussion of results.

RESULTS AND DISCUSSION

The performances of the CMPs have been considered in terms of future projections over a 20-year period, and in particular the following four categories of performance statistics which are intended to capture key features of the trade-off choices to be made.

Catches achieved

Average annual catch:

$$\overline{C^s} = \frac{1}{20}\sum_{y=2021}^{2040} C_y^s\,,$$

where *s* represents simulation *s;* averages of annual catch for different periods within these projections are also considered.

Risk to resource

Final resource depletion:

$$\frac{B_{2040}^{sp(s)}}{K^{sp(s)}}$$

Final resource depletion relative to current (2017):

$$\frac{B_{2040}^{sp(s)}}{B_{2017}^{sp(s)}}$$

Final resource depletion relative to the MSY level:

$$\frac{B_{2040}^{sp(s)}}{B_{MSY}^{sp(s)}}$$

Industrial stability

Average annual catch variation (over 20 years):

$$AAV^s = \frac{1}{20}\sum_{y=2019}^{2040}\frac{\left|C_y^s - C_{y-1}^s\right|}{C_{y-1}^s}$$

Economic viability

Final CPUE relative to recent levels:

$$\frac{CPUE_{2040}^s}{\frac{1}{3}\sum_{y=2015}^{2017} CPUE_y^s}.$$

Over the simulations *s* there is a distribution for each of these statistics, and performance is reported in terms of statistics of those distributions (typically the median and 90% probability interval).

Experimentation with different values of the control parameters led to the selection for the CMPs as shown in Table 1, given a specified target value of the median final depletion under OM10.

A full discussion of results for iteration 1 through to iteration 3 are given in Appendix B, so that only the main conclusions drawn and the suggestions for further work suggested by the Task Team will be discussed here.

ITERATION 1

The adjusted form of CMP(mean+tag) of Brandão and Butterworth (2019a) performed satisfactorily under most of the OMs, in that median catches increased for most of the projection period while catch rates kept increasing and the median final depletion remained above the specified target value under OM10 (Figures I1.1 and I1.2). The performance of this CMP under OM17 was still not satisfactory, but as this OM assumes quite an extreme tag loss, it was suggested to consider OM17 as a robustness test rather than part of the Reference Set.

Task Team suggestions:

Considering this initial satisfactory performance of the CMP, the Task Team suggested further work to address certain concerns. To this end a set of Robustness tests were constructed that addressed the issue of the appreciable under-catching of the TAC by the fishery and the number of tags that are assumed to be released in the future (details of these are given earlier in the text). Previous Reference set OMs that had been decided to be a part instead of the Robustness set were also added to that list (such as OM11, OM17 and OM18).

The CMP constrained TACs to a maximum inter-annual change of 15%. It was considered that this might be too high to ensure industrial stability, and a value of 10% was suggested, with sensitivities of 5% and 15% to be investigated.

The parameters of this CMP were tuned to achieve a target median final depletion level of 40% under OM10. Sensitivities to evaluate alternative depletion tuning factors of 30% and 50% were also suggested.

It was also suggested that as by this stage the 2019 fishery data were available and the TAC for 2020 had been set, that this information should be incorporated in the testing of the CMP. It was also agreed that new information with regard to the portion of the TAC that is not allocated should be incorporated as well. Projections of the TAC under the CMP were also to be corrected to account for the two-year lag in information available when setting a TAC.

ITERATION 2

Results for the Baseline CMP01 (maximum inter-annual change of 10% and tuned to achieve a target median final depletion level of 40% under OM10) that incorporated the changes suggested by the Task Team in Iteration 1 were provided for the RS of OMs and for the Robustness tests. Under most OMs, the performance of the CMP was satisfactory (Figures I2.1 and I2.2 for RS and Figures I2.4 and I2.5 for ROBs). However, also under most OMs and Robustness tests, there was an increase in median TACs initially followed by a later drop in TACs, which was considered an undesirable feature (Figure I2.2 and I2.5).

Task Team suggestions:

Alternative CMPs to the Baseline CMP to address suggestions from Iteration 1 that had not been addressed under Iteration 2 (such as the value for the inter-annual TAC change and the value to which the CMP is tuned under OM10) should be investigated.

Investigate the introduction of an initial smoothing of the TAC to attempt to minimise the initial increase in TAC followed by a drop a few years later that is observed under most OMs and Robustness tests.

Since the CMP considers the available data for 2018 and 2019 as well as the known TAC set for 2020, the projections from generated data start only from 2021. Therefore, it was suggested that the performance statistics should be based on generated projections only. To still base these on twenty-year projections, the final year of projection period then needed to be changed from 2038 to 2040.

It was suggested that results for the various CMPs to be considered at the next iteration should be restricted to results under OM02 (a more optimistic final status of the resource), OM10 (intermediate final status of the resource and the OM to which CMPs are tuned) and OM15 (a more pessimistic final status of the resource).

ITERATION 3

Results for five CMPs (CMP01 to CMP05 for which details are given above) that either constrain the TAC to various maximum inter-annual changes, or for which the median final depletion under OM10 varies, were examined to decide on the choice of these values for a proposed MP (Figures I3.1 to I3.3). The results for these CMPs, but with an initial smoothing of the TAC implemented, were also examined (Figures I3.4 to I3.6). Figure I3.7 that compares the results for a CMP with and without an initial smoothing of the TAC was examined to decide on the appropriateness of a smoothing factor to include in the CMP.

Task Team suggestions:

It was agreed that a MP that considers an initial smoothing of the TAC, be tuned to a target of 40% for the median final depletion under OM10 and constrains the TAC to a maximum inter-annual change of 10% would the appropriate. Results for this MP for the Reference Set and Robustness tests should be obtained.

An alternative form of this MP in which a non-symmetrical maximum inter-annual variation in the TAC of 5% down and 10% was also suggested for investigation. The results presented for this CMP should be restricted to OM02, OM10 and OM15.

ITERATION 4

Testing the Baseline MP10-10 for the Reference Set OMs yields the results shown in Tables 5 to 7. Results for the performance statistics are shown calculated for each individual OM as well as for combining the outputs from all 14 OMs together. Figure 2 compares the performance of this MP under the Reference Set OMs.

Table 6 reports various catch statistics, while Table 7 gives results based on CPUE statistics. Median projections for some performance statistics under each individual selected OM are shown in Figures 3a to 3b. Figure 4 shows results when combining all the outputs from the 14 OMs together and calculating the performance statistics for the 14x100 simulations. Figure 4 also shows one randomly selected worm projection from each of the OMs.

A similar set of results for MP10-10 but for the Robustness tests are shown in Tables 8 to 10 and Figures 5 to 7. The MP performs satisfactorily under nearly all these Robustness tests. The exception is ROB02 which imposes a very extreme tag loss rate. The results for this Robustness test are excluded from the calculations of performance statistics when combining all Robustness tests, as they distort plots of the results.

Under most OMs, the performance of this simple empirical MP seems to be satisfactory in that median catches increase for most of the projection period, while catch rates also keep increasing and the median final depletion remains above the specified target value under OM10. Under OM03 and OM15, the median final depletion is only slightly below this target value.

The application of an initial TAC smoothing generally eliminates the effect of an increase in median TACs initially before a later drop. For those OMs that show a drop in TACs, this drop is mainly towards the end of the projection period rather than after a few years only as previous results had shown. However, for all OMs the median TAC remains above its current value despite this drop.

Tables 11 to 13 compare the performance statistics for CMP5-10 and MP10-10 under OM02, OM10 and OM15. Figure 8 compares the median trajectories of the TAC and spawning biomass depletion for these CMPs and the selected OMs. Constraining the maximum downward inter-annual change in the TAC to 5% instead of 10% has a minimal impact on the performance of the CMP under the selected OMs. Even though there is minimal difference between the results under MP10-10 and CMP5-10, MP10-10 is proposed as the MP to recommend for toothfish given that the rationale for a non-symmetrical inter-annual change in the TAC is not particularly compelling.

REFERENCES

Brandão, A. and Butterworth, D.S. 2019a. Initial results for a further four Candidate Management Procedures for the toothfish (*Dissostichus eleginoides*) resource in the Prince Edward Islands vicinity. Department of Agriculture, Forestry and Fisheries Document: FISHERIES/2019/OCT/SWG-DEM/27.

Brandão, A. and Butterworth, D.S. 2019b. Conditioning of the Reference Set of Operating Models for the toothfish resource in the Prince Edward Islands vicinity. Department of Agriculture, Forestry and Fisheries Document: FISHERIES/2019/MAR/SWG-DEM/04.

Table 1. A list of the various CMPs investigated and their specifications at various iterations of investigation of the CMP. Entries in bold highlight the difference between that CMP and the CMP in the iteration above. For iteration 3, the changes highlighted for CMP02 to CMP05 reflect changes from CMP01. The changes highlighted for CMP01S to CMP05S reflect changes from the respective CMP without the initial TAC smoothing (CMP01 to CMP05). The changes highlighted in iteration 4 refer to changes from CMP01.

Iteration	CMP reference	Final depletion under OM10 that CMP is tuned	Inter-annual TAC variation (down/up)	Smoothing parameter ψ ($x = 1$ implies no smoothing)	First year of TAC projection	Final year of projection	Further available data for catch, CPUE and tagging	Years TAC not fully allocated	Control parameters
1	**CMP(mean+tag)**	40%	15%/15%	$x = 1$	2020	2038	2018	2019 and 2020	$\lambda = 1,\ \gamma = 1,\ t* = 0.780$ and $s_t^* = 45$
2	**CMP01***	40%	**10%/10%**	$x = 1$	**2021**	2038	**2018 and 2019**	**none**	$\lambda = 1,\ \gamma = 1,\ t* = 0.785$ and $s_t^* = 45$
3	**CMP01**	40%	10%/10%	$x = 1$	2021	**2040**	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.741$ and $s_t^* = 45$
	CMP02	40%	**5%/5%**	$x = 1$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.735$ and $s_t^* = 44$
	CMP03	40%	**15%/15%**	$x = 1$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.735$ and $s_t^* = 45$
	CMP04	**30%**	10%/10%	$x = 1$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.589$ and $s_t^* = 54$
	CMP05	**50%**	10%/10%	$x = 1$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.925$ and $s_t^* = 34$
	CMP01S	40%	10%/10%	$\boldsymbol{x = 0.95}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.741$ and $s_t^* = 45$
	CMP02S	40%	5%/5%	$\boldsymbol{x = 0.97}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.735$ and $s_t^* = 44$
	CMP03S	40%	15%/15%	$\boldsymbol{x = 0.90}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.735$ and $s_t^* = 45$
	CMP04S	30%	10%/10%	$\boldsymbol{x = 0.95}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.589$ and $s_t^* = 54$
	CMP05S	50%	10%/10%	$\boldsymbol{x = 0.97}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.925$ and $s_t^* = 34$
4	**MP10-10**	40%	10%/10%	$\boldsymbol{x = 0.95}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.760$ and $s_t^* = 44$
	CMP5-10	40%	**5%/10%**	$\boldsymbol{x = 0.95}$	2021	2040	2018 and 2019	none	$\lambda = 1,\ \gamma = 1,\ t* = 0.798$ and $s_t^* = 44$

Table 2. A list of the Reference Set OMs with details of the differences between the Base case OM (OM01) and each alternative OM. Length related units are cm. Note that there are 14 OMs in total, as OM11 is no longer included.

Operating Model	Description	Base case values
OM01	Base case	
OM02	Natural mortality = 0.10	0.13
OM03	Natural mortality = 0.16	0.13
OM04	Steepness parameter h = 0.6	0.75
OM05	Steepness parameter h = 0.9	0.75
OM06	Cetacean predation (longlines) = +30%	+10%
OM07	Cetacean predation (trotlines) = 0%	+5%
OM08	Cetacean predation (trotlines) = +10%	+5%
OM09	Weight applied to all CPUE = 5	1
OM10	Weight applied to all CPUE = 10	1
OM12	ℓ_∞= 174.5 κ = 0.0425 t_{o} = -1.4575	ℓ_∞= 152.0 κ = 0.067 t_{o} = -1.49
OM13†	c = $4.09\text{x}10^{-9}$ d = 3.196	c = $2.54\text{x}10^{-8}$ d = 2.8
OM14†	c = $4.17\text{x}10^{-9}$ d = 3.206	c = $2.54\text{x}10^{-8}$ d = 2.8
OM15	Tag reporting rate = 0.8	1

† The mass at length conversion is given in terms of cm to tonnes.

Table 3. A list of the **Robustness tests** with details of the differences between the Base case OM (OM01) and each Robustness test.

Operating Model	Description	Base case values
ROB01	σ_R = 0.1 (until 1997), 0.5 (after 1997)	0.5
ROB02	Annual tag loss/mortality rate = 0.5	0
ROB03	Basecase (no bias in projections of CPUE, i.e. $\vartheta = 1$)	Bias in projections of CPUE
ROB04	TAC is not fully caught with the under-catch = average proportion of under catch over the last 5 years (2015 to 2019)	TAC fully caught
ROB05	Under-catch proportion assumed in ROB04 applies for the next 5 years and then the TAC is fully caught (from 2025)	TAC fully caught
ROB06	Number of tags released is assumed to be $400*TAC_y/TAC_{2020}$	400
ROB07	Number of tags released assumed to be as for ROB06 until 2024. From 2025 number of tags released is assumed to be "tripled" to $400*(3*TAC_y)/TAC_{2020}$	400

Table 4. The GLMM relative abundance indices for toothfish provided by the standardised commercial trotline CPUE series for the Prince Edward Islands EEZ. This series has been updated to include the 2019 "fishing"[2] year data that is now available. The cumulative number of all recaptured tags is also given. The MP proposed uses these two pieces of information for input.

"Fishing"-year	GLMM *CPUE*	Cumulative number of recaptured tags
2007	—	2
2008	—	2
2009	—	5
2010	1.179	7
2011	1.000	16
2012	1.125	21
2013	0.938	26
2014	0.741	38
2015	0.821	64
2016	0.531	85
2017	0.545	107
2018	0.930	138
2019	0.892	149

[2] A "fishing"- year *y* is defined to be from 1 December of year *y*-1 to 30 November of year *y*.

Table 5. Medians of the distributions of several performance statistics under the simple **MP10-10** considered for the selected **Reference Set OMs**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all 14 RS OMs, giving equal weight to each OM. MP10-10 is tuned to provide the median result for OM10 shown in **bold** in the second column.

RS	$\frac{B^{sp}_{2040}}{K^{sp}}$	$\frac{B^{sp}_{2040}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2040}}{B_{MSY}}$	$\frac{B^{sp}_{2024}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
OM01 (Basecase)	0.44 (0.37; 0.53)	1.04 (0.88; 1.25)	1.79 (1.52; 2.16)	1.63 (1.53; 1.94)	792 (604; 986)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
OM02 (M = 0.1)	0.52 (0.46; 0.61)	1.01 (0.88; 1.17)	2.07 (1.81; 2.41)	2.00 (1.93; 2.23)	638 (497; 834)	561 (553; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
OM03 (M=0.16)	0.39 (0.32; 0.49)	1.04 (0.85; 1.32)	1.63 (1.34; 2.07)	1.45 (1.32; 1.86)	936 (683; 1112)	561 (561; 561)	0.08 (0.06; 0.08)	0.05 (0.05; 0.05)
OM04 (h = 0.6)	0.41 (0.34; 0.49)	1.01 (0.85; 1.22)	1.32 (1.11; 1.60)	1.23 (1.16; 1.47)	724 (544; 903)	561 (560; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
OM05 (h = 0.9)	0.46 (0.40; 0.56)	1.06 (0.90; 1.28)	2.77 (2.36; 3.35)	2.46 (2.32; 2.94)	853 (631; 1055)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
OM06 ($P_{longline}$ = +30%)	0.44 (0.38; 0.53)	1.04 (0.89; 1.25)	1.79 (1.54; 2.16)	1.64 (1.54; 1.95)	821 (626; 1007)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
OM07 ($P_{trotline}$ = +0%)	0.44 (0.37; 0.53)	1.04 (0.88; 1.26)	1.78 (1.51; 2.15)	1.62 (1.52; 1.93)	827 (598; 1013)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
OM08 ($P_{trotline}$ = +10%)	0.44 (0.38; 0.53)	1.03 (0.88; 1.25)	1.80 (1.54; 2.18)	1.64 (1.54; 1.95)	773 (588; 973)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
OM09 (w_{CPUE} = 5)	0.40 (0.35; 0.49)	0.96 (0.82; 1.18)	1.66 (1.42; 2.03)	1.44 (1.34; 1.74)	763 (582; 974)	561 (557; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
OM10 (w_{CPUE} = 10)	**0.40** (0.34; 0.48)	0.88 (0.75; 1.06)	1.66 (1.42; 2.00)	1.36 (1.27; 1.65)	700 (523; 902)	561 (545; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
OM12 (alt growth)	0.43 (0.37; 0.51)	0.68 (0.58; 0.81)	1.74 (1.48; 2.07)	1.74 (1.67; 1.99)	787 (580; 1001)	554 (534; 561)	0.07 (0.06; 0.09)	0.05 (0.03; 0.06)
OM13 (mass at lt Area 48.4)	0.44 (0.37; 0.52)	1.03 (0.87; 1.23)	1.73 (1.47; 2.07)	1.56 (1.47; 1.84)	773 (577; 973)	561 (560; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
OM14 (mass at lt Area 58.5.2)	0.44 (0.37; 0.52)	1.03 (0.87; 1.23)	1.73 (1.46; 2.07)	1.55 (1.47; 1.83)	770 (577; 973)	561 (560; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
OM15 (tag report rate = 0.8)	0.36 (0.29; 0.44)	0.93 (0.76; 1.14)	1.46 (1.19; 1.79)	1.44 (1.34; 1.74)	835 (614; 1029)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
Combined OMs	0.43 (0.34; 0.55)	1.00 (0.72; 1.24)	1.74 (1.30; 2.63)	1.59 (1.26; 2.40)	786 (558; 1029)	561 (550; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)

Table 6. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple **MP10-10** considered for the selected **Reference Set OMs**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all 14 RS OMs, giving equal weight to each OM.

RS	$\bar{C}_{2019-2040}$ (20 yrs)	$\bar{C}_{2019-2035}$ (15 yrs)	$\bar{C}_{2019-2030}$ (10 yrs)	$\bar{C}_{2019-2024}$ (4 yrs)	C_{2040} (20 yrs)	C_{2035} (15 yrs)	C_{2030} (10 yrs)	C_{2024} (4 yrs)
OM01 (Basecase)	832 (634; 1036)	819 (633; 900)	707 (608; 707)	589 (589; 589)	931 (588; 1569)	1027 (490; 1540)	956 (578; 956)	629 (629; 629)
OM02 (M = 0.1)	670 (521; 875)	662 (518; 832)	654 (543; 707)	589 (581; 589)	686 (437; 1107)	641 (381; 1198)	727 (443; 956)	629 (595; 629)
OM03 (M=0.16)	983 (717; 1168)	887 (697; 900)	707 (671; 707)	589 (589; 589)	1196 (738; 2080)	1455 (721; 1540)	956 (789; 956)	629 (629; 629)
OM04 (h = 0.6)	760 (572; 948)	750 (567; 893)	694 (584; 707)	589 (588; 589)	782 (474; 1211)	802 (437; 1446)	877 (492; 956)	629 (622; 629)
OM05 (h = 0.9)	896 (663; 1108)	855 (656; 900)	707 (639; 707)	589 (589; 589)	1093 (676; 1668)	1223 (570; 1540)	956 (669; 956)	629 (629; 629)
OM06 ($P_{longline}$ = +30%)	862 (657; 1057)	835 (646; 900)	707 (629; 707)	589 (589; 589)	986 (601; 1617)	1083 (512; 1540)	956 (619; 956)	629 (629; 629)
OM07 ($P_{trotline}$ = +0%)	827 (598; 1013)	793 (613; 857)	674 (599; 674)	561 (561; 561)	937 (584; 1549)	1049 (472; 1467)	911 (598; 911)	599 (599; 599)
OM08 ($P_{trotline}$ = +10%)	851 (647; 1071)	841 (645; 943)	739 (629; 741)	618 (618; 618)	953 (588; 1562)	1008 (500; 1614)	983 (569; 1002)	659 (659; 659)
OM09 (w_{CPUE} = 5)	801 (611; 1022)	801 (597; 900)	704 (589; 707)	589 (585; 589)	918 (561; 1410)	961 (513; 1540)	933 (524; 956)	629 (610; 629)
OM10 (w_{CPUE} = 10)	735 (549; 947)	717 (511; 890)	672 (542; 707)	589 (572; 589)	830 (546; 1254)	772 (484; 1388)	791 (395; 956)	629 (559; 629)
OM12 (alt growth)	826 (609; 1051)	770 (534; 900)	653 (507; 707)	582 (561; 589)	1127 (638; 1732)	1021 (569; 1540)	831 (449; 956)	599 (519; 629)
OM13 (mass at lt Area 48.4)	812 (606; 1022)	803 (605; 900)	703 (595; 707)	589 (588; 589)	906 (565; 1416)	952 (472; 1540)	923 (536; 956)	629 (623; 629)
OM14 (mass at lt Area 58.5.2)	809 (605; 1022)	802 (604; 900)	703 (593; 707)	589 (588; 589)	903 (564; 1410)	950 (470; 1540)	922 (533; 956)	629 (623; 629)
OM15 (tag report rate = 0.8)	876 (645; 1080)	844 (652; 900)	707 (640; 707)	589 (589; 589)	995 (582; 1617)	1186 (538; 1540)	956 (655; 956)	629 (629; 629)
Combined OMs	827 (585; 1080)	797 (572; 900)	702 (570; 711)	589 (561; 618)	932 (547; 1595)	996 (478; 1540)	921 (515; 956)	629 (581; 659)

Table 7. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2040 being less than this average under the simple **MP10-10** considered for the selected **Reference Set OMs**, together with their 90% probability intervals are also reported. The last row reports these performance statistics as medians across all simulations combined for all 14 RS OMs, giving equal weight to each OM.

RS	$\frac{CPUE_{2040}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2035}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2030}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2024}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2040}}{CPUE_{15-17}}$	Probability $\frac{CPUE_{2040}}{CPUE_{15-17}} < 1$
OM01 (Basecase)	1.52 (1.02; 2.39)	1.41 (0.98; 2.03)	1.41 (0.97; 2.26)	1.28 (0.85; 1.87)	1.31 (0.88; 2.06)	0.18
OM02 (M = 0.1)	1.38 (0.85; 2.18)	1.21 (0.84; 1.79)	1.20 (0.79; 2.08)	1.15 (0.74; 1.75)	1.19 (0.74; 1.88)	0.32
OM03 (M=0.16)	1.63 (1.06; 2.35)	1.56 (1.13; 2.23)	1.60 (1.09; 2.34)	1.38 (0.97; 1.93)	1.41 (0.92; 2.02)	0.11
OM04 (h = 0.6)	1.43 (0.94; 2.33)	1.32 (0.90; 1.91)	1.31 (0.90; 2.09)	1.23 (0.82; 1.82)	1.23 (0.81; 2.01)	0.27
OM05 (h = 0.9)	1.58 (1.05; 2.47)	1.48 (1.04; 2.12)	1.49 (1.03; 2.38)	1.30 (0.87; 1.91)	1.36 (0.90; 2.13)	0.15
OM06 ($P_{longline}$ = +30%)	1.52 (0.98; 2.41)	1.41 (0.97; 2.02)	1.42 (0.98; 2.28)	1.28 (0.85; 1.89)	1.31 (0.84; 2.07)	0.18
OM07 ($P_{trotline}$ = +0%)	1.54 (1.01; 2.43)	1.43 (0.98; 2.06)	1.43 (0.99; 2.29)	1.29 (0.86; 1.89)	1.32 (0.87; 2.10)	0.17
OM08 ($P_{trotline}$ = +10%)	1.51 (1.01; 2.39)	1.39 (0.97; 2.04)	1.40 (0.96; 2.23)	1.27 (0.84; 1.86)	1.30 (0.87; 2.06)	0.21
OM09 (w_{CPUE} = 5)	1.66 (1.14; 2.46)	1.56 (1.12; 2.19)	1.58 (1.07; 2.26)	1.35 (0.96; 1.88)	1.43 (0.98; 2.12)	0.06
OM10 (w_{CPUE} = 10)	1.80 (1.27; 2.59)	1.68 (1.27; 2.23)	1.61 (1.21; 2.31)	1.41 (1.05; 1.92)	1.55 (1.10; 2.23)	0.04
OM12 (alt growth)	1.51 (1.08; 2.06)	1.55 (1.14; 1.93)	1.45 (1.09; 2.09)	1.14 (0.92; 1.48)	1.30 (0.93; 1.78)	0.09
OM13 (mass at lt Area 48.4)	1.50 (1.00; 2.34)	1.37 (0.97; 2.00)	1.37 (0.96; 2.18)	1.24 (0.83; 1.81)	1.29 (0.86; 2.02)	0.20
OM14 (mass at lt Area 58.5.2)	1.50 (1.00; 2.34)	1.37 (0.97; 2.00)	1.37 (0.96; 2.17)	1.24 (0.83; 1.81)	1.29 (0.86; 2.02)	0.20
OM15 (tag report rate = 0.8)	1.46 (0.98; 2.29)	1.40 (0.97; 2.02)	1.45 (0.98; 2.23)	1.30 (0.88; 1.86)	1.26 (0.85; 1.97)	0.27
Combined OMs	1.52 (0.98; 2.39)	1.43 (0.97; 2.06)	1.43 (0.96; 2.27)	1.28 (0.85; 1.88)	1.31 (0.85; 2.06)	0.18

Table 8. Medians of the distributions of several performance statistics under the simple **MP10-10** considered for the selected **Robustness tests**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all six Robustness tests (ROB02 is excluded from calculations as it distorts the distributions of the results), giving equal weight to each test. For comparison, the results for OM01 are also shown.

RS	$\frac{B^{sp}_{2040}}{K^{sp}}$	$\frac{B^{sp}_{2040}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2040}}{B_{MSY}}$	$\frac{B^{sp}_{2024}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
OM01 (Basecase)	0.44 (0.37; 0.53)	1.04 (0.88; 1.25)	1.79 (1.52; 2.16)	1.63 (1.53; 1.94)	792 (604; 986)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
ROB01 (recruit var diff)	0.56 (0.46; 0.69)	1.17 (0.96; 1.44)	2.26 (1.85; 2.78)	1.85 (1.76; 2.19)	1120 (925; 1135)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
ROB02 (tag loss = 0.5)	0.01 (0.00; 0.10)	0.04 (0.01; 0.45)	0.03 (0.01; 0.43)	0.63 (0.54; 0.87)	750 (515; 950)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
ROB03 (no CPUE bias)	0.37 (0.31; 0.47)	0.88 (0.74; 1.12)	1.52 (1.28; 1.93)	1.63 (1.53; 1.94)	954 (773; 1098)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
ROB04 (TAC under-catch)	0.52 (0.39; 0.66)	1.23 (0.92; 1.55)	2.13 (1.59; 2.67)	1.72 (1.63; 2.05)	1135 (1060; 1135)	561 (561; 561)	0.13 (0.12; 0.13)	0.05 (0.05; 0.05)
ROB05 (TAC under-catch to 2024)	0.44 (0.38; 0.53)	1.05 (0.89; 1.26)	1.81 (1.53; 2.17)	1.72 (1.63; 2.05)	842 (642; 1019)	561 (561; 561)	0.12 (0.11; 0.13)	0.05 (0.05; 0.05)
ROB06 (tags released fn(TAC))	0.51 (0.42; 0.62)	1.20 (0.99; 1.47)	2.08 (1.71; 2.54)	1.63 (1.53; 1.94)	650 (553; 764)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
ROB07 (tags released fn(TAC))	0.59 (0.48; 0.72)	1.38 (1.14; 1.69)	2.39 (1.96; 2.92)	1.63 (1.53; 1.94)	495 (417; 547)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
Combined ROBs[3]	0.48 (0.35; 0.65)	1.13 (0.83; 1.54)	1.95 (1.43; 2.67)	1.66 (1.54; 2.01)	807 (470; 1135)	561 (561; 561)	0.08 (0.06; 0.13)	0.05 (0.04; 0.05)

[3] ROB02 is excluded from the statistics when combining all ROBs as it distorts the distributions of the results.

Table 9. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple **MP10-10** considered for the selected **Robustness tests**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all six Robustness tests (ROB02 is excluded from calculations as it distorts the distributions of the results), giving equal weight to each test. For comparison, the results for OM01 are also shown.

RS	$\bar{C}_{2019-2040}$ (20 yrs)	$\bar{C}_{2019-2035}$ (15 yrs)	$\bar{C}_{2019-2030}$ (10 yrs)	$\bar{C}_{2019-2024}$ (4 yrs)	C_{2040} (20 yrs)	C_{2035} (15 yrs)	C_{2030} (10 yrs)	C_{2024} (4 yrs)
OM01 (Basecase)	832 (634; 1036)	819 (633; 900)	707 (608; 707)	589 (589; 589)	931 (588; 1569)	1027 (490; 1540)	956 (578; 956)	629 (629; 629)
ROB01 (recruit var diff)	1176 (971; 1192)	900 (796; 900)	707 (676; 707)	589 (589; 589)	2325 (1306; 2480)	1540 (1135; 1540)	956 (863; 956)	629 (629; 629)
ROB02 (tag loss = 0.5)	787 (541; 997)	819 (604; 900)	707 (634; 707)	589 (589; 589)	574 (296; 1109)	928 (412; 1540)	956 (635; 956)	629 (629; 629)
ROB03 (no CPUE bias)	1002 (812; 1153)	898 (766; 900)	707 (707; 707)	589 (589; 589)	1149 (756; 1891)	1521 (841; 1540)	956 (956; 956)	629 (629; 629)
ROB04 (TAC under-catch)	726 (651; 726)	461 (458; 461)	362 (362; 362)	302 (302; 302)	2480 (1663; 2480)	789 (767; 789)	490 (490; 490)	322 (322; 322)
ROB05 (TAC under-catch to 2024)	826 (616; 1012)	775 (583; 823)	592 (562; 592)	302 (302; 302)	977 (616; 1644)	1132 (540; 1540)	956 (781; 956)	322 (322; 322)
ROB06 (tags released fn(TAC))	682 (580; 802)	690 (553; 823)	690 (591; 707)	589 (589; 589)	642 (450; 1025)	636 (429; 977)	825 (490; 956)	629 (629; 629)
ROB07 (tags released fn(TAC))	519 (438; 574)	593 (485; 652)	655 (571; 690)	589 (589; 589)	333 (234; 456)	373 (254; 462)	632 (423; 782)	629 (629; 629)
Combined ROBs[4]	726 (494; 1080)	704 (461; 900)	656 (362; 707)	589 (302; 589)	945 (295; 2480)	789 (332; 1540)	845 (490; 956)	629 (322; 629)

[4] ROB02 is excluded from the statistics when combining all ROBs as it distorts the distribution of the results.

Table 10. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2040 being less than this average under the simple **MP10-10** considered for the selected **Robustness tests**, together with their 90% probability intervals are also reported. The last row reports these performance statistics as medians across all simulations combined for all six Robustness tests (ROB02 is excluded from calculations as it distorts the distributions of the results), giving equal weight to each test. For comparison, the results for OM01 are also shown.

RS	$\frac{CPUE_{2040}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2035}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2030}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2024}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2040}}{CPUE_{15-17}}$	Probability $\frac{CPUE_{2040}}{CPUE_{15-17}} < 1$
OM01 (Basecase)	1.52 (1.02; 2.39)	1.41 (0.98; 2.03)	1.41 (0.97; 2.26)	1.28 (0.85; 1.87)	1.31 (0.88; 2.06)	0.18
ROB01 (recruit var diff)	1.45 (0.90; 2.30)	1.38 (0.96; 2.05)	1.36 (0.92; 2.28)	1.17 (0.75; 1.76)	1.25 (0.78; 1.98)	0.23
ROB02 (tag loss = 0.5)	0.42 (0.14; 1.23)	0.66 (0.33; 1.18)	1.21 (0.71; 1.82)	1.35 (1.00; 1.81)	0.36 (0.12; 1.06)	0.92
ROB03 (no CPUE bias)	1.97 (1.20; 2.89)	1.89 (1.32; 2.85)	2.01 (1.39; 3.22)	1.82 (1.21; 2.67)	1.70 (1.04; 2.49)	0.04
ROB04 (TAC under-catch)	1.62 (1.00; 2.55)	1.62 (1.14; 2.37)	1.59 (1.10; 2.57)	1.35 (0.90; 1.99)	1.40 (0.86; 2.19)	0.13
ROB05 (TAC under-catch to 2024)	1.53 (0.96; 2.37)	1.44 (1.00; 2.06)	1.47 (1.02; 2.37)	1.35 (0.90; 1.99)	1.32 (0.82; 2.04)	0.19
ROB06 (tags released fn(TAC))	1.67 (1.06; 2.66)	1.46 (1.03; 2.16)	1.42 (0.98; 2.27)	1.28 (0.85; 1.87)	1.44 (0.91; 2.29)	0.11
ROB07 (tags released fn(TAC))	1.85 (1.17; 2.83)	1.54 (1.09; 2.23)	1.43 (0.99; 2.30)	1.28 (0.85; 1.87)	1.59 (1.01; 2.44)	0.05
Combined ROBs[5]	1.66 (1.03; 2.70)	1.54 (1.03; 2.36)	1.52 (1.00; 2.59)	1.36 (0.88; 2.14)	1.43 (0.89; 2.33)	0.12

[5] ROB02 is excluded from the statistics when combining all ROBs as it distorts the distribution of the results.

Table 11. Comparison of medians of the distributions of several performance statistics under the two **CMPs (CMP5-10 and MP10-10)** considered for the selected **OMs**, together with their 90% probability intervals. CMPs are tuned to provide the median result for OM10 shown in **bold** in the third column.

CMP	OM	$\frac{B^{sp}_{2040}}{K^{sp}}$	$\frac{B^{sp}_{2040}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2040}}{B_{MSY}}$	$\frac{B^{sp}_{2024}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
CMP5-10	**OM02 (M = 0.1)**	0.53 (0.46; 0.60)	1.01 (0.88; 1.15)	2.08 (1.81; 2.37)	2.00 (1.93; 2.23)	638 (492; 810)	561 (547; 561)	0.06 (0.05; 0.07)	0.05 (0.04; 0.05)
	OM10 (w_{CPUE} = 10)	**0.40** (0.33; 0.49)	0.88 (0.72; 1.08)	1.66 (1.36; 2.03)	1.36 (1.27; 1.65)	705 (542; 918)	561 (541; 561)	0.06 (0.05; 0.07)	0.05 (0.04; 0.05)
	OM15 (tag report rate = 0.8)	0.35 (0.28; 0.44)	0.92 (0.74; 1.15)	1.45 (1.16; 1.81)	1.44 (1.34; 1.74)	849 (627; 1024)	561 (558; 561)	0.06 (0.05; 0.07)	0.05 (0.05; 0.05)
MP10-10	**OM02 (M = 0.1)**	0.52 (0.46; 0.61)	1.01 (0.88; 1.17)	2.07 (1.81; 2.41)	2.00 (1.93; 2.23)	638 (497; 834)	561 (553; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
	OM10 (w_{CPUE} = 10)	**0.40** (0.34; 0.48)	0.88 (0.75; 1.06)	1.66 (1.42; 2.00)	1.36 (1.27; 1.65)	700 (523; 902)	561 (545; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
	OM15 (tag report rate = 0.8)	0.36 (0.29; 0.44)	0.93 (0.76; 1.14)	1.46 (1.19; 1.79)	1.44 (1.34; 1.74)	835 (614; 1029)	561 (561; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)

Table 12. Comparison of projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the two **CMPs (CMP5-10 and MP10-10)** considered for the selected **OMs**, together with their 90% probability intervals.

CMP	OM	$\bar{C}_{2019-2040}$ (20 yrs)	$\bar{C}_{2019-2035}$ (15 yrs)	$\bar{C}_{2019-2030}$ (10 yrs)	$\bar{C}_{2019-2024}$ (4 yrs)	C_{2040} (20 yrs)	C_{2035} (15 yrs)	C_{2030} (10 yrs)	C_{2024} (4 yrs)
CMP5-10	**OM02 (M = 0.1)**	670 (517; 850)	652 (515; 802)	639 (541; 707)	589 (574; 589)	733 (452; 1159)	685 (442; 1013)	679 (459; 956)	629 (567; 629)
	OM10 (w_{CPUE} = 10)	741 (569; 964)	694 (527; 877)	661 (523; 707)	589 (568; 589)	901 (595; 1360)	801 (489; 1334)	724 (436; 956)	629 (543; 629)
	OM15 (tag report rate = 0.8)	892 (658; 1075)	830 (655; 900)	707 (617; 707)	589 (586; 589)	1081 (654; 1618)	1134 (624; 1540)	954 (609; 956)	629 (616; 629)
MP10-10	**OM02 (M = 0.1)**	670 (521; 875)	662 (518; 832)	654 (543; 707)	589 (581; 589)	686 (437; 1107)	641 (381; 1198)	727 (443; 956)	629 (595; 629)
	OM10 (w_{CPUE} = 10)	735 (549; 947)	717 (511; 890)	672 (542; 707)	589 (572; 589)	830 (546; 1254)	772 (484; 1388)	791 (395; 956)	629 (559; 629)
	OM15 (tag report rate = 0.8)	876 (645; 1080)	844 (652; 900)	707 (640; 707)	589 (589; 589)	995 (582; 1617)	1186 (538; 1540)	956 (655; 956)	629 (629; 629)

Table 13. Comparison of projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2040 being less than this average under the two **CMPs (CMP5-10 and MP10-10)** considered for the selected **OMs**, together with their 90% probability intervals are also reported.

CMP	RS	$\frac{CPUE_{2040}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2035}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2030}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2024}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2040}}{\overline{CPUE}_{15-17}}$	Probability $\frac{CPUE_{2040}}{\overline{CPUE}_{15-17}} < 1$
CMP5-10	**OM02 (M = 0.1)**	1.38 (0.85; 2.17)	1.22 (0.84; 1.78)	1.21 (0.80; 2.09)	1.15 (0.74; 1.75)	1.19 (0.73; 1.87)	0.33
	OM10 (w_{CPUE} = 10)	1.82 (1.25; 2.52)	1.68 (1.27; 2.32)	1.62 (1.19; 2.31)	1.41 (1.05; 1.92)	1.57 (1.08; 2.17)	0.03
	OM15 (tag report rate = 0.8)	1.43 (0.95; 2.26)	1.40 (0.98; 2.06)	1.46 (0.98; 2.23)	1.30 (0.88; 1.86)	1.23 (0.82; 1.94)	0.26
MP10-10	**OM02 (M = 0.1)**	1.38 (0.85; 2.18)	1.21 (0.84; 1.79)	1.20 (0.79; 2.08)	1.15 (0.74; 1.75)	1.19 (0.74; 1.88)	0.32
	OM10 (w_{CPUE} = 10)	1.80 (1.27; 2.59)	1.68 (1.27; 2.23)	1.61 (1.21; 2.31)	1.41 (1.05; 1.92)	1.55 (1.10; 2.23)	0.04
	OM15 (tag report rate = 0.8)	1.46 (0.98; 2.29)	1.40 (0.97; 2.02)	1.45 (0.98; 2.23)	1.30 (0.88; 1.86)	1.26 (0.85; 1.97)	0.27

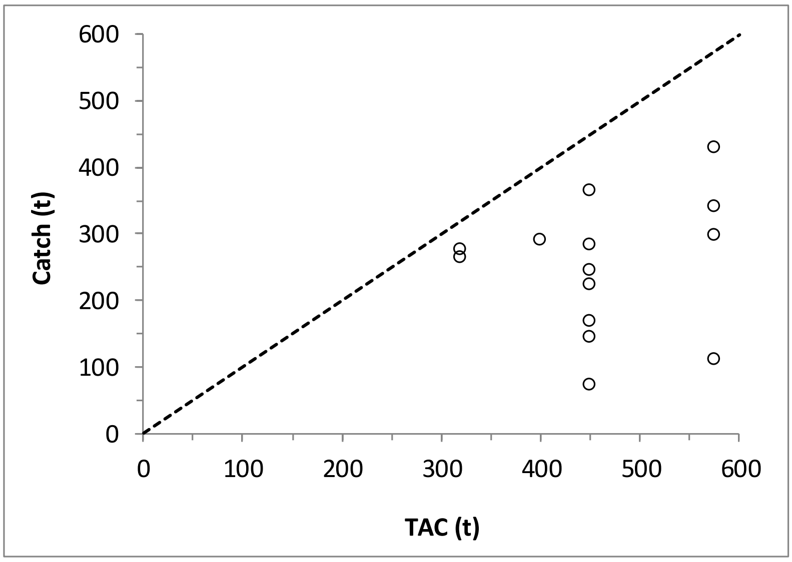

Figure 1. Scatter plot of catch taken against the TAC set over the period from 2005 to 2019.

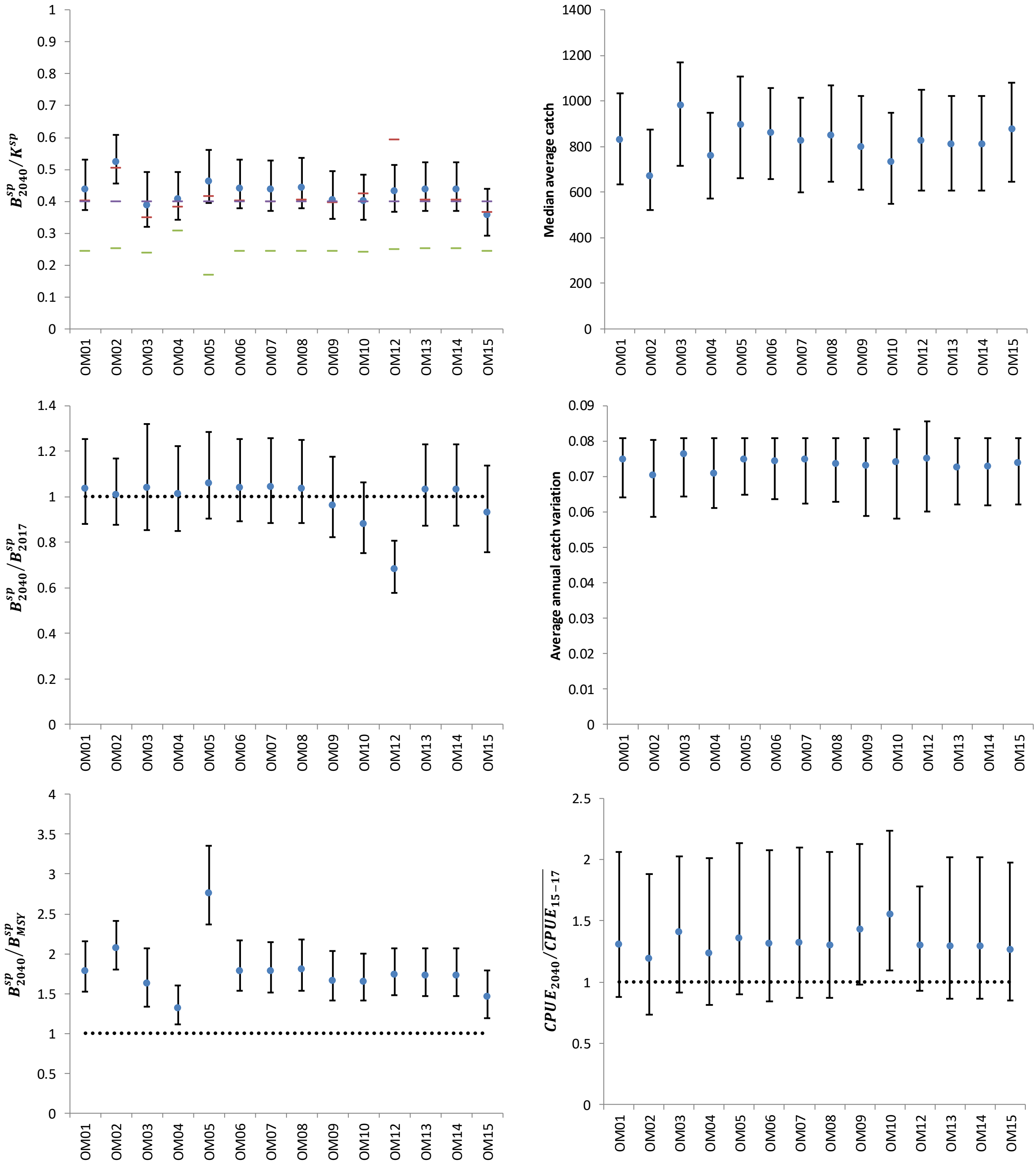

Figure 2. Zeh plots for some of the performance statistics reported in the Tables for each **OM** for **MP10-10**, which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2040 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2021 to 2040; the average annual variation in catch; and the CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2018) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned, and the green dashes represent the MSYL (relative to *K*).

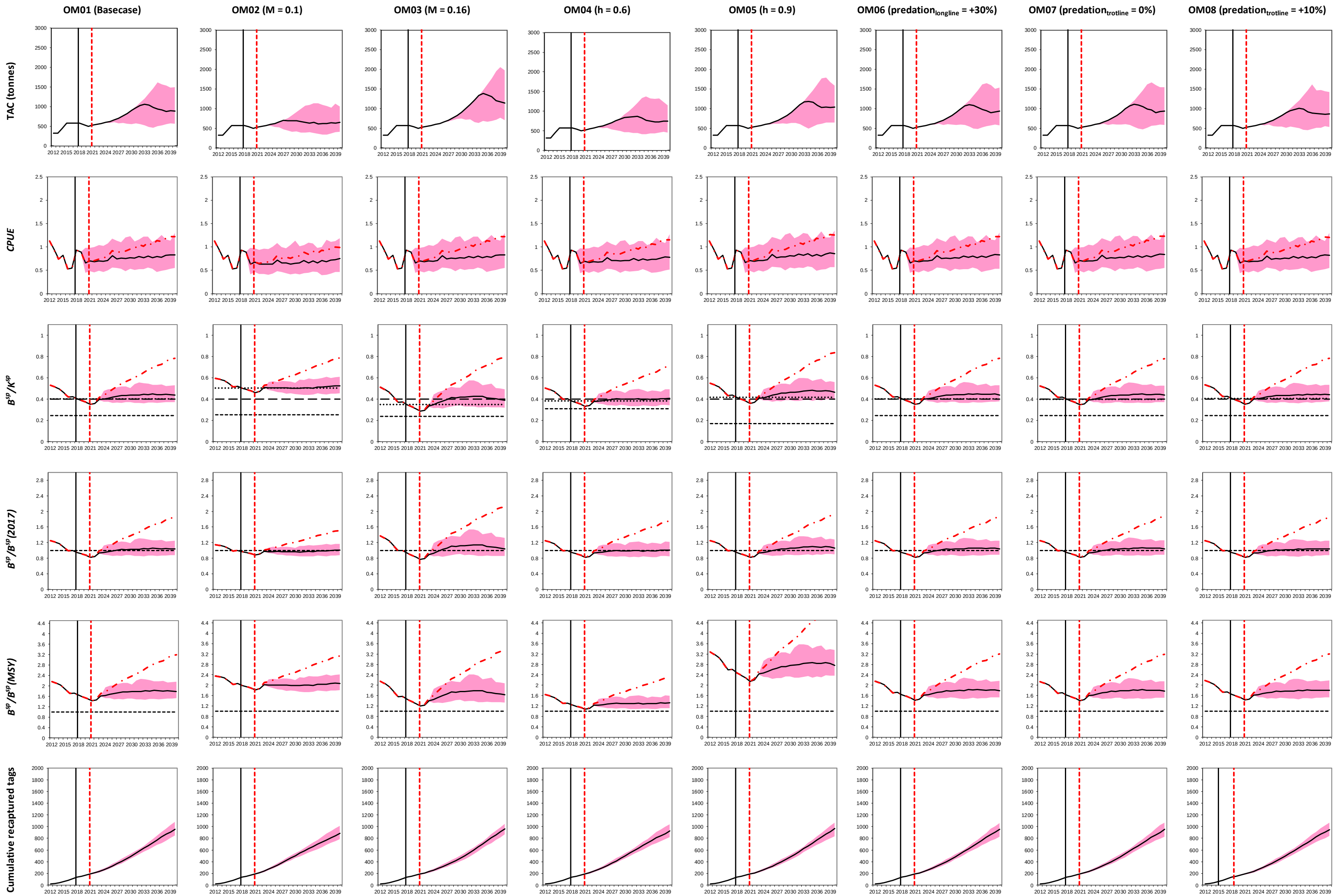

Figure 3a. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under **MP10-10**. That CMP is based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **OM01 to OM08**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to K). The red dot-dash lines represent the median trajectories under a zero catch scenario.

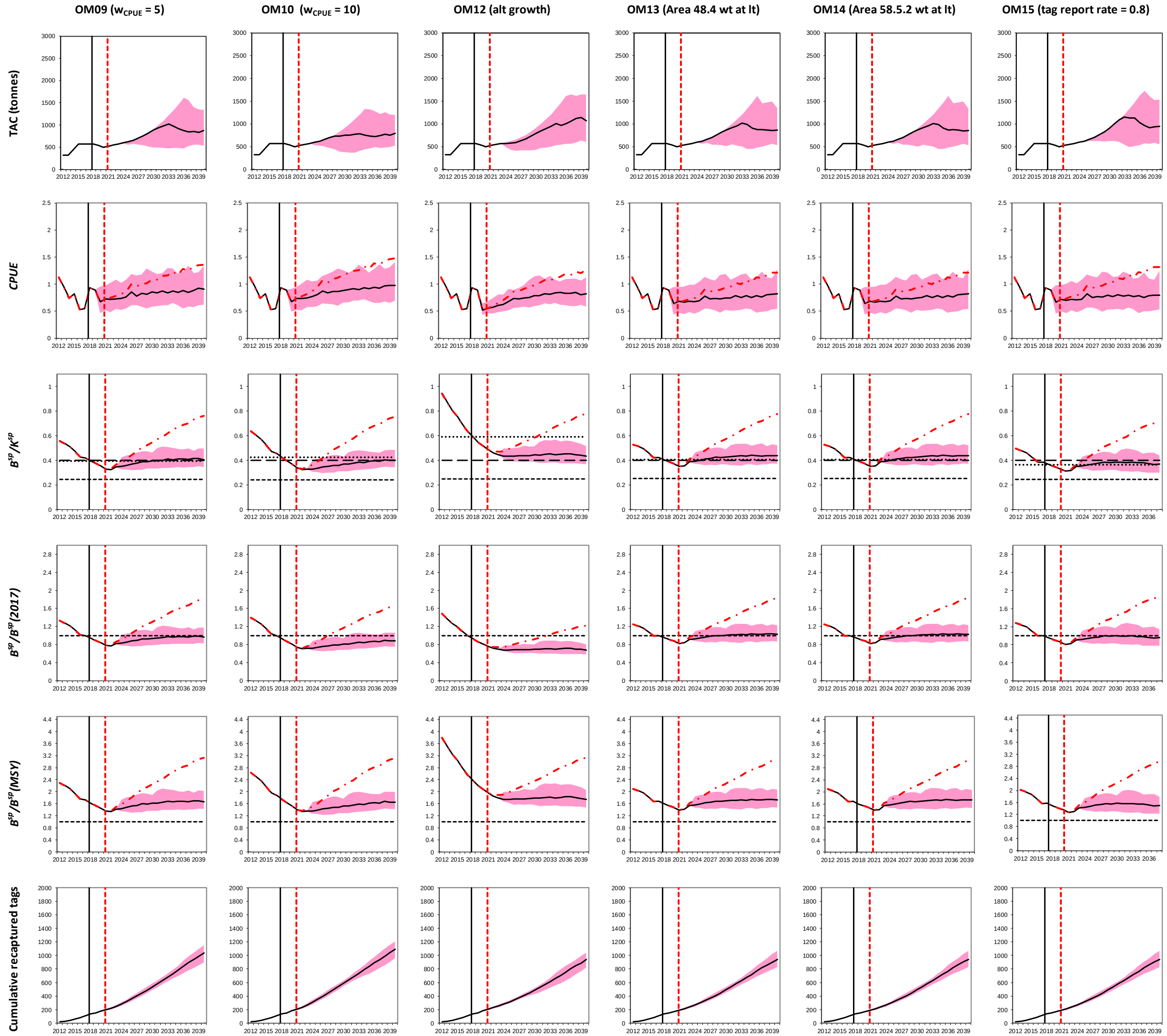

Figure 3b. Projection results as in Figure 2a, but here for **OM09 to OM15**.

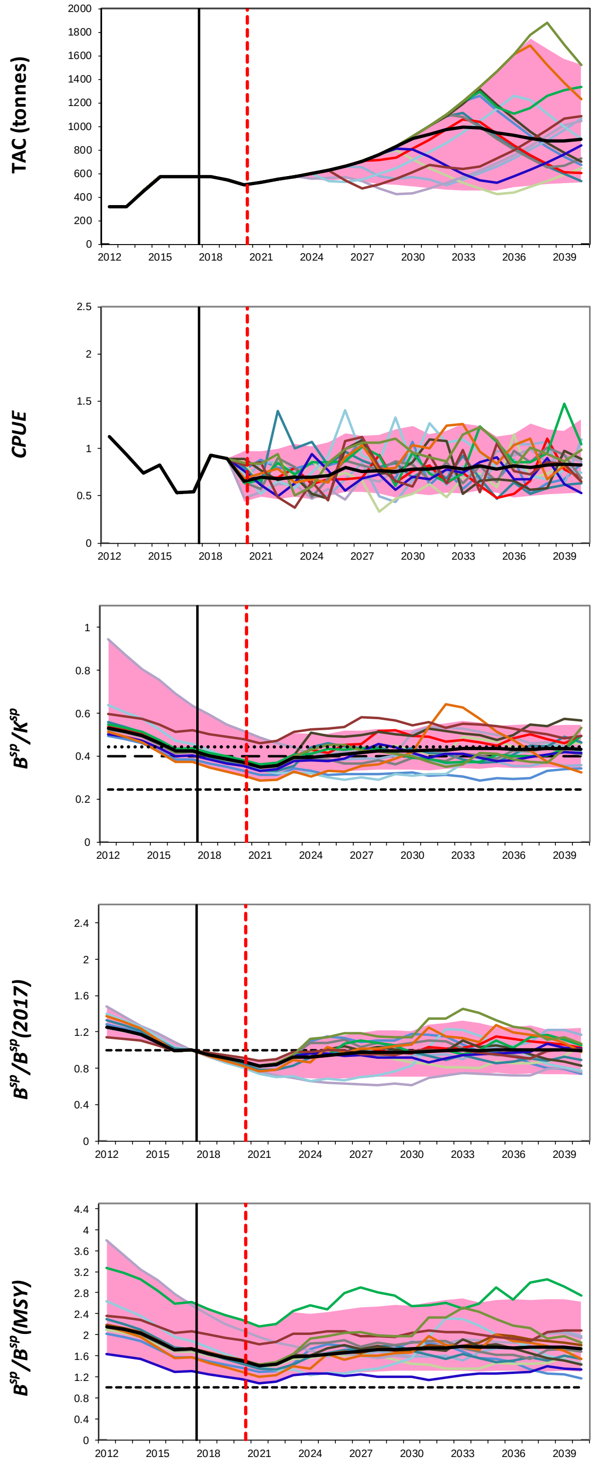

Figure 4. Median trajectories (thick black lines) of the TAC (in tonnes), CPUE trends, spawning biomass depletion, spawning biomass relative to the 2017 value and spawning biomass relative to B_{MSY} under **MP10-10** across all simulations for all 14 **RS OMs**, giving equal weight to each OM. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. A random selection of worm plots, one from each of the 14 OMs, is also shown (coloured lines) and the median projection for OM01 is also shown for comparison (red dashed line). For the middle plot, the large dashed line is the value ($0.4K^{sp}$) to which this CMP was tuned under OM10, the dotted line is the average median current (2018) spawning biomass depletion over all 14 RS OMs, while the small dash line is the average MSYL (relative to *K*) over all 14 RS OMs.

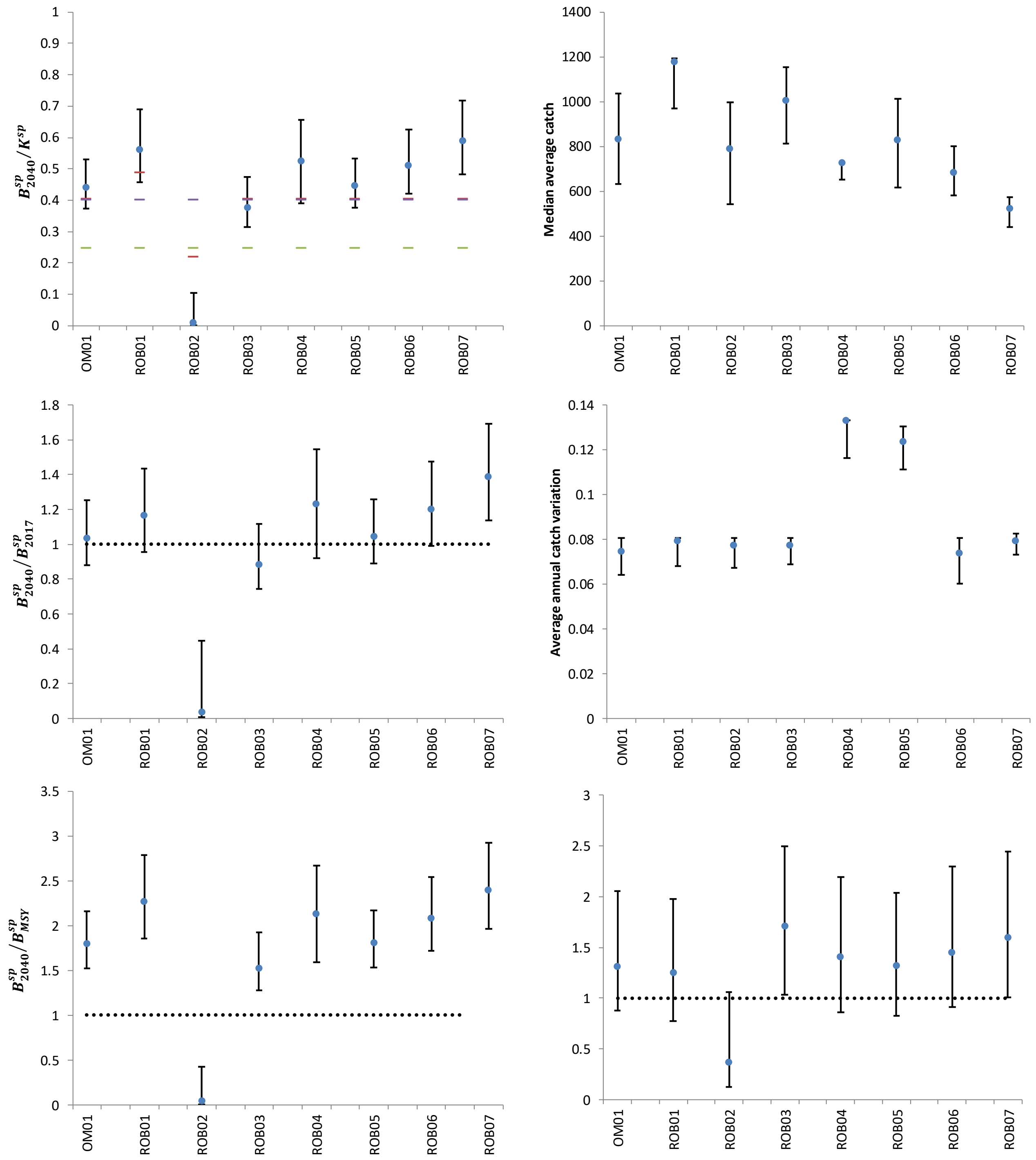

Figure 5. Zeh plots for some of the performance statistics reported in the Tables for each **Robustness test** for **MP10-10**, which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2040 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2021 to 2040; the average annual variation in catch; and the CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2017) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned, and the green dashes represent the MSYL (relative to *K*). For comparison, the results for OM01 are also shown.

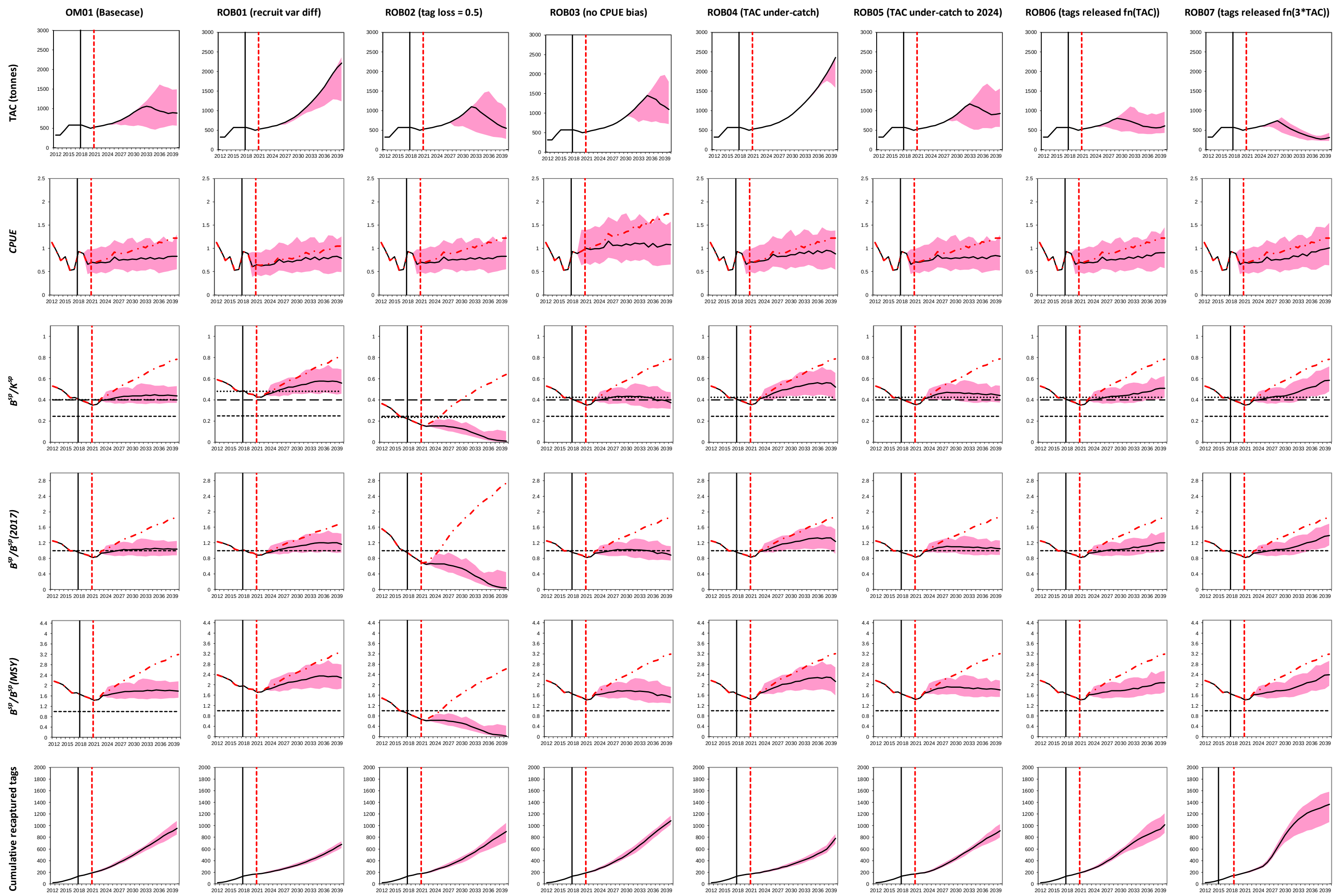

Figure 6. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under **MP10-10**. That CMP is based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **ROB01 to ROB07**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to K). The red dot-dash lines represent the median trajectories under a zero catch scenario. For comparison, the results for OM01 are also shown.

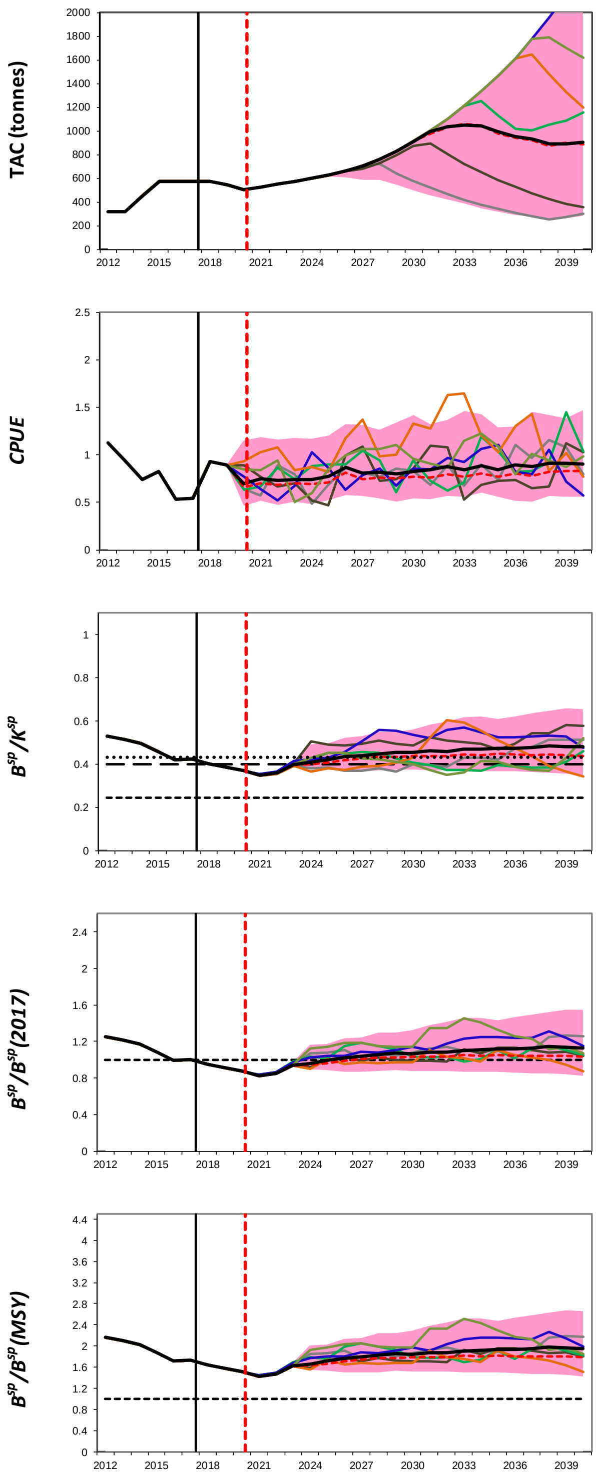

Figure 7. Median trajectories (thick black lines) of the TAC (in tonnes), CPUE trends, spawning biomass depletion, spawning biomass relative to the 2017 value and spawning biomass relative to B_{MSY} under **MP10-10** across all simulations for all six[6] **Robustness tests**, giving equal weight to each test. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. A random selection of worm plots, one from each of the six Robustness tests, is also shown (coloured lines). The median projection for OM01 is also shown for comparison (red dashed line) (indistinguishable from the median TAC projection of the combined six Robustness tests). For the middle plot, the large dashed line is the value to which this CMP was tuned under OM10, the dotted line is the median current (2018) spawning biomass depletion, while the small dash line is the average MSYL (relative to *K*) over all 7 Robustness tests.

[6] ROB02 has been excluded as it distorts the distributions of the results.

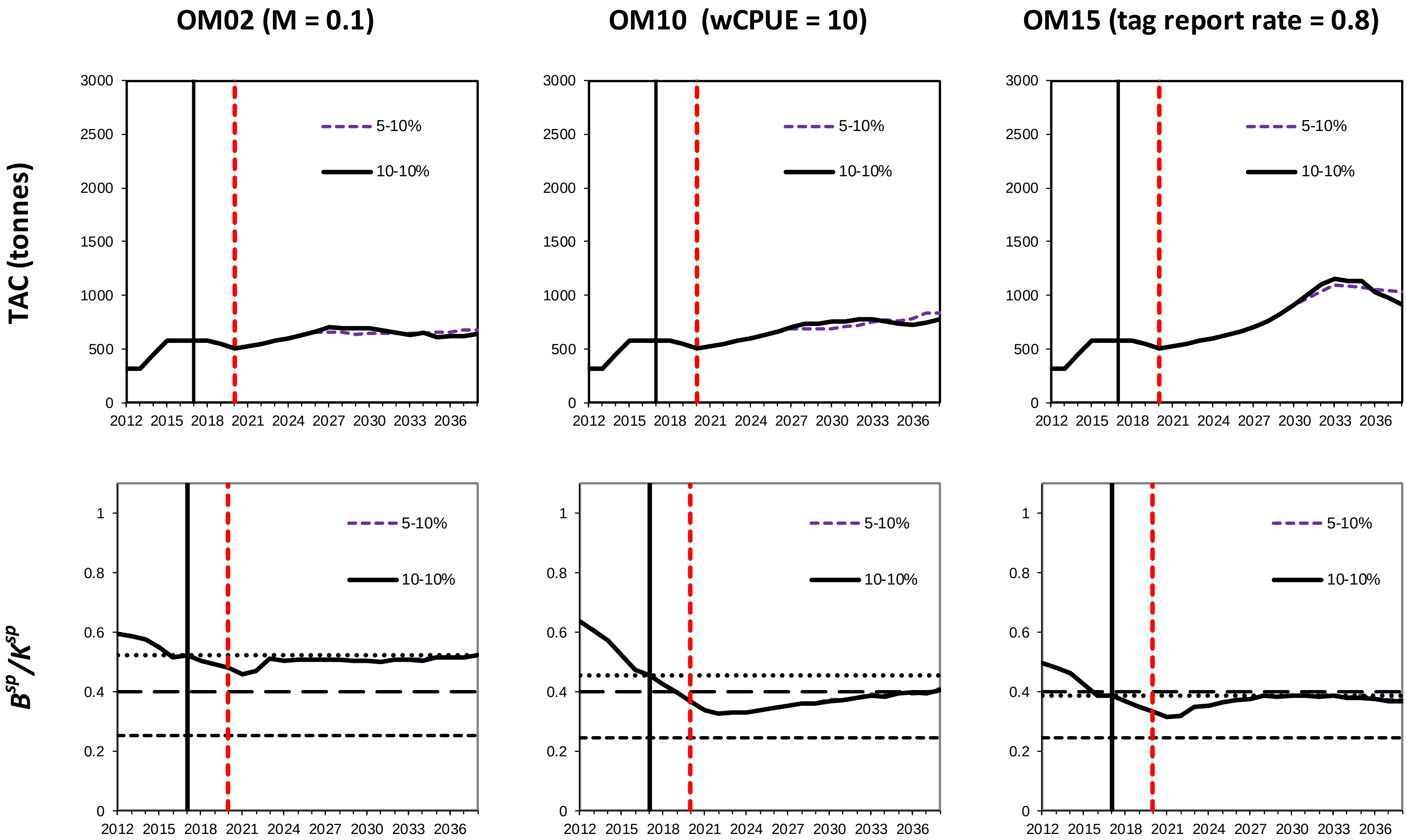

Figure 8. Comparison of median trajectories of the TAC (in tonnes) and spawning biomass depletion, under **CMP5-10 and MP10-10** (which reflect a different downward maximum inter-annual change in TAC) for the selected **OMs**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines. For the bottom row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to *K*). The projections of spawning biomass depletion for the two CMPs are indistinguishable.

APPENDIX A

THE AGE STRUCTURED PRODUCTION MODEL (ASPM) ASSESSMENT METHODOLOGY

THE BASIC DYNAMICS

The toothfish population dynamics are given by the equations

$$N_{y+1,0} = R(B_{y+1}^{sp}) \tag{A1.1}$$

$$N_{y+1,a+1} = (N_{y,a} - C_{y,a})\ e^{-M} \qquad 0 \le a \le m\text{-}2 \tag{A1.2}$$

$$N_{y+1,m} = (N_{y,m} - C_{y,m})\ e^{-M} + (N_{y,m-1} - C_{y,m-1})\ e^{-M} \tag{A1.3}$$

where

$N_{y,a}$ is the number of toothfish of age *a* at the start of year *y*,

$C_{y,a}$ is the number of toothfish of age *a* taken by the fishery in year *y*,

$R(B^{sp})$ is the Beverton-Holt stock-recruitment relationship described by equation (A1.10) below,

B^{sp} is the spawning biomass at the start of year *y*,

M is the natural mortality rate of fish (assumed to be independent of age), and

m is the maximum age considered (i.e. the “plus group”), taken here to be $m = 35$.

Note that in the interests of simplicity this model approximates the fishery as a pulse fishery at the start of the year. Given that toothfish are relatively long-lived with low natural mortality, such an approximation would seem adequate.

For a three-gear (or “fleet”) fishery, the total predicted number of fish of age *a* caught in year *y* is given by

$$C_{y,a} = \textstyle\sum_{f=1}^{3} C_{y,a}^{f}, \tag{A1.4}$$

where

$$C_{y,a}^{f} = N_{y,a} S_{y,a}^{f} F_{y}^{f} \tag{A1.5}$$

and

F_y^f is the proportion of the resource above age *a* harvested in year *y* by fleet *f*, and

$S_{y,a}^f$ is the commercial selectivity at age *a* in year *y* for fleet *f*.

The mass-at-age is given by the combination of a von Bertalanffy growth equation $\ell(a)$ defined by constants ℓ_∞, κ and t_0 and a relationship relating length to mass. Note that ℓ refers to standard length.

$$\ell(a) = \ell_\infty[1 - e^{-\kappa(a-t_0)}] \tag{A1.6}$$

$$w_a = c[\ell(a)]^d \tag{A1.7}$$

where

w_a is the mass of a fish at age *a*.

The fleet-specific total catch (given by the sum of the observed legal catch and any assumed illegal component, together with the assumed level of cetacean depredation) by mass in year *y* is given by

$$C_y^f = \sum_{a=0}^{m} w_a C_{y,a}^f = \sum_{a=0}^{m} w_a\, S_{y,a}^f F_y^f N_{y,a} \tag{A1.8}$$

which can be re-written as

$$F_y^f = \frac{C_y^f}{\sum_{a=0}^{m} w_a S_{y,a}^f\, N_{y,a}} \tag{A1.9}$$

FISHING SELECTIVITY

The fleet-specific commercial fishing selectivity, $S_{y,a}^f$, is assumed to be described by a logistic curve, modified by a decreasing selectivity for fish older than age a_c. This is given by

$$S_{y,a}^f = \begin{cases} \left[1 + e^{-\frac{\left(a - a_{50,y}^f\right)}{\delta_y^f}}\right]^{-1} & \text{for } a \le a_c \\ \left[1 + e^{-\frac{\left(a - a_{50,y}^f\right)}{\delta_y^f}}\right]^{-1} e^{-\omega_y^f (a - a_c)} & \text{for } a > a_c \end{cases} \tag{A1.10}$$

where

$a_{50,y}^f$ is the age-at-50% selectivity (in years) for year *y* for fleet *f*,

δ_y^f defines the steepness of the ascending part of the selectivity curve (in years^{-1}) for year *y* for fleet *f*, and

ω_y^f defines the steepness of the descending part of the selectivity curve for fish older than age a_c for year *y* for fleet *f* (for all the results reported in this paper, a_c is fixed at 8 yrs).

In cases where equation (A1.9) yields a value of $F_y^f > 0.9$ for a future year, i.e. the available biomass is near to being less than the proposed catch for that year, F_y^f is restricted to 0.9, and the actual catch considered to be taken will be less than the proposed catch. This procedure makes no adjustment to the exploitation rate ($S_{y,a}^f F_y^f$) for other ages. To avoid the unnecessary reduction of catches from ages where the TAC could have been taken if the selectivity for those ages had been increased, the following procedure is adopted (CCSBT, 2003).

The fishing mortality, F_y^f, is computed as usual using equation (A1.9). If $F_y^f \le 0.9$ no change is made to the computation of the total catch, C_y^f, given by equation (A1.8). If $F_y^f > 0.9$, compute the total catch from

$$C_y^f = \sum_{a=0}^{m} w_a\, g\left(S_{y,a}^f F_y^f\right) N_{y,a}.$$

(A1.11)

Denote the modified selectivity by $S_{y,a}^{f*}$, where

$$S_{y,a}^{f*} = \frac{g(S_{y,a}^{f}F_y^f)}{F_y^f}, \quad (A1.12)$$

so that $C_y^f = \sum_{a=0}^{m} w_a\, S_{y,a}^{f*} F_y^f N_{y,a}$, where

$$g(x) = \begin{cases} x & x \leq 0.9 \\ 0.9 + 0.1\left[1 - e^{(-10(x-0.9))}\right] & 0.9 < x \leq \infty \end{cases}. \quad (A.1.13)$$

Now F_y^f is not bounded at one, but $g\left(S_{y,a}^{f}F_y^f\right) \leq 1$ hence $C_{y,a}^f = g(S_{y,a}^f F_y^f)N_{y,a} \leq N_{y,a}$ as required.

Stock-Recruitment Relationship

The spawning biomass in year *y* is given by

$$B_y^{sp} = \sum_{a=1}^{m} w_a f_a\, N_{y,a} = \sum_{a=a_m}^{m} w_a\, N_{y,a}$$

(A1.14)

where

f_a = the proportion of fish of age *a* that are mature (assumed to be knife-edge at age a_m).

The number of recruits at the start of year *y* is assumed to relate to the spawning biomass at the start of year *y*, B_y^{sp}, by a Beverton-Holt stock-recruitment relationship (assuming deterministic recruitment)

$$R\left(B_y^{sp}\right) = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}}.$$

(A1.15)

The values of the parameters α and β can be calculated given the unexploited equilibrium (pristine) spawning biomass K^{sp} and the steepness of the curve *h*, using equations (A1.15)–(A1.19) below. If the pristine recruitment is $R_0 = R(K^{sp})$, then steepness is the recruitment (as a fraction of R_0) that results when spawning biomass is 20% of its pristine level, i.e.

$$hR_0 = R(0.2K^{sp})$$

(A1.16)

from which it can be shown that

$$h = \frac{0.2(\beta + K^{sp})}{\beta + 0.2K^{sp}}.$$

(A1.17)

Rearranging equation (A1.17) gives

$$\beta = \frac{0.2K^{sp}(1-h)}{h-0.2}$$

(A1.18)

and solving equation (A1.15) for α gives

$$\alpha = \frac{0.8hR_0}{h-0.2}.$$

The population is assumed to be in equilibrium before exploitation starts. Therefore R_0 is equal to the loss in numbers due to natural mortality when $B^{sp} = K^{sp}$, and hence

$$\Omega K^{sp} = R_0 = \frac{\alpha K^{sp}}{\beta + K^{sp}}$$

(A1.19)

where

$$\Omega = \left\{\sum_{a=1}^{m-1} w_a f_a e^{-Ma} + \frac{w_m f_m e^{-Mm}}{1-e^{-M}}\right\}^{-1}.$$

(A1.20)

PAST STOCK TRAJECTORY AND FUTURE PROJECTIONS

Given a value for the pre-exploitation equilibrium spawning biomass (K^{sp}) of toothfish, and the assumption that the initial age structure corresponds to equilibrium, it follows that

$$K^{sp} = R_0\left(\sum_{a=1}^{m-1} w_a f_a\, e^{-Ma} + \frac{w_m f_m e^{-Mm}}{1-e^{-M}}\right)$$

(A1.21)

which can be solved for R_0.

The initial numbers at each age *a* for the trajectory calculations, corresponding to the deterministic equilibrium, are given by

$$N_{0,a} = \begin{cases} R_0 e^{-Ma} & 0 \le a \le m-1 \\ \dfrac{R_0 e^{-Ma}}{1-e^{-M}} & a = m \end{cases}$$

(A1.22)

Numbers-at-age for subsequent years are then computed by means of equations (A1.1)-(A1.5) and (A1.8)-(A1.14) under the series of annual catches given.

The model estimate of the fleet-specific exploitable component of the biomass is given by

$$B_y^{\exp}(f) = \sum_{a=0}^{m} w_a S_{y,a}^{f} N_{y,a}$$

(A1.23)

THE LIKELIHOOD FUNCTION

The age-structured production model (ASPM) is fitted to the fleet-specific GLM standardised CPUE to estimate model parameters. The likelihood is calculated assuming that the observed (standardised) CPUE abundance indices are lognormally distributed about their expected value:

$$I_y^f = \hat{I}_y^f e^{\varepsilon_y^f} \text{ or } \varepsilon_y^f = ln(I_y^f) - ln(\hat{I}_y^f), \tag{A1.24}$$

where

I_y^f is the standardised CPUE series index for year *y* corresponding to fleet *f*,

$\hat{I}_y^f$ $= \frac{1}{\phi}\hat{q}^f \hat{B}_y^{\exp}(f)$ is the corresponding model estimate, where

$\hat{B}_y^{\exp}(f)$ is the model estimate of exploitable biomass of the resource for year *y* corresponding to fleet *f*,

ϕ is a multiplier to account for the effect of cetacean depredation (e.g. a 5% increase due to cetacean depredation would mean that $\phi = 1.05$),

q^f is the catchability coefficient for the standardised commercial CPUE abundance indices for fleet *f*, whose maximum likelihood estimate is given by

$$ln\hat{q}^f = \frac{1}{n^f}\textstyle\sum_y \left(ln\, I_y^f - ln\hat{B}_y^{\exp}(f)\right), \text{ where} \tag{A1.25}$$

n^f is the number of data points in the standardised CPUE abundance series for fleet *f*, and

ε_y^f is normally distributed with mean zero and standard deviation σ^f (assuming homoscedasticity of residuals), whose maximum likelihood estimate is given by

$$\hat{\sigma}^f = \sqrt{\frac{1}{n^f}\sum_y \left(lnI_y^f - ln\hat{q}^f \hat{B}_y^{\exp}(f)\right)^2}. \tag{A1.26}$$

The negative log likelihood function (ignoring constants) which is minimised in the fitting procedure is thus

$$-\,ln\,L = \sum_f \left\{\sum_y \left[\frac{1}{2(\sigma^f)^2}\left(lnI_y^f - ln\left(q^f\ B_y^{\exp}(f)\right)\right)^2\right] + n^f\left(ln\sigma^f\right)\right\}. \tag{A1.27}$$

The estimable parameters of this model are q^f, K^{sp}, and σ^f, where K^{sp} is the pre-exploitation mature biomass. Note that the summation over *f* does not include the pot fishery for which no CPUE data are available.

EXTENSION TO INCORPORATE CATCH-AT-LENGTH INFORMATION

The model above provides estimates of the catches-at-age ($C_{y,a}^f$) by number made by the each fleet in the fishery each year from equation (A1.5). These in turn can be converted into proportions of the catch of age *a*:

$$p_{y,a}^f = \frac{C_{y,a}^f}{\sum_{a'} C_{y,a'}^f}.$$

(A1.28)

Using the von Bertalanffy growth equation (A1.6), these proportions-at-age can then be converted to proportions-at-length – here under the assumption that the distribution of length-at-age remains constant over time:

$$p_{y,\ell}^{f} = \sum_{a} p_{y,a}^{f} A_{a,\ell}^{f}$$

(A1.29)

where $A_{a,\ell}^{f}$ is the proportion of fish of age *a* that fall in length group ℓ for fleet *f*. Note that therefore

$$\sum_{\ell} A_{a,\ell}^{f} = 1 \quad \text{for all ages } a. \qquad \text{(A1.30)}$$

The *A* matrix has been calculated here under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.

$$\ell(a) \sim N^{*}\left[\ell_{\infty}\left\{1 - e^{-\kappa(a-t_0)}\right\};\ \theta^{f}(a)^{2}\right] \qquad \text{(A1.31)}$$

where

N^{*} is a normal distribution truncated at ± 3 standard deviations (to avoid negative values), and

$\theta^{f}(a)$ is the standard deviation of length-at-age *a* for fleet *f*, which is modelled here to be proportional to the expected length at age *a*, i.e.

$$\theta^{f}(a) = \Phi^{f} \ell_{\infty}\left\{1 - e^{-\kappa(a-t_0)}\right\} \qquad \text{(A1.32)}$$

with Φ^{f} a parameter estimated in the model fitting process.

Note that since the model of the population's dynamics is based upon a one-year time step, the value of Φ^{f} and hence the $\theta^{f}(a)$'s estimated will reflect not only the real variability of length-at-age, but also the "spread" that arises from the fact that fish in the same annual cohort are not all spawned at exactly the same time, and that catching takes place throughout the year so that there are differences in the age (in terms of fractions of a year) of fish allocated to the same cohort.

Model fitting is effected by adding the following term to the negative log-likelihood of equation (A1.27):

$$-\ln L_{len} = w_{len} \sum_{f,y,\ell} \left\{ \ln\left[\frac{\sigma_{len}^{f}}{\sqrt{p_{y,\ell}^{f}}}\right] + \left(\frac{p_{y,\ell}^{f}}{\left(2\left(\sigma_{len}^{f}\right)^{2}\right)}\right)\left[\ln p_{y,\ell}^{obs}(f) - \ln p_{y,\ell}^{f}\right]^{2} \right\}$$

(A1.33)

where

$p_{y,\ell}^{obs}(f)$ is the proportion by number of the catch in year *y* in length group ℓ for fleet *f*, and

σ_{len}^{f} has a closed form maximum likelihood estimate given by

$$\left(\hat{\sigma}_{len}^{f}\right)^{2} = \frac{\sum_{y,\ell} p_{y,\ell}^{f}\left[\ln p_{y,\ell}^{obs}(f) - \ln p_{y,\ell}^{f}\right]^{2}}{\sum_{y,\ell} 1}.$$

(A1.34)

Equation (A1.33) makes the assumption that proportions-at-length data are log-normally distributed about their model-predicted values. The associated variance is taken to be inversely proportional to $p_{y,\ell}^{f}$ to downweight contributions from expected small proportions which will correspond to small observed sample sizes. This adjustment (known as the Punt-Kennedy approach) is of the form to be expected if a Poisson-like sampling variability component makes a major contribution to the overall variance. Given that overall sample sizes for length distribution data differ quite appreciably from year to year, subsequent refinements of this approach may need to adjust the variance assumed for equation (A1.33) to take this into account.

The w_{len} weighting factor may be set at a value less than 1 to downweight the contribution of the catch-at-length data to the overall negative log-likelihood compared to that of the CPUE data in equation (A1.27). The reason that this factor is introduced is that the $p_{y,\ell}^{obs}(f)$ data for a given year frequently show evidence of strong positive correlation, and so would not be as informative as the independence assumption underlying the form of equation (A1.33) would otherwise suggest.

In the practical application of equation (A1.33), length observations were grouped by 2 cm intervals, with minus- and plus-groups specified below 54 and above 138 cm respectively for the longline fleet, and plus-groups above 176 cm for the pot fleet, to ensure $p_{y,\ell}^{obs}(f)$ values in excess of about 2% for all these cells (hence no numerical problems arise for $p_{y,\ell}^{obs}(f)$ values of zero).

ADJUSTMENT TO INCORPORATE RECRUITMENT VARIABILIITY

To allow for stochastic recruitment, the number of recruits at the start of year *y* given by equation (A1.15) is replaced by

$$R\left(B_y^{sp}\right) = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{\left(\zeta_y - \frac{\sigma_R^2}{2}\right)},$$

(A1.35)

where ζ_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation σ_R (which is input). The ζ_y are estimable parameters of the model.

The stock-recruitment function residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative log-likelihood function is given by

$$-\ln L_{rec} = \sum_{y=1961} \left\{ \ln \sigma_R + \frac{\zeta_y^2}{(2\sigma_R^2)} \right\},$$

(A1.36)

which is added to the negative log-likelihood of equation (A1.27) as a penalty (the frequentist equivalent of a Bayesian prior for these parameters). In the present application, it is assumed that the resource is not at equilibrium at the start of the fishery, but rather in such equilibrium in 1960 with zero catches taken until the start of the fishery in 1997 (by which time virtually all "memory" of the original equilibrium has been lost because of subsequent recruitment variability). For the computations reported in this paper $\sigma_R = 0.5$.

EXTENSION TO INCLUDE TAG-RECAPTURE DATA

The approach described by Butterworth *et al*. (2003) has been implemented in this paper to take into account tag-recapture data. The recaptures are assumed to be governed by a Poisson distribution and therefore the following term is added to the negative log-likelihood of equation (A1.27)

$$-\ln L_{tag} = \sum_{f,y,a} \left\{ \hat{r}_{y,a}^f - r_{y,a}^f \ln \hat{r}_{y,a}^f \right\}$$

(A1.37)

where

$r_{y,a}^{f}$ is the number of recaptured tags from toothfish of age *a* in year *y* by fleet *f* that have been at large for more than a year, and

$\hat{r}_{y,a}^{f}$ is the expected number of recaptures of age *a* in year *y* by fleet *f*, given by

$$\hat{r}_{y,a}^{f} = \eta_{y,a} \frac{F_{y,a}^{f}}{M_a + F_{y,a} + \xi} \left\{1 - e^{-(M_a + F_{y,a} + \xi)}\right\} \sum_{k=1}^{a-1} R_{y-k,a-k}\, e^{-(M_{a-k} + F_{y-k,a-k}^{*} + \xi)} \left[\prod_{j=1,k\geq 2}^{k-1} e^{-(M_{a-j} + F_{y-j,a-j} + \xi)}\right] \quad \text{(A1.38)}$$

where

$R_{y-k,a-k}$ is the number of tags released in year *y-k* of age *a-k*,

$F_{y,a}$ is the fishing mortality for toothfish in year *y* of age *a*, which is given by the summation of the fleet specific fishing mortalities $F_{y,a}^{f}$,

M_a is the natural mortality rate for toothfish of age *a* (assumed to be independent of age),

ξ is the tag loss rate (in yr^{-1}),

$\eta_{y,a}$ is the proportion of tags reported for toothfish in year *y* of age *a*, and

$F_{y-k,a-k}^{*}$ is the fishing mortality of tagged toothfish in year *y-k* of age *a-k* during the first year at large. This is estimated from the number of tags recaptured by each fleet within the first year that the toothfish are at large. However, in this instance, as there are minimal recaptures for longlines and for trotlines within the first year, these fishing mortalities have been assumed to be the same as $F_{y-k,a-k}$.

APPENDIX B

SET OF RESULTS FOR EACH ITERATION CONDUCTED IN DEVELOPING A MP FOR TOOTHFISH

ITERATION 1

The CMP(mean+tag) of Brandão and Butterworth (2019a) was modified so that the slope of the number of cumulative tags recaptured was calculated as a linear regression of the cumulative number of recaptured tags against time instead of as a log-linear regression. All other specifications of the CMP remain as for Brandão and Butterworth (2019a) (see Table 1).

Note that here results are given for OM18; however, this is a robustness test and refers to ROB03 in Table 3. This robustness test affects only projections of CPUE and has been run corresponding to the Base case OM only.

Results

Testing CMP(mean+tag) for the OMs of the Reference Set yields the results shown in Table I1.1. Results for the performance statistics are shown calculated for each individual OM as well as for combining the outputs from all OMs together. Figure I1.1 compares the performance of this CMP under the Reference Set OMs.

Table I1.2 reports various catch statistics, while Table I1.3 gives results based on CPUE statistics. Median projections for some performance statistics under each individual OM are shown in Figures I1.2a to I1.2b. Figure I1.3 shows results when combining all the outputs from the 15 OMs together and calculating the performance statistics on the 15x100 simulations. Figure I1.3 also shows one randomly selected worm trajectory from each of the OMs.

Under most OMs, the performance of this simple empirical CMP seems to be satisfactory in that median catches increase for most of the projection period, while catch rates also keep increasing and the median final depletion remains above the specified target value under OM10. Under OM03 and OM15, the median final depletion is only slightly below this target value. Under OM17, in which a better fit to the observed lower trotline CPUE indices in the last two years is achieved by increasing the tag loss rate, the CMP still falls well below the target value for median final depletion.

If no bias is incorporated in the projections of CPUE (OM18), the CMP exhibits much better performance than was shown by previous CMPs reported by Brandão and Butterworth (2019a), except for CMP(slope). The CMP reacts appropriately by not sharply increasing catches and consequently maintains the resource biomass just below the target value for median final depletion and current (2017) value.

With the adjustment made to the form of the CMP, attempts to incorporate the cumulative numbers of tag returns in the CMP seem to have been successful in improving performance for OM18 which showed problematic resource trends with previous CMPs (Brandão and Butterworth, 2019a). The performance of the CMP under OM17 is still not satisfactory. It might be that it will not be possible to improve the performance of the CMP under OM17 without decreasing TACs under other scenarios in which the status of the resource does not necessitate lower catches. However, as this OM assumes quite an extreme tag loss, perhaps less weight should be accorded to the performance of the CMP under this scenario, even perhaps considering it as a robustness test rather than part of the Reference Set.

Of all the CMPs considered in Brandão and Butterworth (2019a), only one showed an improvement in some respects under OM17. This is CMP(dep t) , which is based on the average of recent CPUE indices and allows for a time-dependent target value. An initial attempt at the incorporation of the tag recapture information in the specification of this CMP (i.e. specifying CMP(dep t+tag) in a similar manner as in CMP(mean+tag)), did not result in an improvement in the performance under OM17, so that this approach was not pursued further.

The form of CMP(mean+tag) in Brandão and Butterworth (2019a) had the added unsatisfactory behaviour under most OMs in that there is a drop in TACs for about the first ten years. With the adjustment made to the CMP reported here, this is no longer the case. Under most OMs, there is now an increase in TACs initially before a later drop in TACs, but for most OMs this drop still keeps the TAC above its present value.

Table I1.1. Medians of the distributions of several performance statistics under the simple CMP(mean+tag) considered for the selected Reference Set OMs, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations for all 15 RS OMs, giving equal weight to each OM.

RS	$\frac{B^{sp}_{2038}}{K^{sp}}$	$\frac{B^{sp}_{2038}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2038}}{B_{MSY}}$	$\frac{B^{sp}_{2022}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
OM01 (Basecase)	0.45 (0.38; 0.53)	1.06 (0.90; 1.25)	1.83 (1.55; 2.16)	1.42 (1.40; 1.44)	763 (584; 945)	671 (620; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM02 (M = 0.1)	0.53 (0.46; 0.62)	1.01 (0.88; 1.18)	2.09 (1.81; 2.44)	1.83 (1.82; 1.84)	616 (493; 761)	659 (606; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM03 (M=0.16)	0.39 (0.33; 0.49)	1.05 (0.87; 1.31)	1.65 (1.37; 2.06)	1.19 (1.17; 1.22)	902 (695; 1088)	678 (626; 678)	0.14 (0.11; 0.16)	0.25 (0.22; 0.25)
OM04 (h = 0.6)	0.41 (0.35; 0.48)	1.02 (0.87; 1.20)	1.33 (1.14; 1.57)	1.07 (1.06; 1.09)	688 (529; 853)	667 (613; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM05 (h = 0.9)	0.47 (0.40; 0.56)	1.08 (0.92; 1.28)	2.83 (2.40; 3.35)	2.14 (2.12; 2.17)	829 (638; 1012)	674 (622; 678)	0.14 (0.11; 0.16)	0.25 (0.22; 0.25)
OM06 ($P_{longline}$ = +30%)	0.45 (0.38; 0.54)	1.06 (0.90; 1.27)	1.83 (1.55; 2.19)	1.42 (1.41; 1.44)	791 (607; 970)	674 (622; 678)	0.14 (0.11; 0.16)	0.25 (0.22; 0.25)
OM07 ($P_{trotline}$ = +0%)	0.45 (0.38; 0.53)	1.06 (0.90; 1.26)	1.82 (1.55; 2.15)	1.40 (1.39; 1.42)	787 (603; 973)	674 (622; 678)	0.14 (0.11; 0.16)	0.25 (0.22; 0.25)
OM08 ($P_{trotline}$ = +10%)	0.45 (0.38; 0.54)	1.05 (0.90; 1.26)	1.84 (1.56; 2.19)	1.43 (1.41; 1.45)	751 (575; 922)	670 (616; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM09 (w_{CPUE} = 5)	0.42 (0.35; 0.49)	0.99 (0.84; 1.16)	1.71 (1.45; 2.00)	1.29 (1.28; 1.32)	748 (574; 891)	655 (599; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM10 (w_{CPUE} = 10)	0.40 (0.34; 0.47)	0.89 (0.75; 1.03)	1.67 (1.42; 1.94)	1.30 (1.28; 1.32)	672 (524; 810)	629 (571; 678)	0.14 (0.11; 0.16)	0.23 (0.21; 0.25)
OM12 (alt growth)	0.44 (0.38; 0.55)	0.69 (0.60; 0.86)	1.76 (1.54; 2.20)	1.81 (1.80; 1.82)	739 (560; 906)	595 (563; 632)	0.14 (0.11; 0.16)	0.23 (0.20; 0.24)
OM13 (mass at lt Area 48.4)	0.45 (0.38; 0.53)	1.05 (0.90; 1.25)	1.76 (1.51; 2.10)	1.37 (1.36; 1.39)	741 (565; 911)	663 (612; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM14 (mass at lt Area 58.5.2)	0.45 (0.38; 0.54)	1.05 (0.90; 1.26)	1.76 (1.51; 2.12)	1.37 (1.36; 1.39)	740 (566; 910)	663 (612; 678)	0.14 (0.11; 0.16)	0.24 (0.22; 0.25)
OM15 (tag report rate = 0.8)	0.37 (0.31; 0.45)	0.95 (0.80; 1.16)	1.50 (1.25; 1.82)	1.25 (1.23; 1.27)	801 (612; 969)	677 (624; 678)	0.14 (0.11; 0.16)	0.25 (0.22; 0.25)
OM17 (tag loss = 0.5)	0.07 (0.00; 0.15)	0.32 (0.01; 0.64)	0.31 (0.01; 0.61)	0.56 (0.52; 0.60)	627 (467; 809)	678 (636; 678)	0.15 (0.12; 0.17)	0.25 (0.22; 0.25)
OM18 (no CPUE bias)	0.37 (0.30; 0.44)	0.87 (0.71; 1.04)	1.51 (1.23; 1.79)	1.42 (1.40; 1.44)	950 (789; 1115)	678 (678; 678)	0.15 (0.13; 0.16)	0.25 (0.25; 0.25)
Combined OMs	0.39 (0.02; 0.51)	0.88 (0.07; 1.20)	1.59 (0.07; 2.08)	1.30 (0.53; 1.43)	686 (503; 902)	663 (591; 678)	0.15 (0.11; 0.17)	0.24 (0.21; 0.25)

Table I1.2. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple CMP(mean+tag) considered for the selected Reference Set OMs, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations for all 15 RS OMs, giving equal weight to each OM.

RS	$\bar{C}_{2019-2038}$ (20 yrs)	$\bar{C}_{2019-2033}$ (15 yrs)	$\bar{C}_{2019-2028}$ (10 yrs)	$\bar{C}_{2019-2022}$ (4 yrs)	C_{2038} (20 yrs)	C_{2033} (15 yrs)	C_{2028} (10 yrs)	C_{2022} (4 yrs)
OM01 (Basecase)	798 (610; 988)	762 (569; 916)	720 (554; 921)	689 (634; 695)	981 (535; 1720)	839 (478; 1279)	672 (424; 1138)	840 (636; 867)
OM02 (M = 0.1)	643 (514; 796)	640 (491; 779)	646 (505; 802)	676 (621; 695)	676 (336; 1324)	614 (338; 972)	549 (360; 892)	789 (611; 867)
OM03 (M=0.16)	944 (726; 1139)	870 (628; 1066)	823 (614; 1057)	695 (641; 695)	1183 (665; 2000)	1007 (560; 1536)	856 (507; 1483)	867 (653; 867)
OM04 (h = 0.6)	719 (552; 892)	700 (531; 847)	693 (534; 869)	684 (628; 695)	799 (436; 1489)	740 (403; 1121)	611 (399; 1043)	823 (623; 867)
OM05 (h = 0.9)	867 (666; 1059)	802 (598; 963)	741 (574; 961)	691 (637; 695)	1059 (588; 1979)	951 (531; 1394)	725 (457; 1227)	851 (637; 867)
OM06 ($P_{longline}$ = +30%)	827 (634; 1016)	780 (581; 938)	732 (570; 940)	692 (636; 695)	994 (542; 1790)	875 (482; 1346)	701 (449; 1187)	852 (639; 867)
OM07 ($P_{trotline}$ = +0%)	784 (600; 970)	742 (555; 897)	699 (535; 893)	658 (606; 662)	933 (519; 1734)	844 (469; 1275)	668 (428; 1118)	809 (607; 826)
OM08 ($P_{trotline}$ = +10%)	823 (629; 1011)	778 (584; 947)	746 (571; 940)	720 (661; 729)	993 (539; 1790)	870 (485; 1329)	689 (439; 1149)	874 (660; 908)
OM09 (w_{CPUE} = 5)	782 (599; 932)	708 (534; 860)	666 (521; 855)	671 (613; 695)	969 (552; 1588)	902 (483; 1270)	636 (387; 1067)	779 (597; 867)
OM10 (w_{CPUE} = 10)	702 (547; 847)	630 (471; 777)	577 (473; 774)	644 (583; 695)	880 (506; 1436)	833 (475; 1235)	572 (320; 855)	677 (548; 867)
OM12 (alt growth)	772 (585; 948)	654 (506; 842)	545 (478; 674)	609 (575; 647)	1118 (647; 1845)	990 (595; 1436)	620 (357; 947)	586 (528; 675)
OM13 (mass at lt Area 48.4)	775 (590; 953)	730 (547; 893)	697 (546; 879)	680 (626; 695)	953 (514; 1681)	829 (476; 1247)	635 (407; 1108)	806 (620; 867)
OM14 (mass at lt Area 58.5.2)	774 (591; 952)	730 (547; 895)	696 (546; 878)	680 (626; 695)	956 (519; 1694)	831 (475; 1258)	629 (406; 1104)	806 (620; 867)
OM15 (tag report rate = 0.8)	838 (639; 1014)	784 (576; 969)	744 (577; 968)	694 (639; 695)	967 (507; 1818)	882 (464; 1407)	715 (446; 1279)	862 (642; 867)
OM17 (tag loss = 0.5)	655 (487; 846)	698 (524; 914)	792 (580; 1019)	695 (652; 695)	344 (150; 1041)	448 (231; 943)	658 (375; 1133)	867 (691; 867)
OMP18 (no CPUE bias)	994 (826; 1168)	960 (773; 1122)	911 (783; 1092)	695 (695; 695)	1088 (645; 1669)	1084 (644; 1634)	964 (599; 1465)	867 (867; 867)
Combined OMs	717 (525; 944)	693 (504; 908)	680 (498; 970)	680 (604; 695)	805 (180; 1518)	708 (294; 1241)	634 (352; 1100)	804 (578; 867)

Table I1.3. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2038 being less than this average under the simple CMP(mean+tag) considered for the selected Reference Set OMs, together with their 90% probability intervals are also reported. The last row reports these performance statistics as medians across all simulations for all 15 RS OMs, giving equal weight to each OM.

RS	$\frac{CPUE_{2038}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2033}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2028}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2022}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2038}}{\overline{CPUE_{15-17}}}$	Probability $\frac{CPUE_{2038}}{\overline{CPUE_{15-17}}} < 1$
OM01 (Basecase)	1.54 (1.04; 2.44)	1.55 (0.99; 2.51)	1.42 (0.94; 2.02)	1.33 (0.85; 1.86)	1.29 (0.87; 2.04)	0.18
OM02 (M = 0.1)	1.35 (0.88; 2.19)	1.36 (0.84; 2.25)	1.27 (0.84; 1.82)	1.26 (0.77; 1.79)	1.13 (0.74; 1.83)	0.33
OM03 (M=0.16)	1.65 (1.13; 2.54)	1.61 (1.11; 2.58)	1.52 (1.00; 2.14)	1.42 (0.94; 1.94)	1.38 (0.94; 2.13)	0.10
OM04 (h = 0.6)	1.44 (0.98; 2.27)	1.45 (0.93; 2.36)	1.36 (0.90; 1.92)	1.30 (0.83; 1.82)	1.21 (0.82; 1.90)	0.25
OM05 (h = 0.9)	1.61 (1.08; 2.55)	1.62 (1.04; 2.60)	1.48 (0.99; 2.09)	1.35 (0.86; 1.88)	1.34 (0.91; 2.13)	0.13
OM06 ($P_{longline}$ = +30%)	1.53 (1.04; 2.43)	1.55 (0.99; 2.50)	1.42 (0.96; 2.02)	1.33 (0.85; 1.87)	1.28 (0.87; 2.03)	0.19
OM07 ($P_{trotline}$ = +0%)	1.55 (1.05; 2.45)	1.56 (1.01; 2.54)	1.44 (0.97; 2.04)	1.34 (0.86; 1.87)	1.30 (0.88; 2.05)	0.17
OM08 ($P_{trotline}$ = +10%)	1.53 (1.04; 2.42)	1.54 (0.99; 2.49)	1.41 (0.95; 2.00)	1.32 (0.85; 1.85)	1.28 (0.87; 2.02)	0.19
OM09 (w_{CPUE} = 5)	1.72 (1.20; 2.68)	1.69 (1.16; 2.68)	1.58 (1.05; 2.21)	1.39 (0.92; 1.89)	1.43 (1.00; 2.24)	0.05
OM10 (w_{CPUE} = 10)	1.85 (1.34; 2.69)	1.83 (1.32; 2.78)	1.72 (1.17; 2.44)	1.40 (0.99; 1.89)	1.55 (1.12; 2.25)	0.03
OM12 (alt growth)	1.56 (1.21; 2.17)	1.64 (1.17; 2.37)	1.49 (1.11; 1.91)	1.10 (0.84; 1.40)	1.31 (1.01; 1.81)	0.05
OM13 (mass at lt Area 48.4)	1.51 (1.03; 2.41)	1.54 (0.99; 2.44)	1.40 (0.95; 1.98)	1.29 (0.83; 1.80)	1.26 (0.86; 2.01)	0.17
OM14 (mass at lt Area 58.5.2)	1.51 (1.03; 2.40)	1.54 (0.98; 2.44)	1.40 (0.96; 1.98)	1.29 (0.83; 1.80)	1.26 (0.86; 2.01)	0.17
OM15 (tag report rate = 0.8)	1.50 (1.04; 2.32)	1.51 (0.99; 2.45)	1.40 (0.92; 1.95)	1.34 (0.87; 1.86)	1.25 (0.87; 1.94)	0.22
OM17 (tag loss = 0.5)	0.80 (0.19; 1.53)	0.93 (0.23; 1.70)	0.83 (0.45; 1.51)	1.29 (0.91; 1.76)	0.67 (0.16; 1.28)	0.86
OM18 (no CPUE bias)	1.98 (1.32; 3.01)	1.98 (1.27; 3.19)	1.86 (1.22; 2.73)	1.89 (1.21; 2.65)	1.65 (1.11; 2.52)	0.04
Combined OMs	1.47 (0.44; 2.44)	1.46 (0.41; 2.54)	1.39 (0.52; 2.19)	1.34 (0.91; 1.85)	1.23 (0.37; 2.04)	0.36

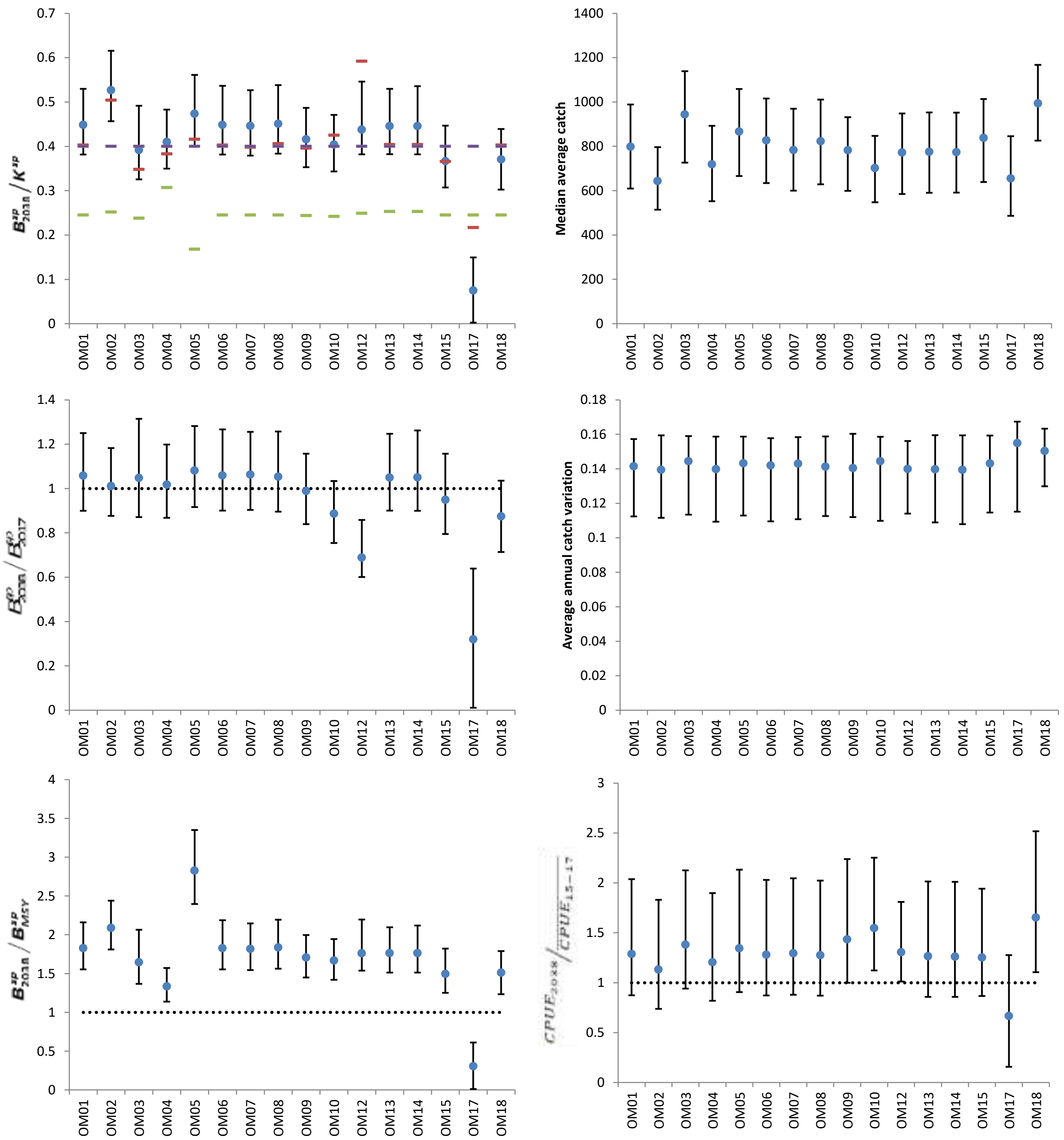

Figure I1.1. Zeh plots for some of the performance statistics reported in the Tables for each OM for CMP(mean+tag), which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2038 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2019 to 2038; the average annual variation in catch; and the CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2018) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned and the green dashes represent the MSYL (relative to *K*).

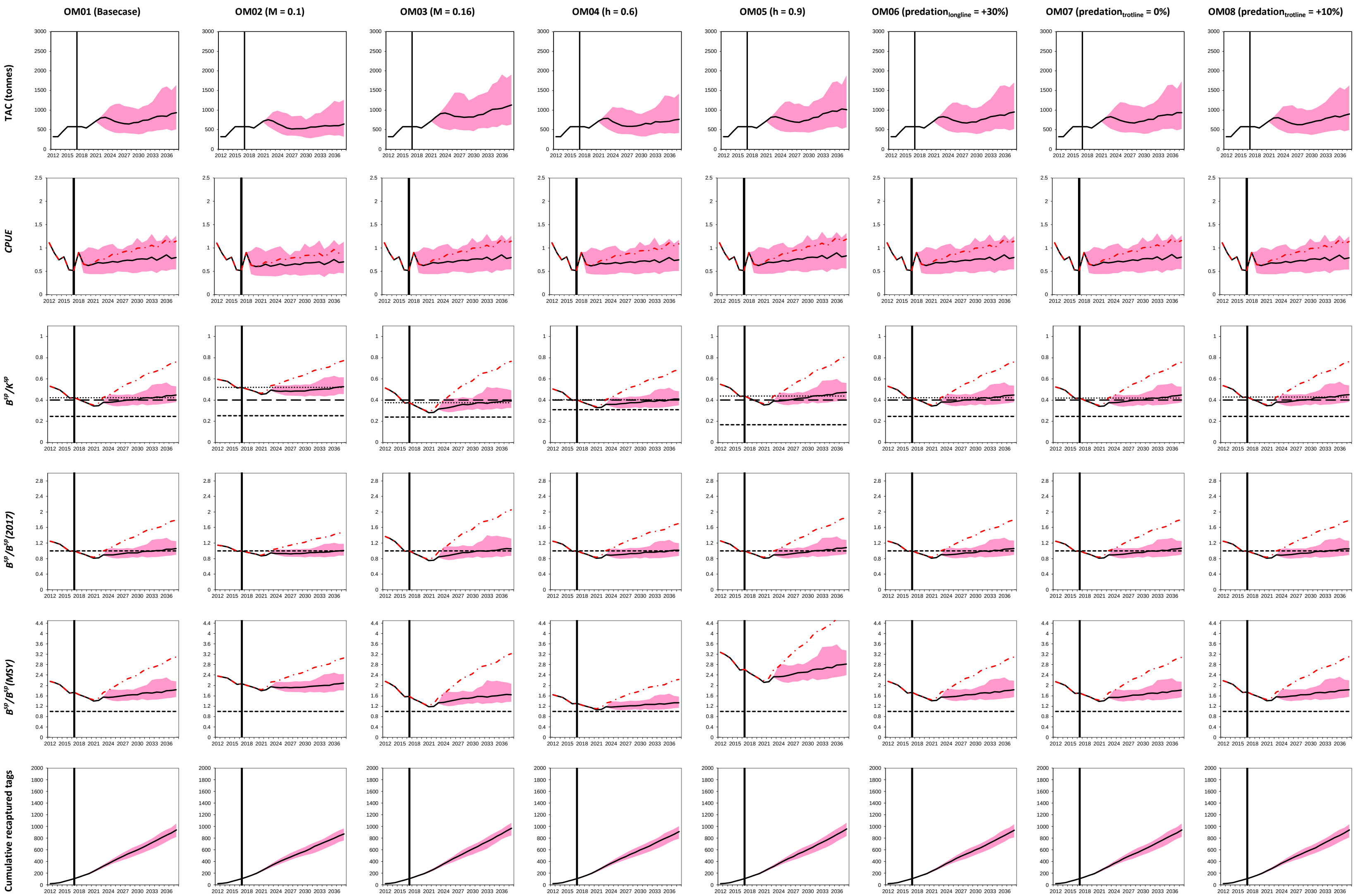

Figure I1.2a. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under CMP(mean+tag). That CMP is based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **OM01 to OM08**. Projections commence to the right of the thick vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to *K*). The red lines represent the median trajectories under a zero catch scenario.

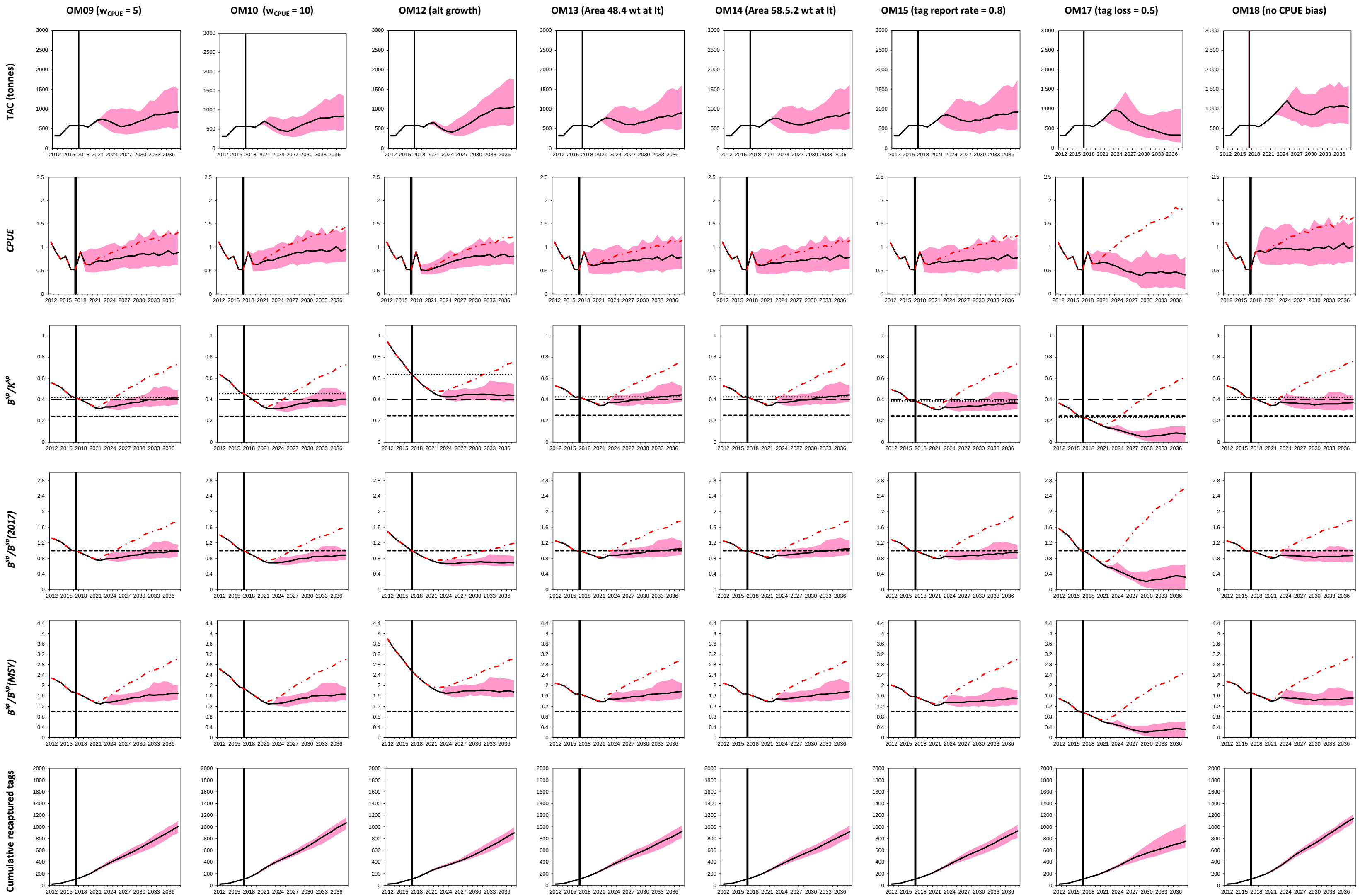

Figure I1.2b. Projection results as in Figure 2a, but here for **OM09 to OM18**.

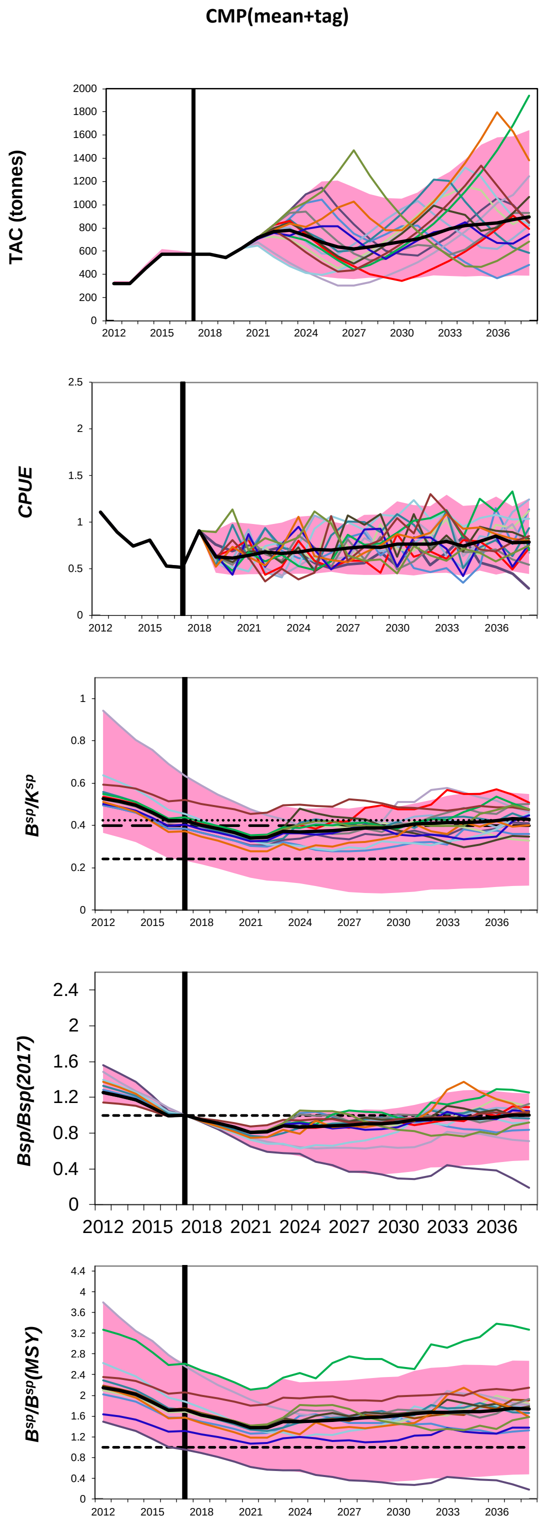

Figure I1.3. Median trajectories (thick black lines) of the TAC (in tonnes), CPUE trends, spawning biomass depletion, spawning biomass relative to the 2017 value and spawning biomass relative to B_{MSY} under CMP(mean+tag) across all simulations for all 15 RS OMs, giving equal weight to each OM. Projections commence to the right of the vertical lines and the shaded areas represent 90% probability envelopes. A random selection of worm plots, one from each of the 15 OMs, is also shown (coloured lines). For the middle plot, the large dashed line is the value to which this CMP was tuned under OM10, the dotted line is the median current (2018) spawning biomass depletion, while the small dash line is the average MSYL (relative to *K*) over all 15 RS OMs.

ITERATION 2

The CMP of iteration 1 was adjusted to include the following suggestions made by the Task Team:

- **a) Changes to the Base case OM:** It was suggested the new information with regards to the portion of the TAC that is not allocated and to account for the now known catch in 2019 and the TAC set in 2020 be incorporated. These changes are reflected in the calculation of the true catch ($C_{y'}$) (removals from the population) and the calculation of future TACs which are described in points (3) and (4) above. Given the availability now of the 2019 data, the standardised CPUE index for 2019 as well as the tagging data for 2019 are also input for the evaluation of the CMP. Table 4 shows the standardised CPUE series that incorporates data to 2019 as well as the cumulative number of recaptured tags observed to 2019.
- **b) Changes to the Baseline CMP:** It was proposed that the Baseline CMP constrain TACs to a maximum inter-annual change of 10% instead of 15% as previously. A two-year lag in the calculation of the CMP is applied to account for the fact that at the time the TAC is set in year y, complete data are available only to year $y-2$.

Results

Testing this CMP for the OMs of the Reference Set yields the results shown in Table I2.1. Results for the performance statistics are shown calculated for each individual OM as well as for combining the outputs from all OMs together. Figure I2.1 compares the performance of this CMP under the Reference Set OMs.

Table I2.2 reports various catch statistics, while Table I2.3 gives results based on CPUE statistics. Median projections for some performance statistics under each individual OM are shown in Figures I2.2a to I2.2b. Figure I2.3 shows results when combining all the outputs from the 14 OMs together and calculating the performance statistics on the 14x100 simulations. Figure I2.3 also shows one randomly selected worm trajectory from each of the OMs.

Under most OMs, the performance of this simple empirical CMP seems to be satisfactory in that median catches increase for most of the projection period, while catch rates also keep increasing and the median final depletion remains above the specified target value under OM10. Under OM03 and OM15, the median final depletion is only slightly below this target value.

Under most OMs, there is an increase in TACs initially before a later drop in TACs, but for most OMs this drop still keeps the TAC above its present value. This effect was also observed in the previous results of Brandão and Butterworth (2020), but only allowing an inter-annual change in the TAC of 10% instead of 15% and the other changes introduced to the Baseline CMP has exacerbated this effect.

A similar set of results for CMP01 but for the Robustness tests are shown in Tables I2.4 to I2.6 and Figures I2.4 to I2.6.

Table I2.1. Medians of the distributions of several performance statistics under the simple **CMP01*** considered for the selected **Reference Set OMs**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all 14 RS OMs, giving equal weight to each OM. CMP01* is tuned to provide the median result for OM10 shown in **bold** in the first column.

RS	$\frac{B^{sp}_{2038}}{K^{sp}}$	$\frac{B^{sp}_{2038}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2038}}{B_{MSY}}$	$\frac{B^{sp}_{2022}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
OM01 (Basecase)	0.44 (0.37; 0.55)	1.03 (0.86; 1.29)	1.78 (1.49; 2.23)	1.45 (1.44; 1.47)	767 (638; 964)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM02 (M = 0.1)	0.51 (0.44; 0.62)	0.98 (0.84; 1.19)	2.02 (1.73; 2.46)	1.86 (1.85; 1.87)	651 (541; 788)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
OM03 (M=0.16)	0.38 (0.31; 0.50)	1.02 (0.83; 1.33)	1.60 (1.30; 2.09)	1.23 (1.22; 1.25)	884 (699; 1136)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
OM04 (h = 0.6)	0.40 (0.33; 0.50)	0.99 (0.83; 1.23)	1.30 (1.09; 1.61)	1.11 (1.10; 1.12)	706 (591; 886)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
OM05 (h = 0.9)	0.46 (0.38; 0.58)	1.06 (0.88; 1.32)	2.77 (2.29; 3.45)	2.20 (2.18; 2.22)	818 (667; 1001)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM06 ($P_{longline}$ = +30%)	0.44 (0.37; 0.55)	1.04 (0.87; 1.29)	1.79 (1.50; 2.23)	1.46 (1.45; 1.48)	784 (650; 976)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM07 ($P_{trotline}$ = +0%)	0.44 (0.36; 0.53)	1.04 (0.87; 1.27)	1.77 (1.49; 2.18)	1.44 (1.43; 1.46)	791 (654; 979)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM08 ($P_{trotline}$ = +10%)	0.44 (0.37; 0.55)	1.02 (0.86; 1.28)	1.78 (1.50; 2.23)	1.47 (1.46; 1.48)	759 (632; 948)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM09 (w_{CPUE} = 5)	0.41 (0.35; 0.52)	0.97 (0.82; 1.23)	1.68 (1.42; 2.12)	1.33 (1.32; 1.35)	745 (610; 944)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM10 (w_{CPUE} = 10)	**0.40** (0.34; 0.52)	0.88 (0.75; 1.13)	1.65 (1.41; 2.13)	1.33 (1.32; 1.36)	683 (527; 828)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM12 (alt growth)	0.44 (0.37; 0.56)	0.70 (0.58; 0.88)	1.78 (1.49; 2.26)	1.85 (1.85; 1.86)	737 (522; 951)	551 (551; 551)	0.13 (0.12; 0.14)	0.32 (0.32; 0.32)
OM13 (mass at lt Area 48.4)	0.43 (0.36; 0.54)	1.02 (0.85; 1.28)	1.72 (1.44; 2.16)	1.41 (1.40; 1.42)	744 (619; 910)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM14 (mass at lt Area 58.5.2)	0.43 (0.36; 0.54)	1.02 (0.86; 1.28)	1.72 (1.44; 2.16)	1.41 (1.40; 1.42)	743 (619; 909)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
OM15 (tag report rate = 0.8)	0.36 (0.29; 0.45)	0.92 (0.74; 1.16)	1.46 (1.17; 1.83)	1.29 (1.28; 1.31)	799 (654; 1011)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
Combined OMs	0.43 (0.34; 0.55)	0.99 (0.72; 1.26)	1.74 (1.26; 2.64)	1.43 (1.11; 2.19)	756 (584; 986)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)

Table I2.2. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple **CMP01*** considered for the selected **Reference Set OMs**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all 14 RS OMs, giving equal weight to each OM.

RS	$\bar{C}_{2019-2038}$ (20 yrs)	$\bar{C}_{2019-2033}$ (15 yrs)	$\bar{C}_{2019-2028}$ (10 yrs)	$\bar{C}_{2019-2022}$ (4 yrs)	C_{2038} (20 yrs)	C_{2033} (15 yrs)	C_{2028} (10 yrs)	C_{2022} (4 yrs)
OM01 (Basecase)	791 (655; 998)	795 (643; 939)	733 (638; 745)	507 (507; 507)	798 (484; 1610)	813 (520; 1360)	1052 (703; 1131)	638 (638; 638)
OM02 (M = 0.1)	669 (554; 813)	686 (568; 819)	694 (592; 745)	507 (507; 507)	561 (358; 1210)	607 (398; 919)	849 (556; 1131)	638 (638; 638)
OM03 (M=0.16)	914 (720; 1178)	891 (689; 1002)	745 (684; 745)	507 (507; 507)	1009 (580; 1910)	1051 (624; 1821)	1131 (821; 1131)	638 (638; 638)
OM04 (h = 0.6)	727 (607; 916)	734 (613; 892)	718 (617; 745)	507 (507; 507)	650 (403; 1374)	671 (452; 1163)	946 (622; 1131)	638 (638; 638)
OM05 (h = 0.9)	845 (686; 1036)	825 (659; 966)	739 (645; 745)	507 (507; 507)	911 (543; 1741)	879 (546; 1492)	1094 (754; 1131)	638 (638; 638)
OM06 ($P_{longline}$ = +30%)	808 (668; 1010)	807 (650; 951)	735 (644; 745)	507 (507; 507)	830 (501; 1607)	829 (542; 1404)	1075 (725; 1131)	638 (638; 638)
OM07 ($P_{trotline}$ = +0%)	778 (640; 965)	771 (621; 907)	700 (611; 709)	483 (483; 483)	793 (480; 1555)	812 (519; 1416)	1030 (700; 1077)	608 (608; 608)
OM08 ($P_{trotline}$ = +10%)	820 (680; 1028)	819 (664; 963)	764 (660; 780)	531 (531; 531)	822 (489; 1677)	826 (530; 1461)	1072 (675; 1184)	669 (669; 669)
OM09 (w_{CPUE} = 5)	768 (626; 976)	755 (617; 917)	727 (622; 745)	507 (507; 507)	817 (508; 1563)	728 (467; 1291)	982 (645; 1131)	638 (638; 638)
OM10 (w_{CPUE} = 10)	703 (539; 856)	689 (554; 839)	701 (580; 745)	507 (507; 507)	770 (441; 1333)	606 (391; 989)	825 (548; 1131)	638 (638; 638)
OM12 (alt growth)	759 (534; 985)	710 (531; 896)	644 (546; 743)	507 (507; 507)	960 (538; 1722)	813 (432; 1339)	786 (473; 1122)	638 (638; 638)
OM13 (mass at lt Area 48.4)	766 (636; 941)	773 (618; 915)	724 (622; 745)	507 (507; 507)	762 (459; 1567)	760 (499; 1290)	993 (644; 1131)	638 (638; 638)
OM14 (mass at lt Area 58.5.2)	766 (635; 941)	772 (617; 915)	724 (621; 745)	507 (507; 507)	765 (458; 1584)	758 (498; 1274)	991 (644; 1131)	638 (638; 638)
OM15 (tag report rate = 0.8)	825 (672; 1048)	829 (662; 975)	741 (657; 745)	507 (507; 507)	808 (482; 1608)	864 (538; 1517)	1109 (770; 1131)	638 (638; 638)
Combined OMs	779 (599; 1024)	772 (597; 953)	724 (608; 745)	507 (483; 531)	810 (459; 1603)	789 (458; 1450)	1013 (613; 1131)	638 (608; 669)

Table I2.3. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2038 being less than this average under the simple **CMP01*** considered for the selected **Reference Set OMs**, together with their 90% probability intervals are also reported. The last row reports these performance statistics as medians across all simulations combined for all 14 RS OMs, giving equal weight to each OM.

RS	$\frac{CPUE_{2038}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2033}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2028}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2022}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2038}}{\overline{CPUE_{15-17}}}$	Probability $\frac{CPUE_{2038}}{\overline{CPUE_{15-17}}} < 1$
OM01 (Basecase)	1.45 (0.99; 2.31)	1.42 (0.91; 2.27)	1.33 (0.87; 1.94)	1.30 (0.83; 1.81)	1.25 (0.86; 1.99)	0.20
OM02 (M = 0.1)	1.27 (0.81; 2.00)	1.24 (0.76; 2.01)	1.20 (0.76; 1.73)	1.23 (0.75; 1.74)	1.09 (0.70; 1.72)	0.38
OM03 (M=0.16)	1.53 (1.05; 2.40)	1.51 (1.00; 2.42)	1.45 (0.96; 2.21)	1.39 (0.92; 1.88)	1.32 (0.91; 2.07)	0.13
OM04 (h = 0.6)	1.35 (0.92; 2.16)	1.32 (0.85; 2.13)	1.26 (0.82; 1.83)	1.27 (0.81; 1.78)	1.16 (0.79; 1.86)	0.29
OM05 (h = 0.9)	1.51 (1.02; 2.42)	1.50 (0.95; 2.41)	1.39 (0.90; 2.03)	1.31 (0.84; 1.84)	1.30 (0.88; 2.08)	0.14
OM06 ($P_{longline}$ = +30%)	1.44 (0.99; 2.31)	1.43 (0.91; 2.29)	1.34 (0.87; 1.95)	1.30 (0.83; 1.82)	1.24 (0.86; 1.99)	0.21
OM07 ($P_{trotline}$ = +0%)	1.45 (1.00; 2.33)	1.44 (0.92; 2.31)	1.35 (0.88; 1.96)	1.31 (0.84; 1.83)	1.25 (0.86; 2.01)	0.21
OM08 ($P_{trotline}$ = +10%)	1.43 (0.99; 2.29)	1.41 (0.90; 2.26)	1.32 (0.86; 1.92)	1.29 (0.83; 1.80)	1.23 (0.86; 1.98)	0.21
OM09 (w_{CPUE} = 5)	1.66 (1.16; 2.40)	1.56 (1.04; 2.43)	1.42 (0.97; 2.12)	1.36 (0.91; 1.84)	1.43 (1.00; 2.06)	0.06
OM10 (w_{CPUE} = 10)	1.80 (1.30; 2.52)	1.68 (1.16; 2.50)	1.51 (1.02; 2.16)	1.37 (0.98; 1.86)	1.55 (1.12; 2.17)	0.03
OM12 (alt growth)	1.51 (1.16; 2.06)	1.49 (1.04; 2.16)	1.34 (1.00; 1.79)	1.08 (0.82; 1.36)	1.30 (1.00; 1.78)	0.05
OM13 (mass at lt Area 48.4)	1.43 (0.98; 2.23)	1.40 (0.89; 2.20)	1.31 (0.86; 1.87)	1.26 (0.81; 1.76)	1.24 (0.84; 1.92)	0.20
OM14 (mass at lt Area 58.5.2)	1.43 (0.97; 2.23)	1.40 (0.89; 2.20)	1.31 (0.86; 1.87)	1.26 (0.81; 1.75)	1.23 (0.84; 1.92)	0.20
OM15 (tag report rate = 0.8)	1.41 (0.96; 2.22)	1.38 (0.89; 2.23)	1.32 (0.87; 2.00)	1.32 (0.86; 1.82)	1.22 (0.83; 1.92)	0.26
Combined OMs	1.48 (0.98; 2.33)	1.44 (0.90; 2.30)	1.36 (0.87; 2.02)	1.29 (0.83; 1.82)	1.28 (0.84; 2.01)	0.18

Table I2.4. Medians of the distributions of several performance statistics under the simple **CMP01*** considered for the selected **Robustness tests**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all seven Robustness tests, giving equal weight to each test.

RS	$\frac{B^{sp}_{2038}}{K^{sp}}$	$\frac{B^{sp}_{2038}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2038}}{B_{MSY}}$	$\frac{B^{sp}_{2022}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
OM01 (Basecase)	0.44 (0.37; 0.55)	1.03 (0.86; 1.29)	1.78 (1.49; 2.23)	1.45 (1.44; 1.47)	767 (638; 964)	551 (551; 551)	0.14 (0.12; 0.14)	0.32 (0.32; 0.32)
ROB01 (recruit var diff)	0.52 (0.44; 0.65)	1.09 (0.91; 1.36)	2.12 (1.76; 2.63)	1.72 (1.71; 1.73)	1193 (883; 1312)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
ROB02 (tag loss = 0.5)	0.01 (0.00; 0.09)	0.02 (0.00; 0.38)	0.02 (0.00; 0.36)	0.62 (0.59; 0.65)	738 (561; 954)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
ROB03 (no CPUE bias)	0.36 (0.29; 0.46)	0.85 (0.68; 1.09)	1.47 (1.18; 1.88)	1.45 (1.44; 1.47)	920 (778; 1152)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
ROB04 (TAC under-catch)	0.50 (0.41; 0.62)	1.17 (0.96; 1.46)	2.02 (1.66; 2.52)	1.49 (1.49; 1.50)	1288 (1001; 1312)	551 (551; 551)	0.10 (0.09; 0.10)	0.12 (0.12; 0.12)
ROB05 (TAC under-catch to 2024)	0.44 (0.37; 0.53)	1.04 (0.87; 1.26)	1.79 (1.50; 2.17)	1.49 (1.49; 1.50)	818 (704; 1036)	551 (551; 551)	0.15 (0.14; 0.16)	0.12 (0.12; 0.12)
ROB06 (tags released fn(TAC))	0.51 (0.41; 0.63)	1.19 (0.98; 1.49)	2.06 (1.69; 2.56)	1.45 (1.44; 1.47)	636 (573; 730)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
ROB07 (tags released fn(TAC))	0.53 (0.43; 0.68)	1.25 (1.01; 1.61)	2.16 (1.74; 2.78)	1.45 (1.44; 1.47)	586 (492; 643)	551 (551; 551)	0.14 (0.13; 0.14)	0.32 (0.32; 0.32)
Combined ROBs[7]	0.46 (0.00; 0.62)	1.06 (0.01; 1.42)	1.87 (0.01; 2.50)	1.46 (0.61; 1.72)	826 (553; 1312)	551 (551; 551)	0.14 (0.10; 0.15)	0.32 (0.12; 0.32)

[7] Note that ROB02 should be excluded from the computation of the combined statistics as it distorts the distribution of the results.

Table I2.5. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple **CMP01*** considered for the selected **Robustness tests**, together with their 90% probability intervals. The last row reports these performance statistics as medians across all simulations combined for all seven Robustness tests, giving equal weight to each test.

RS	$\bar{C}_{2019-2038}$ (20 yrs)	$\bar{C}_{2019-2033}$ (15 yrs)	$\bar{C}_{2019-2028}$ (10 yrs)	$\bar{C}_{2019-2022}$ (4 yrs)	C_{2038} (20 yrs)	C_{2033} (15 yrs)	C_{2028} (10 yrs)	C_{2022} (4 yrs)
OM01 (Basecase)	791 (655; 998)	795 (643; 939)	733 (638; 745)	507 (507; 507)	798 (484; 1610)	813 (520; 1360)	1052 (703; 1131)	638 (638; 638)
ROB01 (recruit var diff)	1238 (912; 1363)	986 (827; 1002)	745 (692; 745)	507 (507; 507)	1951 (1061; 2932)	1708 (955; 1821)	1131 (948; 1131)	638 (638; 638)
ROB02 (tag loss = 0.5)	760 (575; 987)	820 (644; 964)	745 (688; 745)	507 (507; 507)	482 (288; 883)	796 (452; 1414)	1131 (756; 1131)	638 (638; 638)
ROB03 (no CPUE bias)	952 (802; 1195)	934 (803; 1002)	745 (738; 745)	507 (507; 507)	1030 (630; 1705)	1219 (743; 1821)	1131 (1061; 1131)	638 (638; 638)
ROB04 (TAC under-catch)	692 (538; 705)	522 (473; 522)	395 (394; 395)	294 (294; 294)	1392 (705; 1501)	932 (616; 932)	579 (576; 579)	327 (327; 327)
ROB05 (TAC under-catch to 2024)	766 (646; 995)	745 (633; 887)	587 (569; 587)	294 (294; 294)	829 (500; 1475)	891 (638; 1687)	1131 (967; 1131)	327 (327; 327)
ROB06 (tags released fn(TAC))	654 (588; 752)	688 (587; 794)	707 (622; 745)	507 (507; 507)	588 (440; 985)	546 (418; 765)	847 (619; 1131)	638 (638; 638)
ROB07 (tags released fn(TAC))	601 (502; 661)	679 (568; 735)	706 (621; 732)	507 (507; 507)	323 (240; 405)	499 (356; 594)	845 (602; 1005)	638 (638; 638)
Combined ROBs[8]	713 (555; 1284)	741 (522; 1002)	723 (395; 745)	507 (294; 507)	797 (292; 2360)	884 (436; 1821)	1066 (579; 1131)	638 (327; 638)

[8] See Footnote (3).

Table I2.6. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2038 being less than this average under the simple **CMP01*** considered for the selected **Robustness tests**, together with their 90% probability intervals are also reported. The last row reports these performance statistics as medians across all simulations combined for all seven Robustness tests, giving equal weight to each test.

RS	$\frac{CPUE_{2038}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2033}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2028}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2022}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2038}}{\overline{CPUE}_{15-17}}$	Probability $\frac{CPUE_{2038}}{\overline{CPUE}_{15-17}} < 1$
OM01 (Basecase)	1.45 (0.99; 2.31)	1.42 (0.91; 2.27)	1.33 (0.87; 1.94)	1.30 (0.83; 1.81)	1.25 (0.86; 1.99)	0.20
ROB01 (recruit var diff)	1.35 (0.88; 2.14)	1.38 (0.90; 2.30)	1.35 (0.84; 1.96)	1.21 (0.76; 1.73)	1.16 (0.76; 1.84)	0.31
ROB02 (tag loss = 0.5)	0.34 (0.11; 1.02)	0.47 (0.21; 1.20)	1.03 (0.59; 1.58)	1.36 (0.99; 1.85)	0.29 (0.09; 0.88)	0.99
ROB03 (no CPUE bias)	1.82 (1.19; 2.88)	1.84 (1.18; 2.96)	1.88 (1.21; 2.76)	1.85 (1.19; 2.59)	1.57 (1.02; 2.48)	0.04
ROB04 (TAC under-catch)	1.56 (1.00; 2.47)	1.60 (1.03; 2.54)	1.53 (0.98; 2.18)	1.34 (0.86; 1.87)	1.34 (0.86; 2.13)	0.13
ROB05 (TAC under-catch to 2024)	1.44 (0.96; 2.30)	1.39 (0.91; 2.26)	1.42 (0.91; 2.04)	1.34 (0.86; 1.87)	1.25 (0.83; 1.98)	0.22
ROB06 (tags released fn(TAC))	1.62 (1.05; 2.50)	1.50 (0.97; 2.46)	1.34 (0.88; 1.95)	1.30 (0.83; 1.81)	1.40 (0.91; 2.16)	0.11
ROB07 (tags released fn(TAC))	1.68 (1.07; 2.63)	1.52 (1.00; 2.49)	1.34 (0.88; 1.95)	1.30 (0.83; 1.81)	1.45 (0.92; 2.26)	0.11
Combined ROBs[9]	1.46 (0.25; 2.50)	1.43 (0.35; 2.49)	1.40 (0.82; 2.28)	1.40 (0.85; 2.10)	1.26 (0.21; 2.15)	0.27

[9] See footnote (3)

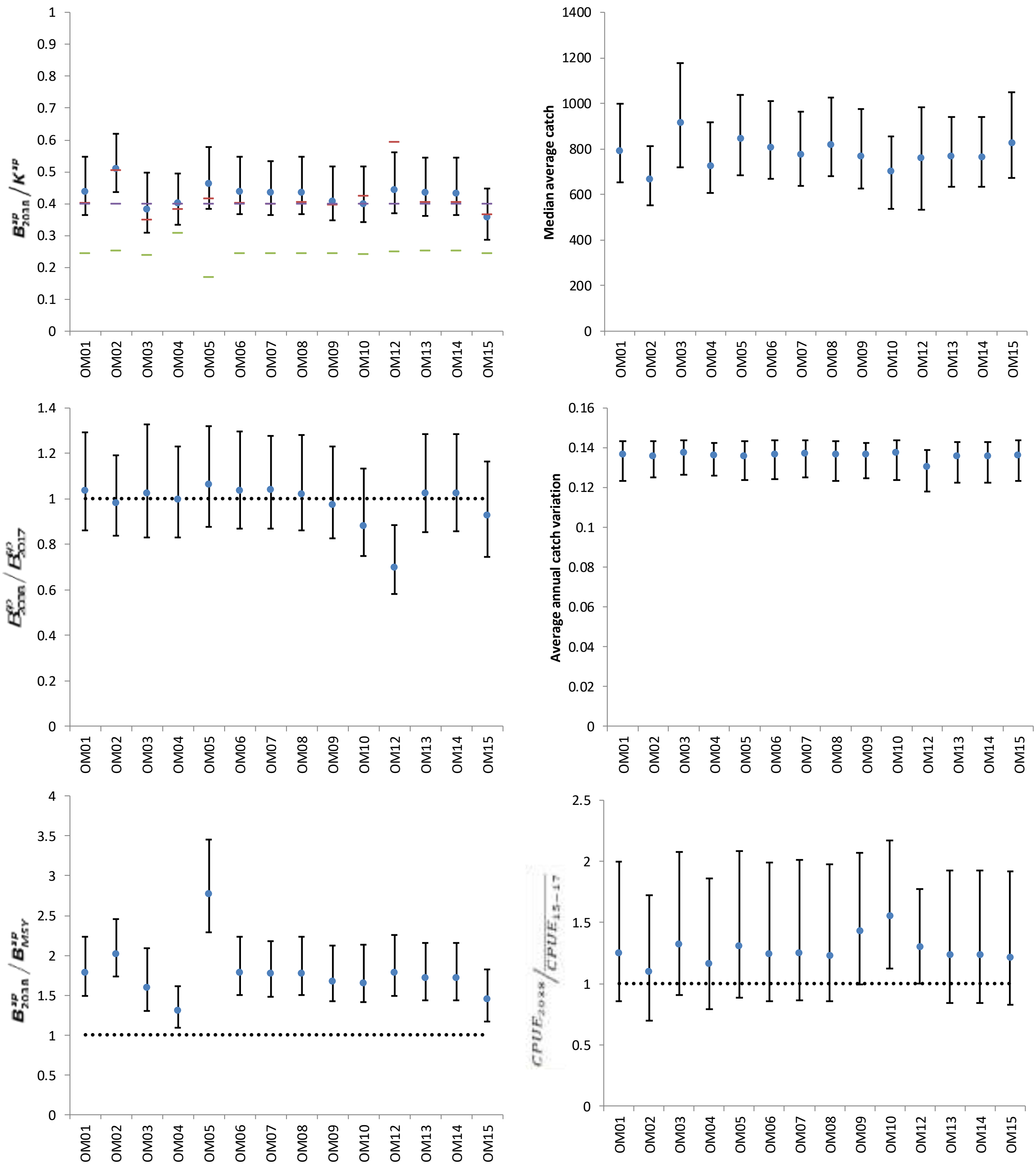

Figure I2.1. Zeh plots for some of the performance statistics reported in the Tables for each **OM** for **CMP01***, which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2038 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2019 to 2038; the average annual variation in catch; and the CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2018) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned, and the green dashes represent the MSYL (relative to *K*).

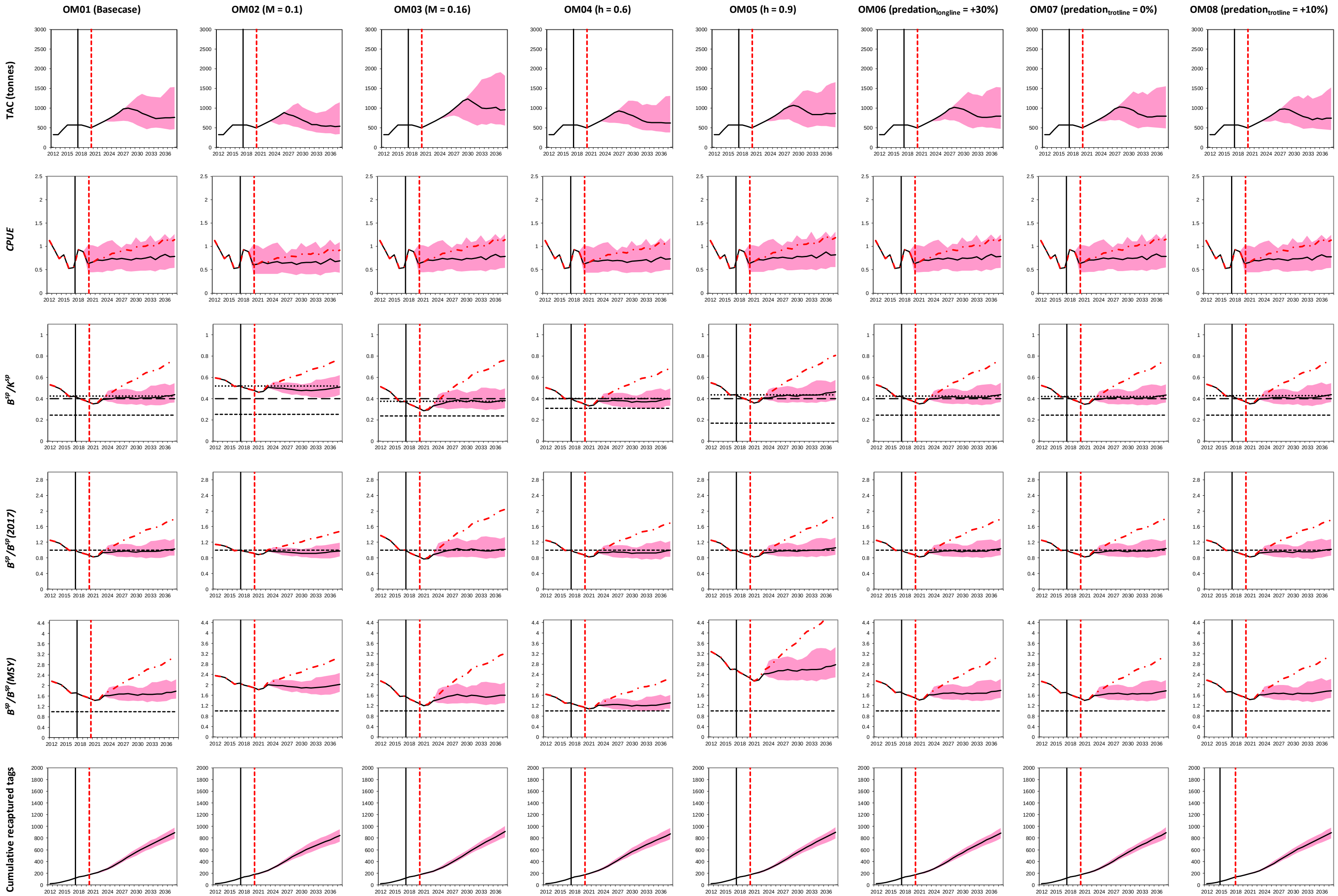

Figure I2.2a. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under **CMP01***. That CMP is based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **OM01 to OM08**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to *K*). The red dot-dash lines represent the median trajectories under a zero catch scenario.

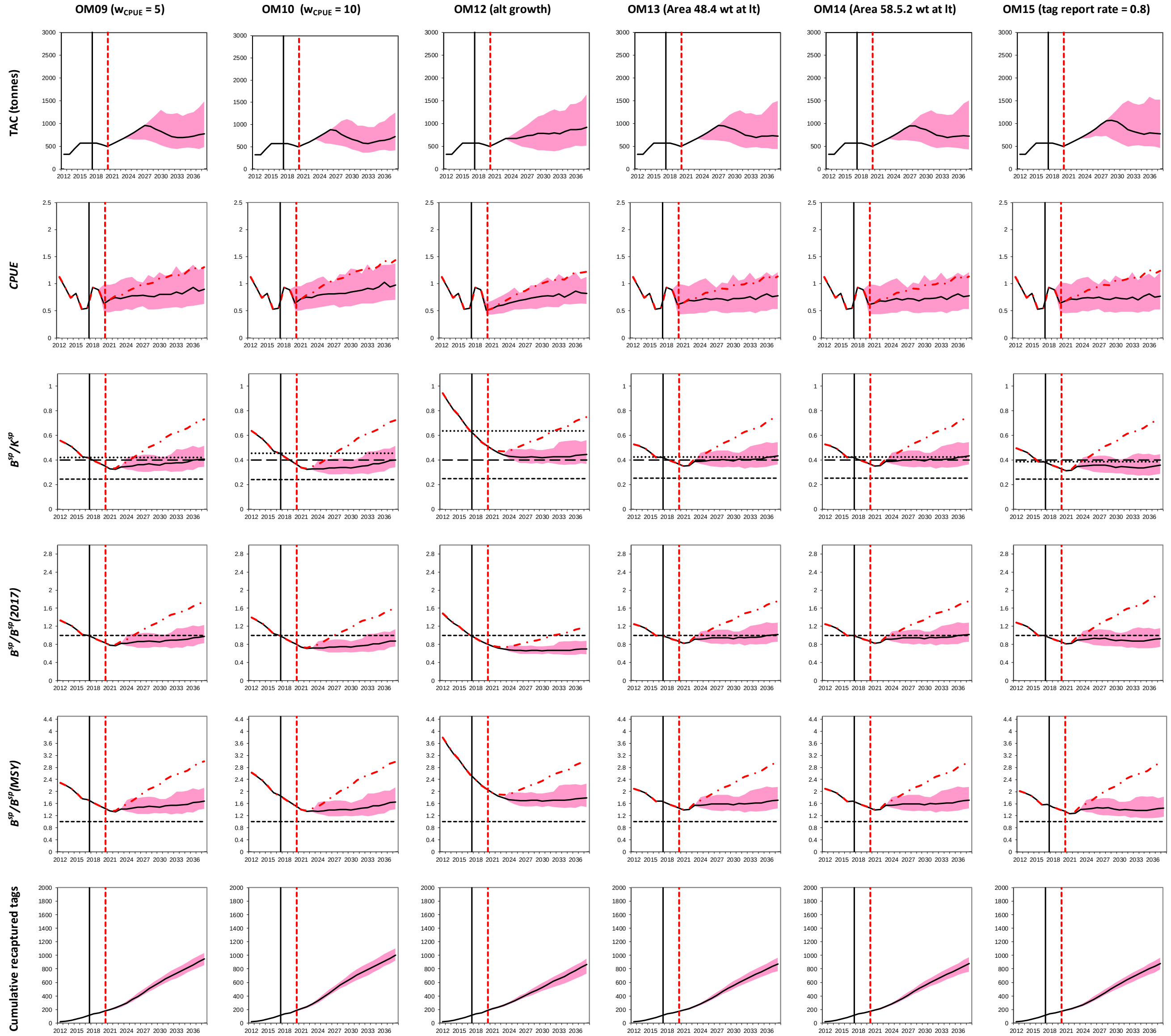

Figure I2.2b. Projection results as in Figure I2.2a, but here for **OM09 to OM15**.

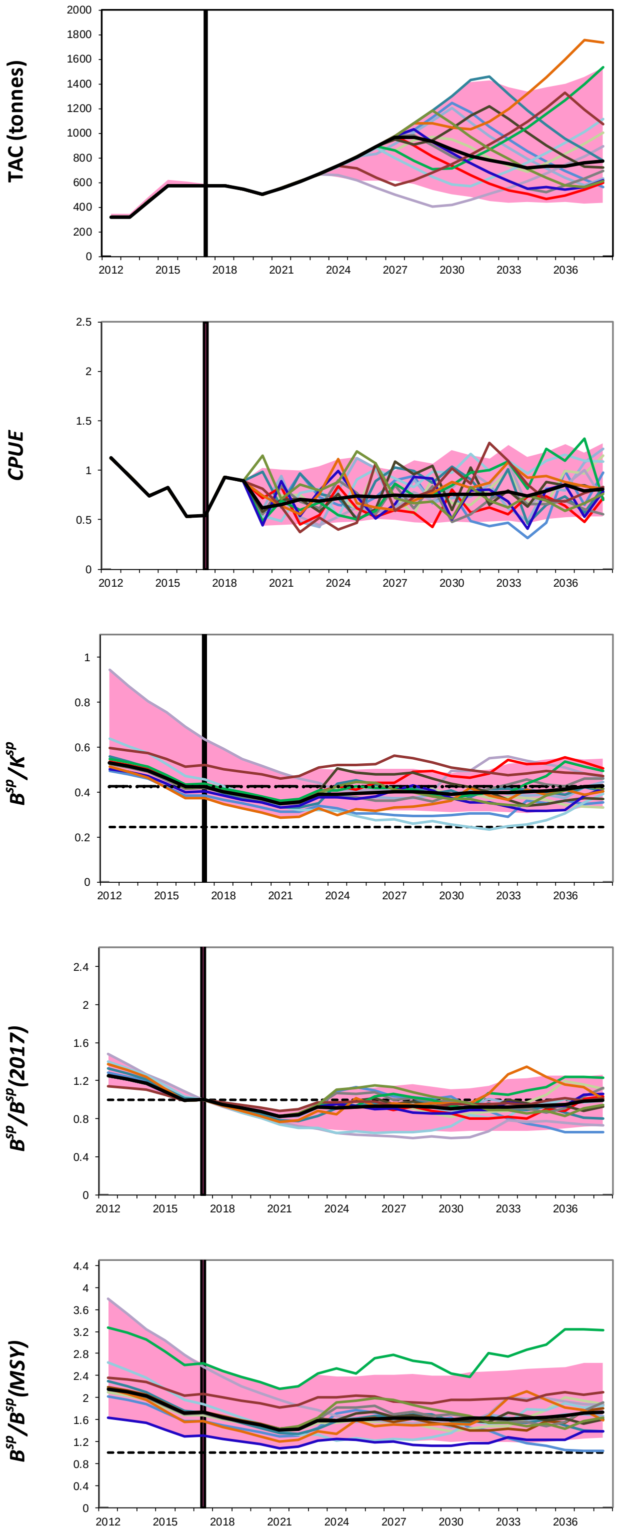

Figure I2.3. Median trajectories (thick black lines) of the TAC (in tonnes), CPUE trends, spawning biomass depletion, spawning biomass relative to the 2017 value and spawning biomass relative to B_{MSY} under **CMP01*** across all simulations for all 14 **RS OMs**, giving equal weight to each OM. Projections commence to the right of the vertical lines and the shaded areas represent 90% probability envelopes. A random selection of worm plots, one from each of the 14 OMs, is also shown (coloured lines). For the middle plot, the large dashed line is the value to which this CMP was tuned under OM10, the dotted line is the median current (2018) spawning biomass depletion, while the small dash line is the average MSYL (relative to *K*) over all 14 RS OMs.

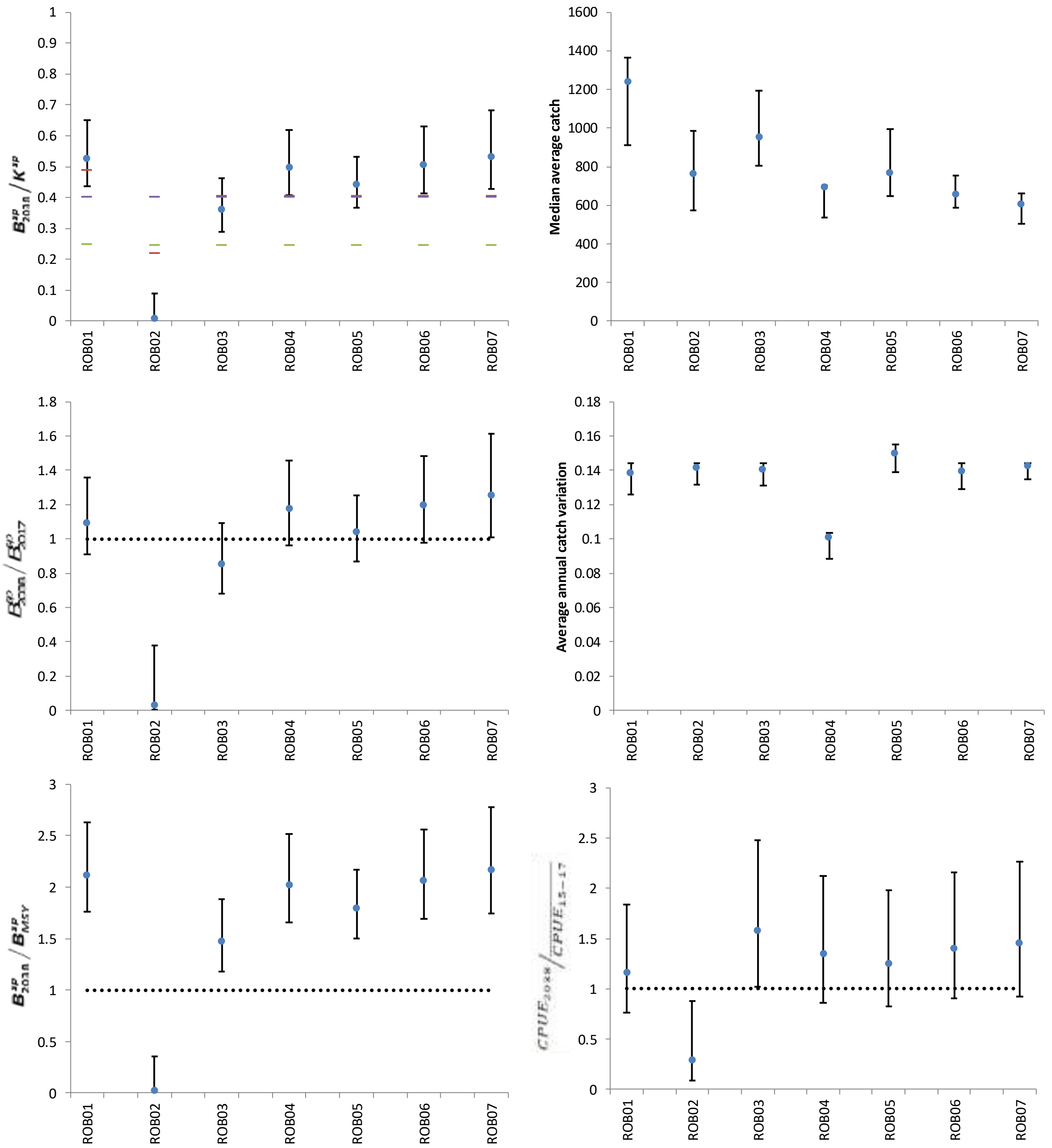

Figure I2.4. Zeh plots for some of the performance statistics reported in the Tables for each **Robustness test** for **CMP01***, which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2038 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2019 to 2038; the average annual variation in catch; and the CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2018) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned and the green dashes represent the MSYL (relative to *K*). Note that in the final version of this paper, OM01 will be added to this plot for comparison.

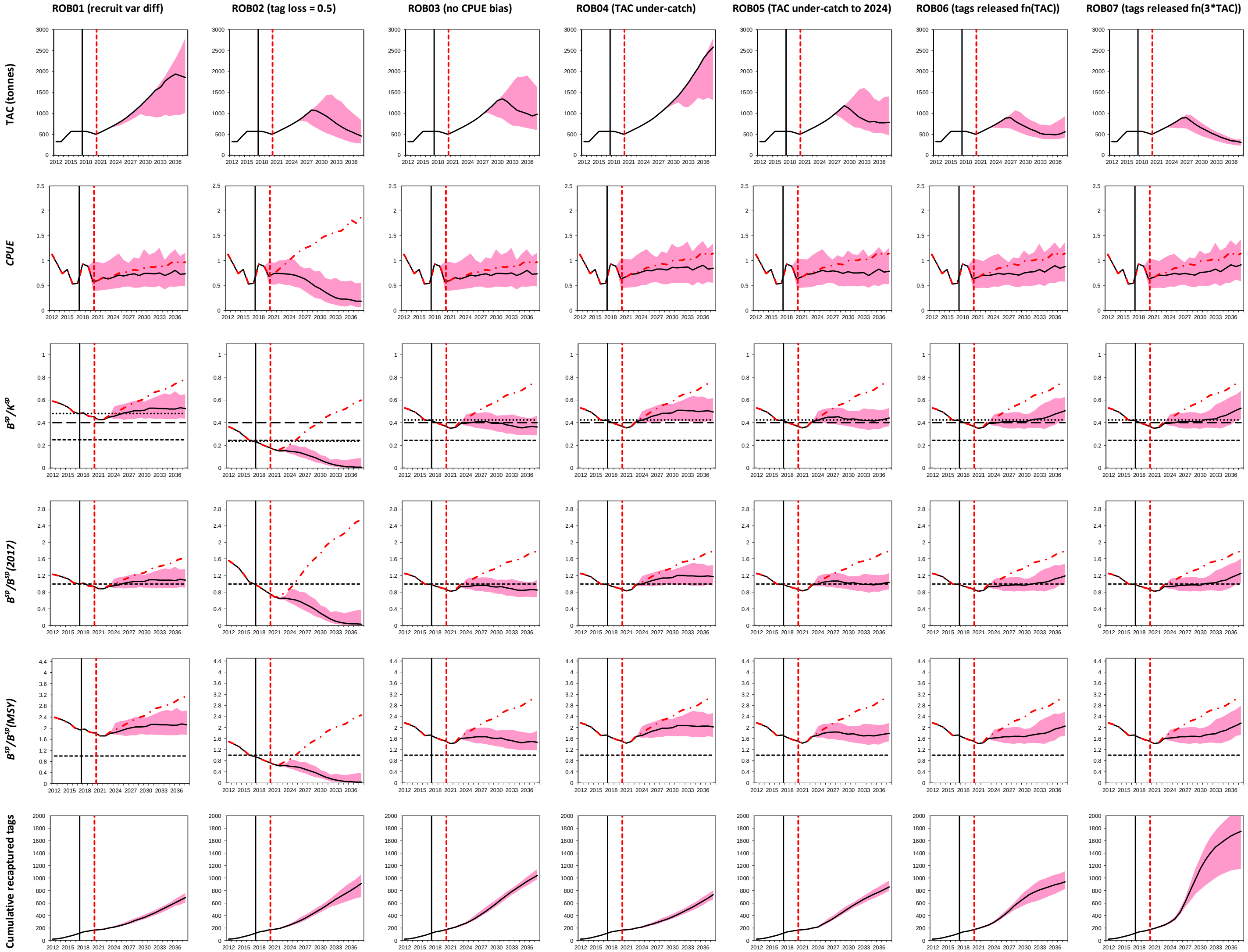

Figure I2.5. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under **CMP01***. That CMP is based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **ROB01 to ROB07**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to *K*). The red dot-dash lines represent the median trajectories under a zero catch scenario.

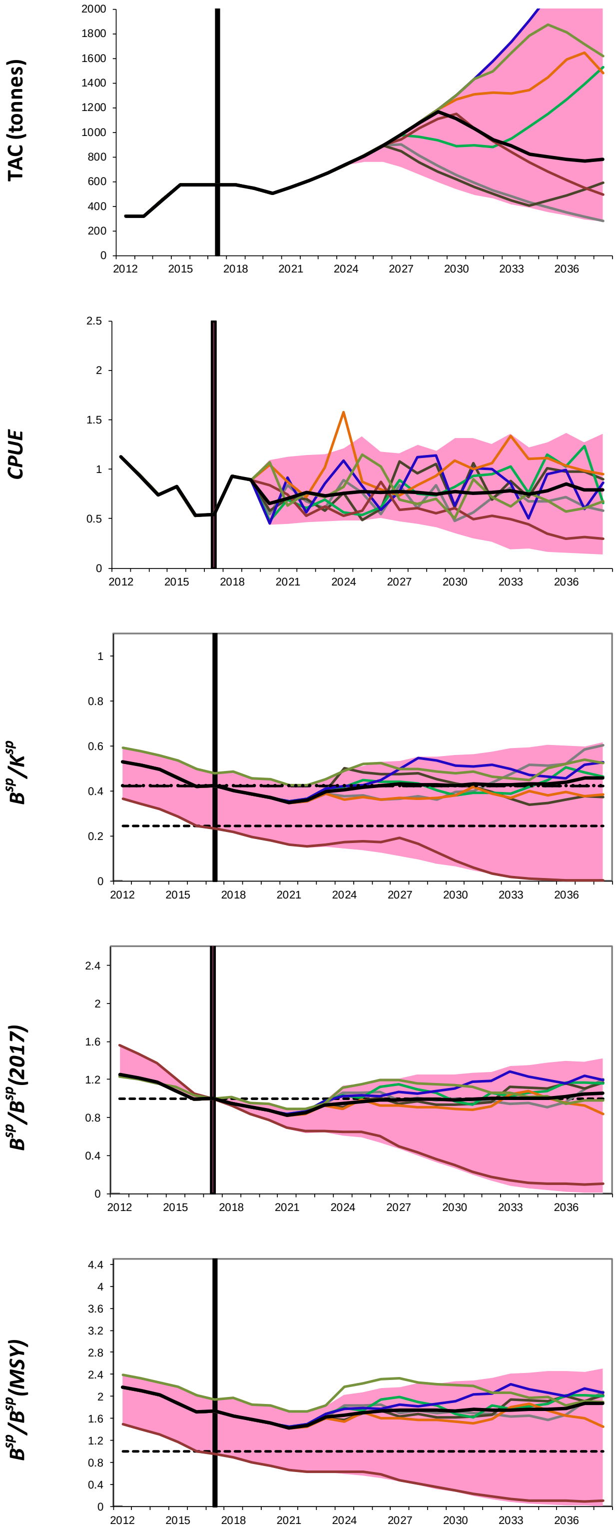

Figure I2.6. Median trajectories (thick black lines) of the TAC (in tonnes), CPUE trends, spawning biomass depletion, spawning biomass relative to the 2017 value and spawning biomass relative to B_{MSY} under **CMP01*** across all simulations for all 7 **Robustness tests**, giving equal weight to each test. Projections commence to the right of the vertical lines and the shaded areas represent 90% probability envelopes. A random selection of worm plots, one from each of the 7 Robustness tests, is also shown (coloured lines). For the middle plot, the large dashed line is the value to which this CMP was tuned under OM10, the dotted line is the median current (2018) spawning biomass depletion, while the small dash line is the average MSYL (relative to *K*) over all 7 Robustness tests. Note that ROB02 should be excluded as it distorts the distribution of the results.

ITERATION 3

The changes made in iteration 2 to the Base case OM meant that projections start from 2021. To continue basing performance statistics on a twenty-year projection period, the final projection year was changed from 2038 to 2040. Alternative CMPs to the Baseline CMP are also investigated to either constrain the TAC to various maximum inter-annual changes or to tune to different median final depletion under OM10 varies. Thus, the following CMPs were investigated:

CMP01: constrain TAC to maximum inter-annual change of 10%.
CMP02: constrain TAC to maximum inter-annual change of 5%.
CMP03: constrain TAC to maximum inter-annual change of 15%.
CMP04: Tune CMP to a target of 30% of the median final depletion under OM10.
CMP05: Tune CMP to a target of 50% of the median final depletion under OM10.

CMP01 to CMP03 assume the Baseline target of 40% of the median final depletion under OM10 and CMP04 and CMP05 assume the Baseline constraint of the TAC to a maximum inter-annual change of 10%. The results presented for these CMPs are restricted to OM02, OM10 and OM15, where the first and last were selected as they reflected the largest positive and negative median final depletions compared to that for OM10.

Alternative CMPs to CMP01 to CMP05 are then considered in which an initial smoothing of the TAC is applied. In this case the CMP is denoted with an “S” for example CMP01S for CMP01 with an initial TAC smoothing. The results presented for all these CMPs are again restricted to OM02, OM10 and OM15.

Results

Testing the CMPs without an initial TAC smoothing for the selected OMs yields the results shown in Tables I3.1 to I3.3. Figures I3.1 and I3.2 compare the performance of these CMPs under the selected OMs.

Table I3.2 reports various catch statistics, while Table I3.3 gives results based on CPUE statistics. Median projections for some performance statistics under each individual selected OM are shown in Figures I3.3a to I3.3b.

A similar set of results for the CMPs but with an initial TAC smoothing are shown in Tables I3.4 to I3.6 and Figures I3.4 to I3.6.

Figure I3.7 compares the median trajectories of the TAC and spawning biomass depletion for each CMP and selected OM with and without smoothing applied to the initial TACs.

Table I3.1. Medians of the distributions of several performance statistics under the simple **CMPs without initial TAC smoothing** considered for the selected **OMs**, together with their 90% probability intervals. CMPs are tuned to provide the median result for OM10 shown in **bold** in the third column.

CMP	OM	$\frac{B^{sp}_{2040}}{K^{sp}}$	$\frac{B^{sp}_{2040}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2040}}{B_{MSY}}$	$\frac{B^{sp}_{2024}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
CMP01	**OM02 (M = 0.1)**	0.50 (0.43; 0.59)	0.97 (0.83; 1.13)	1.99 (1.71; 2.33)	1.99 (1.92; 2.21)	682 (524; 885)	641 (637; 641)	0.09 (0.08; 0.10)	0.10 (0.09; 0.10)
	OM10 (w_{CPUE} = 10)	**0.40** (0.32; 0.47)	0.88 (0.70; 1.04)	1.65 (1.31; 1.96)	1.35 (1.25; 1.64)	720 (565; 912)	641 (624; 641)	0.09 (0.08; 0.10)	0.10 (0.09; 0.10)
	OM15 (tag report rate = 0.8)	0.35 (0.27; 0.44)	0.91 (0.69; 1.15)	1.43 (1.09; 1.80)	1.42 (1.33; 1.72)	865 (677; 1124)	641 (641; 641)	0.09 (0.07; 0.10)	0.10 (0.10; 0.10)
CMP02	**OM02 (M = 0.1)**	0.52 (0.44; 0.59)	0.99 (0.85; 1.14)	2.04 (1.75; 2.34)	2.00 (1.93; 2.22)	658 (533; 800)	568 (568; 568)	0.05 (0.04; 0.05)	0.05 (0.05; 0.05)
	OM10 (w_{CPUE} = 10)	**0.40** (0.35; 0.49)	0.88 (0.76; 1.07)	1.65 (1.44; 2.01)	1.36 (1.27; 1.65)	705 (569; 842)	568 (562; 568)	0.05 (0.04; 0.05)	0.05 (0.05; 0.05)
	OM15 (tag report rate = 0.8)	0.38 (0.31; 0.48)	0.98 (0.79; 1.24)	1.54 (1.25; 1.95)	1.44 (1.34; 1.74)	815 (643; 872)	568 (568; 568)	0.05 (0.04; 0.05)	0.05 (0.05; 0.05)
CMP03	**OM02 (M = 0.1)**	0.51 (0.45; 0.58)	0.97 (0.87; 1.12)	2.01 (1.79; 2.31)	1.97 (1.90; 2.20)	697 (543; 861)	721 (705; 721)	0.13 (0.11; 0.14)	0.15 (0.13; 0.15)
	OM10 (w_{CPUE} = 10)	**0.40** (0.34; 0.49)	0.88 (0.74; 1.09)	1.66 (1.39; 2.04)	1.34 (1.24; 1.62)	737 (562; 921)	721 (695; 721)	0.14 (0.12; 0.15)	0.15 (0.12; 0.15)
	OM15 (tag report rate = 0.8)	0.36 (0.28; 0.47)	0.94 (0.72; 1.21)	1.48 (1.13; 1.90)	1.41 (1.31; 1.70)	869 (691; 1087)	721 (721; 721)	0.13 (0.11; 0.14)	0.15 (0.15; 0.15)
CMP04	**OM02 (M = 0.1)**	0.41 (0.34; 0.49)	0.79 (0.66; 0.94)	1.63 (1.37; 1.93)	1.99 (1.92; 2.21)	895 (731; 1121)	641 (641; 641)	0.09 (0.08; 0.10)	0.10 (0.10; 0.10)
	OM10 (w_{CPUE} = 10)	**0.30** (0.21; 0.37)	0.66 (0.47; 0.82)	1.24 (0.88; 1.54)	1.35 (1.25; 1.64)	901 (723; 1179)	641 (641; 641)	0.09 (0.08; 0.10)	0.10 (0.10; 0.10)
	OM15 (tag report rate = 0.8)	0.22 (0.14; 0.31)	0.58 (0.37; 0.80)	0.91 (0.58; 1.26)	1.42 (1.33; 1.72)	1117 (848; 1354)	641 (641; 641)	0.10 (0.09; 0.10)	0.10 (0.10; 0.10)
CMP05	**OM02 (M = 0.1)**	0.60 (0.52; 0.69)	1.15 (1.00; 1.32)	2.38 (2.06; 2.72)	1.99 (1.92; 2.21)	465 (359; 589)	621 (560; 641)	0.09 (0.07; 0.10)	0.09 (0.06; 0.10)
	OM10 (w_{CPUE} = 10)	**0.50** (0.42; 0.60)	1.10 (0.93; 1.32)	2.07 (1.76; 2.48)	1.35 (1.26; 1.64)	526 (375; 666)	602 (523; 641)	0.09 (0.08; 0.10)	0.09 (0.06; 0.10)
	OM15 (tag report rate = 0.8)	0.48 (0.40; 0.58)	1.24 (1.02; 1.51)	1.95 (1.61; 2.38)	1.42 (1.33; 1.72)	608 (448; 800)	638 (569; 641)	0.09 (0.08; 0.10)	0.10 (0.07; 0.10)

Table I3.2. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple **CMPs without initial TAC smoothing** considered for the selected **OMs**, together with their 90% probability intervals.

CMP	OM	$\bar{C}_{2019-2040}$ (20 yrs)	$\bar{C}_{2019-2035}$ (15 yrs)	$\bar{C}_{2019-2030}$ (10 yrs)	$\bar{C}_{2019-2024}$ (4 yrs)	C_{2040} (20 yrs)	C_{2035} (15 yrs)	C_{2030} (10 yrs)	C_{2024} (4 yrs)
CMP01	**OM02 (M = 0.1)**	716 (550; 929)	745 (585; 923)	798 (667; 896)	673 (669; 673)	664 (413; 1092)	594 (387; 1017)	789 (508; 1247)	772 (754; 772)
	OM10 (w_{CPUE} = 10)	756 (593; 958)	749 (585; 991)	790 (625; 925)	673 (655; 673)	857 (543; 1278)	661 (413; 1076)	749 (469; 1368)	772 (700; 772)
	OM15 (tag report rate = 0.8)	909 (711; 1180)	911 (718; 1157)	900 (747; 925)	673 (673; 673)	890 (526; 1405)	848 (562; 1504)	1147 (679; 1368)	772 (772; 772)
CMP02	**OM02 (M = 0.1)**	690 (560; 840)	688 (590; 788)	680 (605; 697)	597 (597; 597)	715 (471; 1006)	705 (503; 1063)	774 (575; 859)	641 (641; 641)
	OM10 (w_{CPUE} = 10)	740 (597; 884)	720 (590; 797)	688 (603; 697)	597 (590; 597)	832 (581; 1154)	803 (511; 1096)	794 (572; 859)	641 (615; 641)
	OM15 (tag report rate = 0.8)	856 (675; 916)	792 (681; 797)	697 (668; 697)	597 (597; 597)	1081 (673; 1399)	1060 (606; 1096)	859 (708; 859)	641 (641; 641)
CMP03	**OM02 (M = 0.1)**	732 (570; 904)	766 (601; 927)	889 (709; 1038)	757 (741; 757)	642 (387; 1228)	473 (301; 997)	715 (436; 1054)	922 (856; 922)
	OM10 (w_{CPUE} = 10)	774 (590; 967)	765 (567; 938)	861 (634; 1015)	757 (729; 757)	930 (528; 1421)	593 (343; 1077)	659 (378; 1018)	922 (812; 922)
	OM15 (tag report rate = 0.8)	912 (725; 1141)	931 (734; 1266)	1026 (813; 1208)	757 (757; 757)	924 (464; 1622)	635 (431; 1087)	1055 (569; 2013)	922 (922; 922)
CMP04	**OM02 (M = 0.1)**	940 (767; 1178)	978 (806; 1156)	919 (841; 925)	673 (673; 673)	856 (508; 1357)	912 (607; 1530)	1322 (896; 1368)	772 (772; 772)
	OM10 (w_{CPUE} = 10)	946 (759; 1238)	976 (764; 1202)	922 (801; 925)	673 (673; 673)	931 (565; 1449)	916 (561; 1803)	1345 (773; 1368)	772 (772; 772)
	OM15 (tag report rate = 0.8)	1173 (890; 1421)	1156 (907; 1229)	925 (907; 925)	673 (673; 673)	1064 (679; 1872)	1492 (804; 2203)	1368 (1222; 1368)	772 (772; 772)
CMP05	**OM02 (M = 0.1)**	488 (377; 619)	511 (398; 655)	579 (472; 734)	652 (588; 673)	433 (230; 670)	350 (217; 648)	420 (295; 615)	694 (538; 772)
	OM10 (w_{CPUE} = 10)	552 (394; 700)	525 (400; 669)	553 (442; 734)	632 (550; 673)	657 (372; 966)	486 (272; 816)	404 (285; 613)	645 (484; 772)
	OM15 (tag report rate = 0.8)	639 (470; 840)	633 (469; 822)	679 (512; 833)	670 (598; 673)	701 (418; 1091)	527 (325; 1088)	580 (367; 900)	761 (556; 772)

Table I3.3. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2040 being less than this average under the simple **CMPs without initial TAC smoothing** considered for the selected **OMs**, together with their 90% probability intervals are also reported.

CMP	RS	$\frac{CPUE_{2040}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2035}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2030}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2024}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2040}}{\overline{CPUE}_{15-17}}$	Probability $\frac{CPUE_{2040}}{\overline{CPUE}_{15-17}} < 1$
CMP01	OM02 (M = 0.1)	1.36 (0.82; 2.14)	1.16 (0.80; 1.72)	1.13 (0.75; 1.96)	1.14 (0.73; 1.73)	1.18 (0.70; 1.84)	0.36
	OM10 (w_{CPUE} = 10)	1.83 (1.24; 2.59)	1.62 (1.22; 2.29)	1.51 (1.10; 2.14)	1.39 (1.03; 1.89)	1.58 (1.07; 2.23)	0.05
	OM15 (tag report rate = 0.8)	1.45 (0.85; 2.22)	1.31 (0.91; 1.86)	1.33 (0.88; 2.02)	1.28 (0.87; 1.84)	1.25 (0.74; 1.91)	0.24
CMP02	OM02 (M = 0.1)	1.36 (0.83; 2.15)	1.19 (0.83; 1.77)	1.19 (0.79; 2.07)	1.15 (0.74; 1.75)	1.17 (0.72; 1.85)	0.34
	OM10 (w_{CPUE} = 10)	1.83 (1.23; 2.69)	1.68 (1.26; 2.32)	1.60 (1.16; 2.31)	1.41 (1.05; 1.92)	1.58 (1.06; 2.32)	0.02
	OM15 (tag report rate = 0.8)	1.54 (0.96; 2.35)	1.41 (1.00; 2.11)	1.45 (0.98; 2.23)	1.30 (0.88; 1.86)	1.33 (0.82; 2.03)	0.16
CMP03	OM02 (M = 0.1)	1.35 (0.83; 2.17)	1.15 (0.79; 1.70)	1.08 (0.72; 1.87)	1.13 (0.72; 1.72)	1.17 (0.71; 1.87)	0.35
	OM10 (w_{CPUE} = 10)	1.82 (1.25; 2.58)	1.63 (1.20; 2.36)	1.45 (1.00; 2.06)	1.37 (1.01; 1.87)	1.57 (1.08; 2.22)	0.04
	OM15 (tag report rate = 0.8)	1.48 (0.90; 2.24)	1.28 (0.87; 1.87)	1.19 (0.79; 1.80)	1.26 (0.86; 1.81)	1.27 (0.77; 1.93)	0.19
CMP04	OM02 (M = 0.1)	1.17 (0.68; 1.95)	1.03 (0.70; 1.53)	1.10 (0.73; 1.89)	1.14 (0.73; 1.73)	1.01 (0.59; 1.68)	0.49
	OM10 (w_{CPUE} = 10)	1.49 (0.96; 2.15)	1.39 (1.02; 1.92)	1.44 (1.01; 2.09)	1.39 (1.03; 1.89)	1.28 (0.82; 1.85)	0.19
	OM15 (tag report rate = 0.8)	1.08 (0.65; 1.80)	1.10 (0.72; 1.64)	1.31 (0.87; 1.99)	1.28 (0.87; 1.84)	0.93 (0.56; 1.55)	0.59
CMP05	OM02 (M = 0.1)	1.53 (0.95; 2.41)	1.32 (0.90; 1.90)	1.23 (0.84; 2.13)	1.15 (0.73; 1.73)	1.32 (0.82; 2.08)	0.20
	OM10 (w_{CPUE} = 10)	2.10 (1.45; 3.02)	1.88 (1.43; 2.58)	1.69 (1.21; 2.48)	1.40 (1.03; 1.90)	1.81 (1.25; 2.60)	0.00
	OM15 (tag report rate = 0.8)	1.80 (1.17; 2.78)	1.55 (1.10; 2.21)	1.43 (0.96; 2.27)	1.28 (0.87; 1.84)	1.55 (1.01; 2.40)	0.05

Table I3.4. Medians of the distributions of several performance statistics under the simple **CMPs with initial TAC smoothing** considered for the selected **OMs**, together with their 90% probability intervals. CMPs are tuned to provide the median result for OM10 shown in **bold** in the third column.

CMP	OM	$\frac{B^{sp}_{2040}}{K^{sp}}$	$\frac{B^{sp}_{2040}}{B^{sp}_{2017}}$	$\frac{B^{sp}_{2040}}{B_{MSY}}$	$\frac{B^{sp}_{2024}}{B_{MSY}}$	TAC (Av 20 yrs) (tonnes)	TAC (Av 4 yrs) (tonnes)	AAV (20 yrs)	AAV (4 yrs)
CMP01S	**OM02 (M = 0.1)**	0.51 (0.44; 0.59)	0.98 (0.85; 1.14)	2.03 (1.76; 2.36)	2.00 (1.93; 2.23)	664 (515; 851)	561 (558; 561)	0.07 (0.06; 0.08)	0.05 (0.04; 0.05)
	OM10 (w_{CPUE} = 10)	0.39 (0.33; 0.47)	0.85 (0.72; 1.03)	1.60 (1.36; 1.94)	1.36 (1.27; 1.65)	721 (532; 914)	561 (550; 561)	0.07 (0.06; 0.08)	0.05 (0.05; 0.05)
	OM15 (tag report rate = 0.8)	0.35 (0.28; 0.43)	0.90 (0.72; 1.13)	1.41 (1.14; 1.77)	1.44 (1.34; 1.74)	851 (617; 1057)	561 (561; 561)	0.08 (0.06; 0.08)	0.05 (0.05; 0.05)
CMP02S	**OM02 (M = 0.1)**	0.54 (0.45; 0.63)	1.03 (0.86; 1.20)	2.13 (1.78; 2.48)	2.01 (1.94; 2.23)	626 (512; 716)	526 (526; 526)	0.04 (0.03; 0.04)	0.02 (0.02; 0.02)
	OM10 (w_{CPUE} = 10)	0.42 (0.35; 0.53)	0.92 (0.76; 1.16)	1.74 (1.44; 2.19)	1.37 (1.28; 1.66)	676 (525; 721)	526 (522; 526)	0.04 (0.03; 0.04)	0.02 (0.02; 0.02)
	OM15 (tag report rate = 0.8)	0.43 (0.34; 0.55)	1.11 (0.87; 1.43)	1.74 (1.37; 2.25)	1.45 (1.35; 1.75)	721 (613; 721)	526 (526; 526)	0.04 (0.04; 0.04)	0.02 (0.02; 0.02)
CMP03S	**OM02 (M = 0.1)**	0.51 (0.45; 0.59)	0.98 (0.86; 1.12)	2.02 (1.77; 2.32)	2.00 (1.93; 2.23)	665 (494; 857)	548 (540; 548)	0.09 (0.07; 0.11)	0.04 (0.03; 0.04)
	OM10 (w_{CPUE} = 10)	0.39 (0.32; 0.46)	0.85 (0.69; 1.01)	1.61 (1.31; 1.91)	1.36 (1.27; 1.66)	714 (545; 917)	548 (532; 548)	0.10 (0.07; 0.11)	0.04 (0.03; 0.04)
	OM15 (tag report rate = 0.8)	0.32 (0.25; 0.42)	0.84 (0.65; 1.10)	1.32 (1.02; 1.73)	1.44 (1.35; 1.74)	878 (635; 1133)	548 (548; 548)	0.10 (0.07; 0.11)	0.04 (0.04; 0.04)
CMP04S	**OM02 (M = 0.1)**	0.43 (0.36; 0.49)	0.82 (0.70; 0.94)	1.70 (1.44; 1.94)	2.00 (1.93; 2.23)	853 (674; 1046)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
	OM10 (w_{CPUE} = 10)	0.29 (0.24; 0.37)	0.64 (0.54; 0.81)	1.21 (1.01; 1.53)	1.36 (1.27; 1.65)	913 (699; 1068)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
	OM15 (tag report rate = 0.8)	0.26 (0.19; 0.36)	0.68 (0.50; 0.94)	1.08 (0.78; 1.48)	1.44 (1.34; 1.74)	1066 (863; 1135)	561 (561; 561)	0.08 (0.07; 0.08)	0.05 (0.05; 0.05)
CMP05S	**OM02 (M = 0.1)**	0.61 (0.53; 0.70)	1.17 (1.02; 1.35)	2.41 (2.11; 2.79)	2.00 (1.93; 2.22)	438 (333; 577)	577 (515; 592)	0.08 (0.07; 0.10)	0.07 (0.05; 0.09)
	OM10 (w_{CPUE} = 10)	0.51 (0.43; 0.61)	1.11 (0.94; 1.34)	2.09 (1.76; 2.51)	1.36 (1.27; 1.65)	508 (373; 649)	559 (486; 592)	0.09 (0.07; 0.10)	0.07 (0.04; 0.09)
	OM15 (tag report rate = 0.8)	0.48 (0.40; 0.58)	1.25 (1.05; 1.51)	1.97 (1.65; 2.38)	1.43 (1.34; 1.73)	596 (443; 781)	591 (529; 592)	0.08 (0.07; 0.09)	0.07 (0.05; 0.08)

Table I3.5. Projected distribution median average annual legal (trotline) catches of toothfish (in tonnes) over various periods and median catch values after several years of projections under the simple **CMPs with initial TAC smoothing** considered for the selected **OMs**, together with their 90% probability intervals.

CMP	OM	$\bar{C}_{2019-2040}$ (20 yrs)	$\bar{C}_{2019-2035}$ (15 yrs)	$\bar{C}_{2019-2030}$ (10 yrs)	$\bar{C}_{2019-2024}$ (4 yrs)	C_{2040} (20 yrs)	C_{2035} (15 yrs)	C_{2030} (10 yrs)	C_{2024} (4 yrs)
CMP01S	**OM02 (M = 0.1)**	697 (541; 894)	689 (546; 850)	674 (560; 707)	589 (586; 589)	723 (435; 1121)	684 (412; 1261)	796 (474; 956)	629 (615; 629)
	OM10 (w_{CPUE} = 10)	757 (558; 960)	753 (529; 897)	690 (557; 707)	589 (577; 589)	854 (544; 1259)	797 (478; 1504)	866 (420; 956)	629 (579; 629)
	OM15 (tag report rate = 0.8)	894 (648; 1110)	860 (657; 900)	707 (651; 707)	589 (589; 589)	1034 (617; 1675)	1247 (558; 1540)	956 (719; 956)	629 (629; 629)
CMP02S	**OM02 (M = 0.1)**	657 (537; 752)	635 (538; 667)	598 (539; 598)	552 (552; 552)	754 (506; 1049)	725 (478; 886)	694 (514; 694)	568 (568; 568)
	OM10 (w_{CPUE} = 10)	710 (551; 758)	664 (540; 667)	598 (546; 598)	552 (548; 552)	900 (584; 1131)	856 (497; 886)	694 (513; 694)	568 (551; 568)
	OM15 (tag report rate = 0.8)	758 (644; 758)	667 (610; 667)	598 (582; 598)	552 (552; 552)	1131 (723; 1131)	886 (620; 886)	694 (627; 694)	568 (568; 568)
CMP03S	**OM02 (M = 0.1)**	698 (518; 900)	687 (520; 893)	650 (531; 701)	575 (567; 575)	684 (378; 1178)	702 (348; 1309)	823 (417; 1025)	605 (571; 605)
	OM10 (w_{CPUE} = 10)	750 (572; 963)	763 (534; 962)	682 (516; 701)	575 (559; 575)	779 (466; 1380)	829 (428; 1679)	909 (428; 1025)	605 (540; 605)
	OM15 (tag report rate = 0.8)	922 (666; 1190)	898 (652; 997)	701 (634; 701)	575 (575; 575)	915 (493; 1537)	1294 (596; 2062)	1025 (730; 1025)	605 (605; 605)
CMP04S	**OM02 (M = 0.1)**	895 (708; 1098)	873 (708; 900)	707 (683; 707)	589 (589; 589)	974 (641; 1495)	1240 (679; 1540)	956 (858; 956)	629 (629; 629)
	OM10 (w_{CPUE} = 10)	958 (734; 1121)	890 (696; 900)	707 (696; 707)	589 (589; 589)	1045 (649; 1630)	1426 (658; 1540)	956 (860; 956)	629 (629; 629)
	OM15 (tag report rate = 0.8)	1120 (906; 1192)	900 (839; 900)	707 (707; 707)	589 (589; 589)	1651 (909; 2480)	1540 (1155; 1540)	956 (956; 956)	629 (629; 629)
CMP05S	**OM02 (M = 0.1)**	460 (350; 605)	472 (371; 595)	508 (422; 642)	606 (540; 622)	469 (242; 677)	368 (219; 651)	379 (257; 572)	621 (465; 684)
	OM10 (w_{CPUE} = 10)	534 (392; 682)	498 (380; 629)	507 (395; 662)	587 (511; 622)	669 (427; 965)	509 (302; 859)	391 (261; 589)	580 (428; 684)
	OM15 (tag report rate = 0.8)	625 (465; 820)	589 (447; 785)	613 (470; 760)	621 (556; 622)	746 (452; 1165)	564 (346; 1132)	535 (329; 913)	678 (494; 684)

Table I3.6. Projected distribution median CPUE indices relative to the 2017 CPUE index after several years of projections, and the distribution median CPUE index in 2038 as a proportion of the average of the 2015 to 2017 CPUE indices. The probabilities of the CPUE index in 2040 being less than this average under the simple **CMPs with initial TAC smoothing** considered for the selected **OMs**, together with their 90% probability intervals are also reported.

CMP	RS	$\frac{CPUE_{2040}}{CPUE_{2017}}$ (after 20 yrs)	$\frac{CPUE_{2035}}{CPUE_{2017}}$ (after 15 yrs)	$\frac{CPUE_{2030}}{CPUE_{2017}}$ (after 10 yrs)	$\frac{CPUE_{2024}}{CPUE_{2017}}$ (after 4 yrs)	$\frac{CPUE_{2040}}{\overline{CPUE}_{15-17}}$	Probability $\frac{CPUE_{2040}}{\overline{CPUE}_{15-17}} < 1$
CMP01S	**OM02 (M = 0.1)**	1.36 (0.84; 2.18)	1.20 (0.83; 1.77)	1.19 (0.79; 2.07)	1.15 (0.74; 1.75)	1.17 (0.73; 1.88)	0.34
	OM10 (w_{CPUE} = 10)	1.77 (1.25; 2.55)	1.65 (1.25; 2.20)	1.61 (1.20; 2.31)	1.41 (1.05; 1.92)	1.53 (1.07; 2.20)	0.04
	OM15 (tag report rate = 0.8)	1.43 (0.95; 2.23)	1.40 (0.96; 2.00)	1.45 (0.98; 2.23)	1.30 (0.88; 1.86)	1.23 (0.82; 1.92)	0.29
CMP02S	**OM02 (M = 0.1)**	1.38 (0.84; 2.23)	1.22 (0.85; 1.82)	1.23 (0.82; 2.14)	1.16 (0.74; 1.76)	1.19 (0.73; 1.92)	0.32
	OM10 (w_{CPUE} = 10)	1.86 (1.25; 2.63)	1.75 (1.32; 2.42)	1.68 (1.21; 2.41)	1.42 (1.06; 1.93)	1.60 (1.08; 2.27)	0.02
	OM15 (tag report rate = 0.8)	1.61 (1.01; 2.49)	1.52 (1.08; 2.25)	1.51 (1.04; 2.34)	1.30 (0.89; 1.88)	1.39 (0.87; 2.14)	0.13
CMP03S	**OM02 (M = 0.1)**	1.33 (0.84; 2.19)	1.20 (0.83; 1.77)	1.20 (0.79; 2.08)	1.16 (0.74; 1.75)	1.15 (0.73; 1.88)	0.37
	OM10 (w_{CPUE} = 10)	1.77 (1.20; 2.56)	1.60 (1.22; 2.18)	1.64 (1.24; 2.32)	1.42 (1.05; 1.92)	1.52 (1.04; 2.20)	0.04
	OM15 (tag report rate = 0.8)	1.38 (0.90; 2.21)	1.34 (0.90; 1.91)	1.46 (0.99; 2.24)	1.30 (0.89; 1.87)	1.19 (0.77; 1.90)	0.33
CMP04S	**OM02 (M = 0.1)**	1.15 (0.69; 1.86)	1.10 (0.73; 1.65)	1.18 (0.79; 2.06)	1.15 (0.74; 1.75)	0.99 (0.60; 1.61)	0.52
	OM10 (w_{CPUE} = 10)	1.45 (1.02; 2.04)	1.51 (1.08; 2.11)	1.60 (1.11; 2.31)	1.41 (1.05; 1.92)	1.25 (0.88; 1.76)	0.23
	OM15 (tag report rate = 0.8)	1.15 (0.71; 1.78)	1.31 (0.91; 1.97)	1.45 (0.98; 2.23)	1.30 (0.88; 1.86)	0.99 (0.61; 1.53)	0.51
CMP05S	**OM02 (M = 0.1)**	1.55 (0.97; 2.44)	1.34 (0.92; 1.93)	1.25 (0.86; 2.18)	1.15 (0.74; 1.74)	1.34 (0.84; 2.10)	0.19
	OM10 (w_{CPUE} = 10)	2.08 (1.46; 3.01)	1.91 (1.47; 2.64)	1.73 (1.26; 2.53)	1.42 (1.05; 1.91)	1.80 (1.26; 2.60)	0.00
	OM15 (tag report rate = 0.8)	1.79 (1.17; 2.74)	1.57 (1.13; 2.27)	1.47 (1.00; 2.31)	1.29 (0.88; 1.86)	1.54 (1.01; 2.37)	0.05

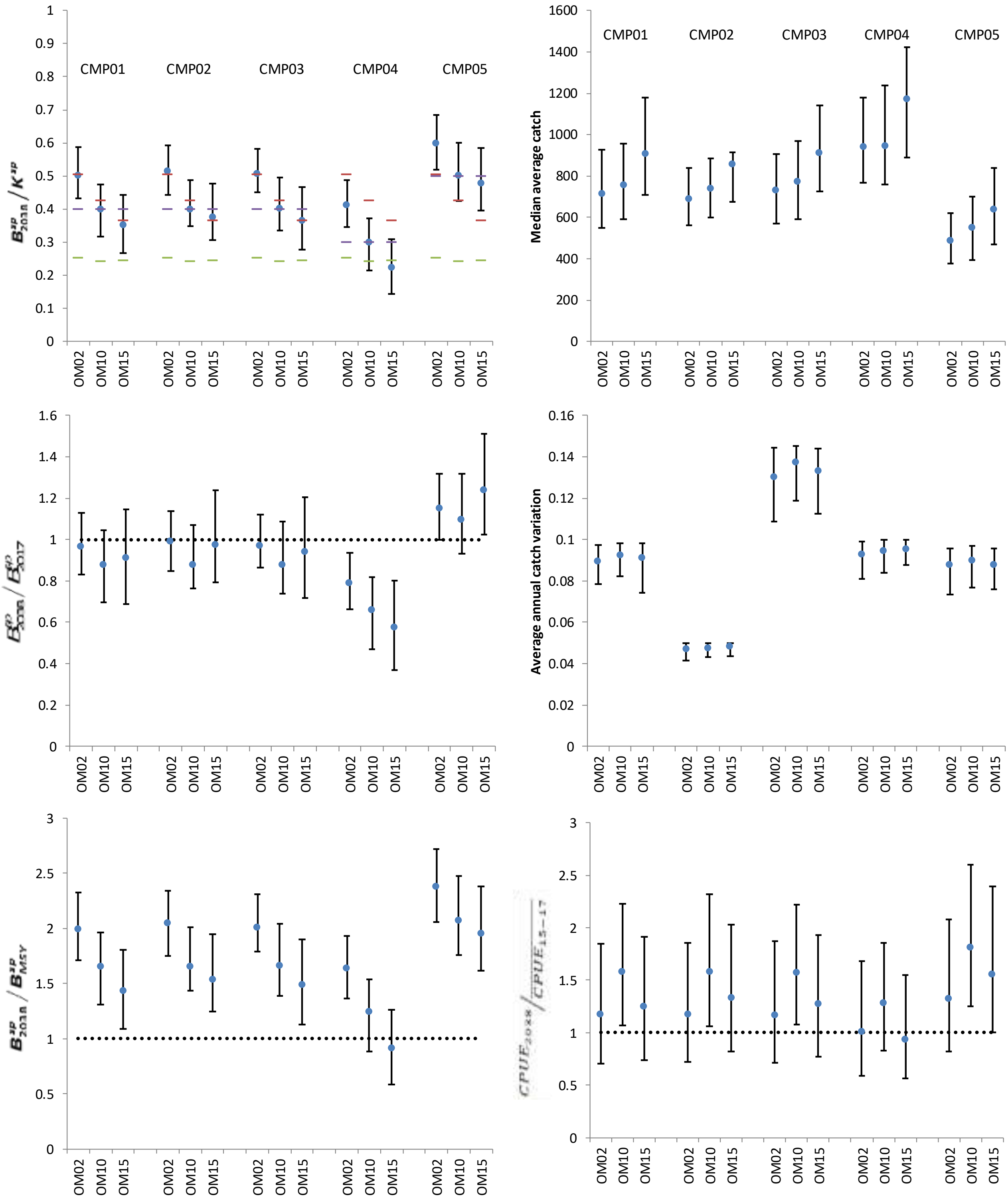

Figure I3.1. Zeh plots for some of the performance statistics reported in the Tables for each selected **OM** for the various **CMPs without initial TAC smoothing**. These are the spawning biomass depletion at the start of 2040 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2021 to 2040; the average annual variation in catch; and the CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2018) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned, and the green dashes represent the MSYL (relative to *K*).

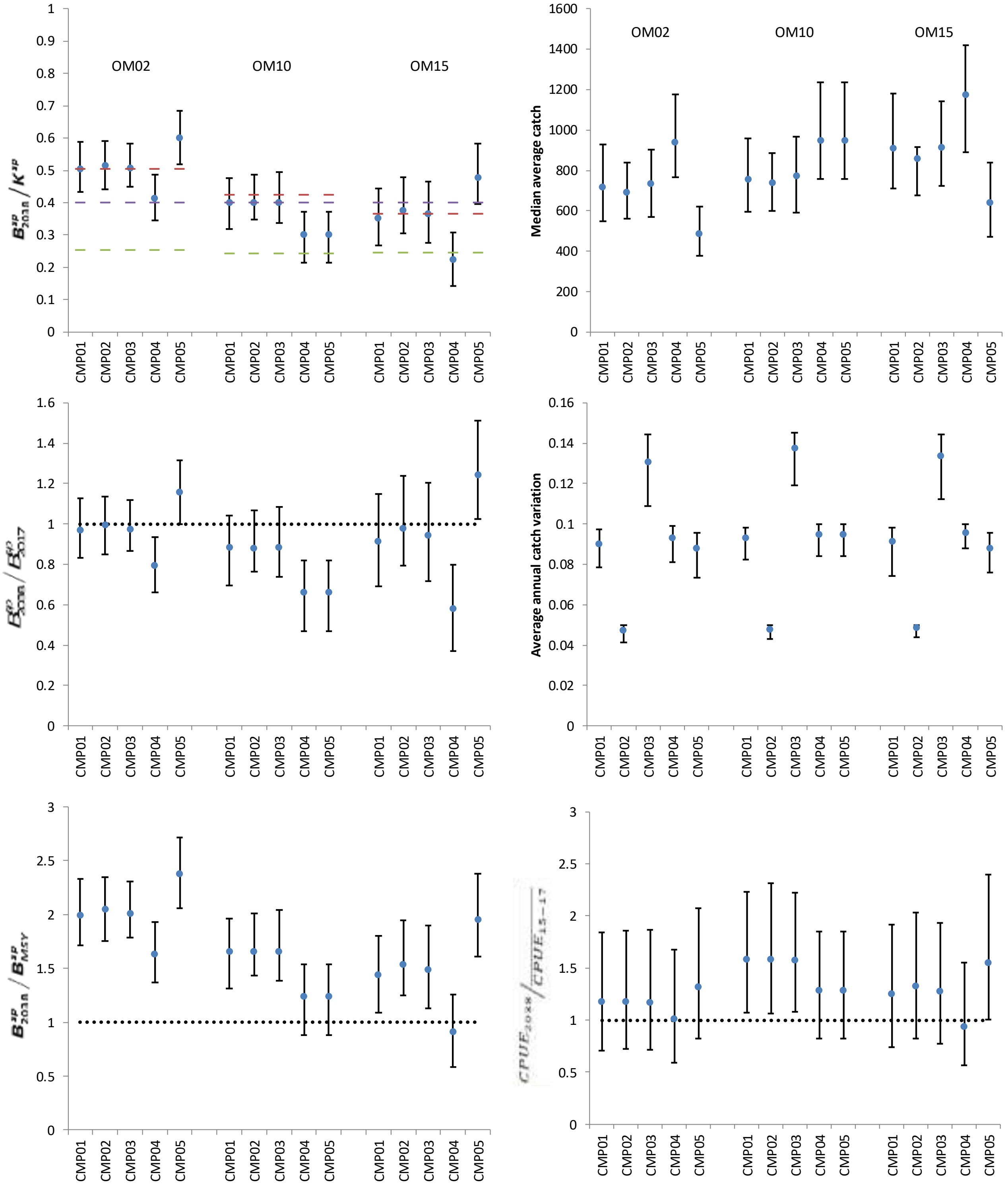

Figure I3.2. Zeh plots for the same results as in Figure 1 but ordered differently.

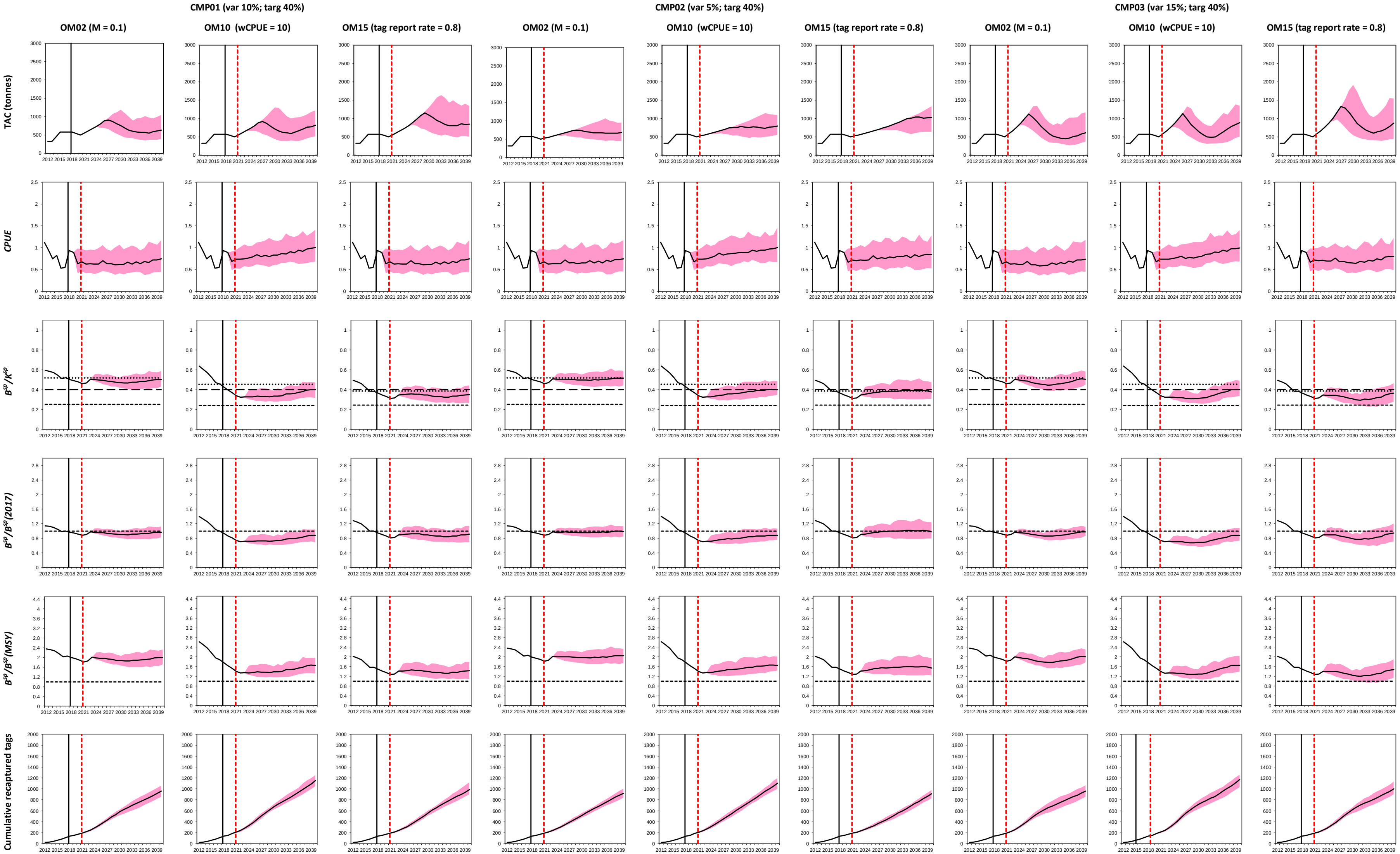

Figure I3.3a. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under **CMP01 to CMP03 without initial TAC smoothing**. These CMPs are based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **selected OMs**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to *K*).

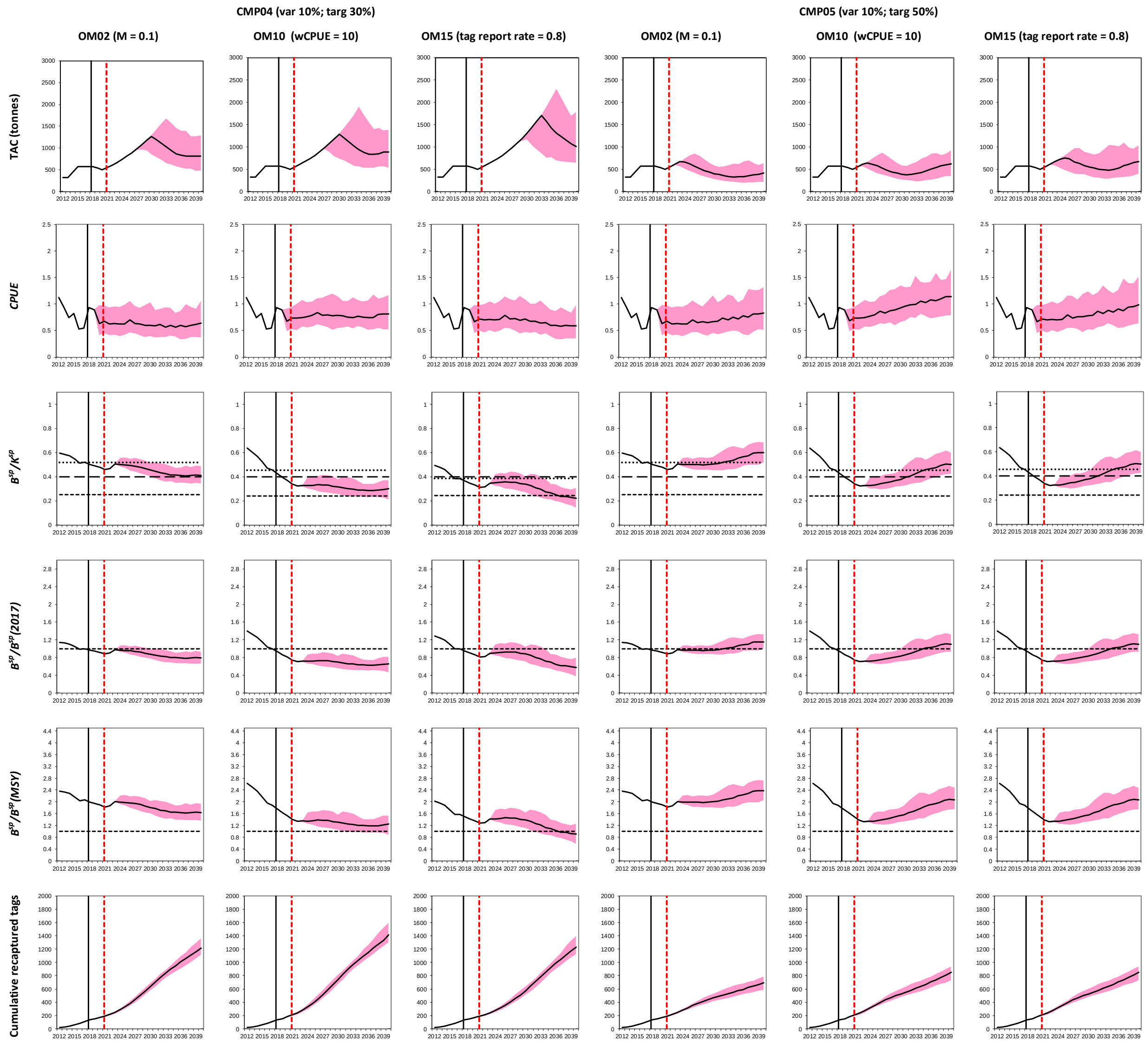

Figure I3.3b. Projection results as in Figure 3a, but here for **CMP04 to CMP05 without initial TAC smoothing**.

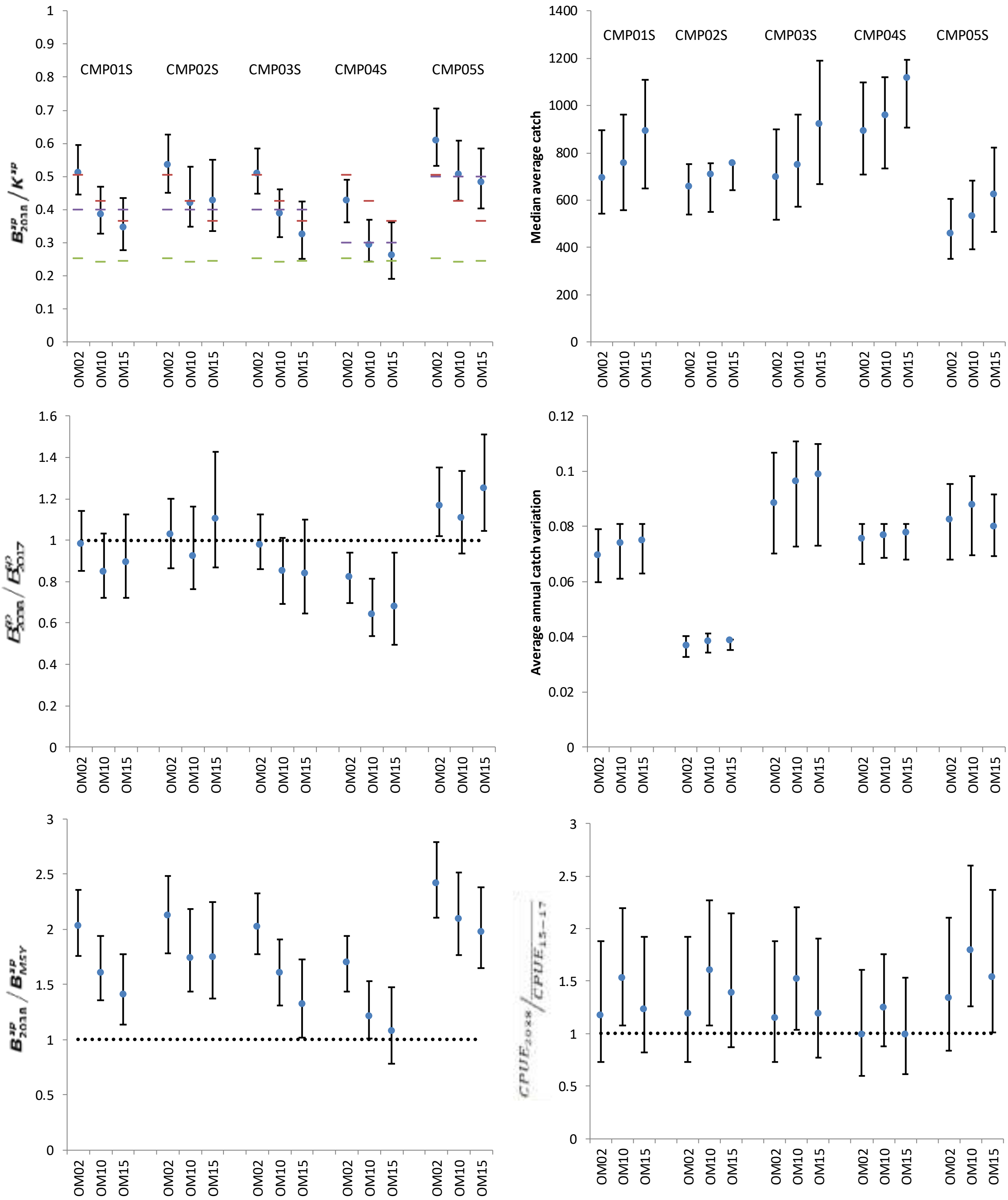

Figure I3.4. Zeh plots for some of the performance statistics reported in the Tables for each selected **OM** for the various **CMPs with initial smoothing of TACs**. These are the spawning biomass depletion at the start of 2040 relative to K, to the spawning biomass in 2017 and to the spawning biomass at MSY; the projected median of the average annual legal (trotline) catches of toothfish (in tonnes) for the period 2021 to 2040; the average annual variation in catch; and the CPUE index in 2040 as a proportion of the average of the 2015 to 2017 CPUE indices. The red dashes represent the current (2018) spawning biomass depletion for each OM, the purple dashes represent the final depletion value under OM10 to which the CMP was tuned, and the green dashes represent the MSYL (relative to *K*).

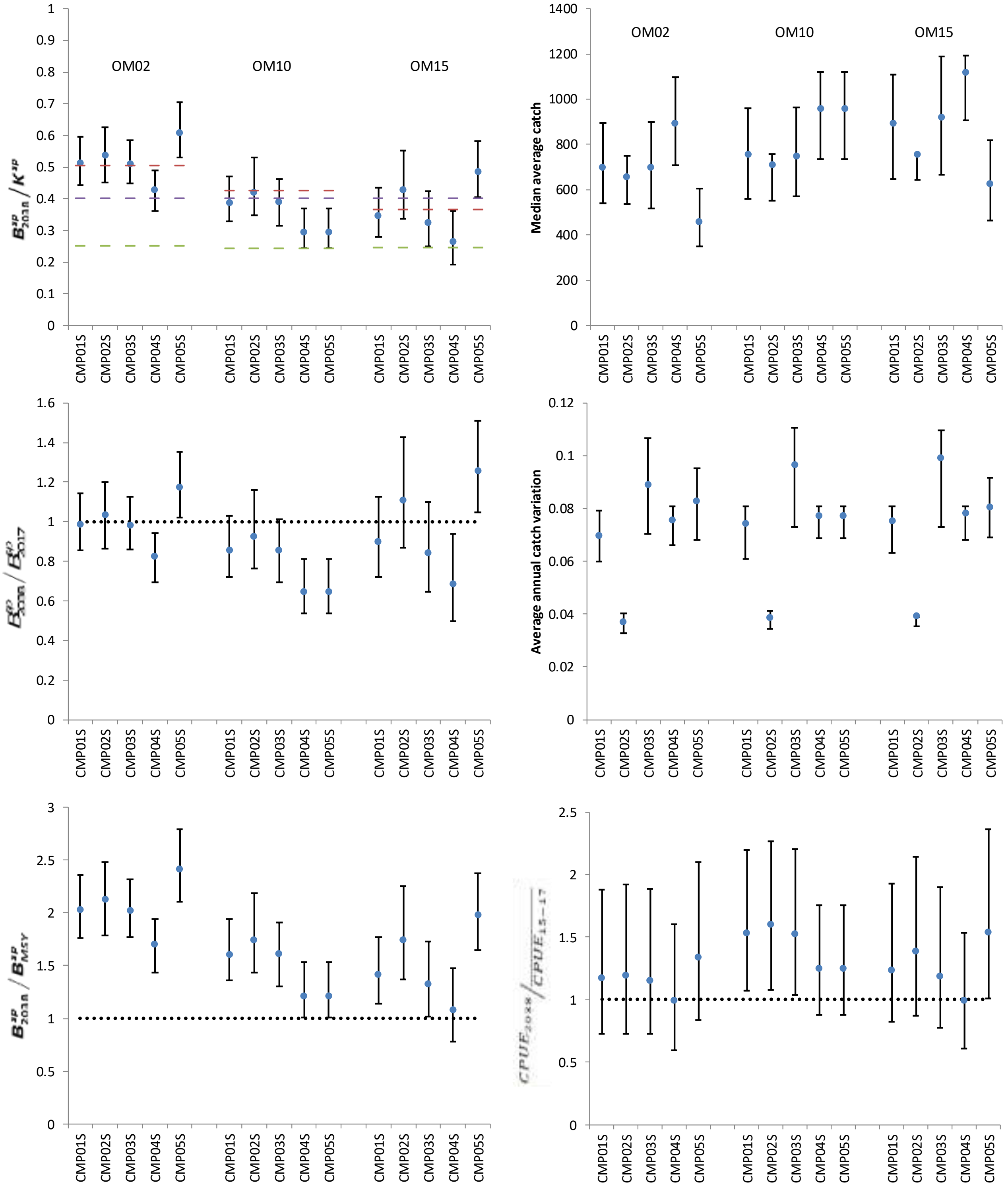

Figure I3.5. Zeh plots for the same results as in Figure 4 but ordered differently.

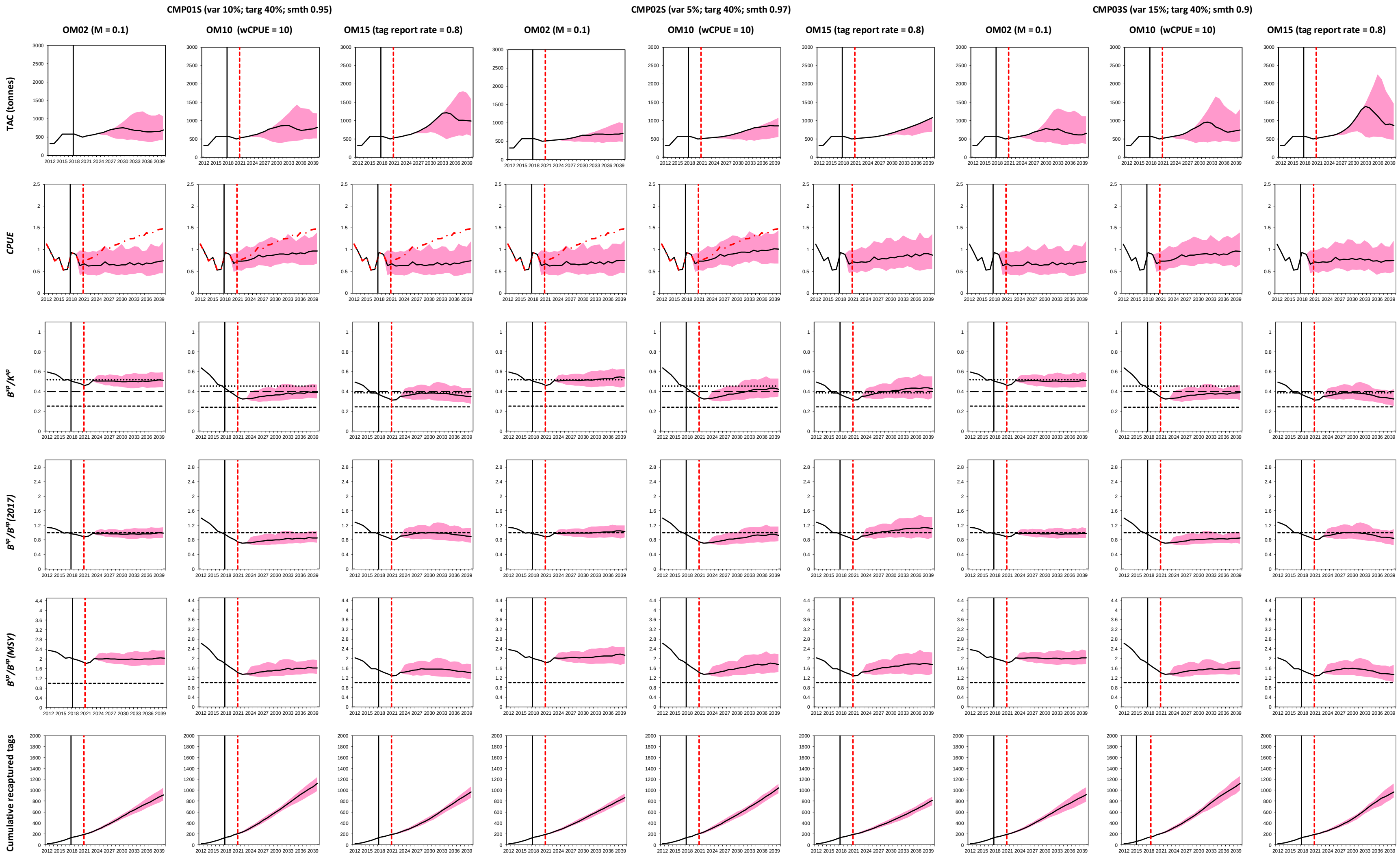

Figure I3.6a. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion, spawning biomass relative to the 2017 value, the spawning biomass relative to B_{MSY} and the cumulative number of recaptured tags under **CMP01 to CMP03 with initial smoothing of TACs**. These CMPs are based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags for **selected OMs**. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines, and the shaded areas represent 90% probability envelopes. For the middle row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to *K*).

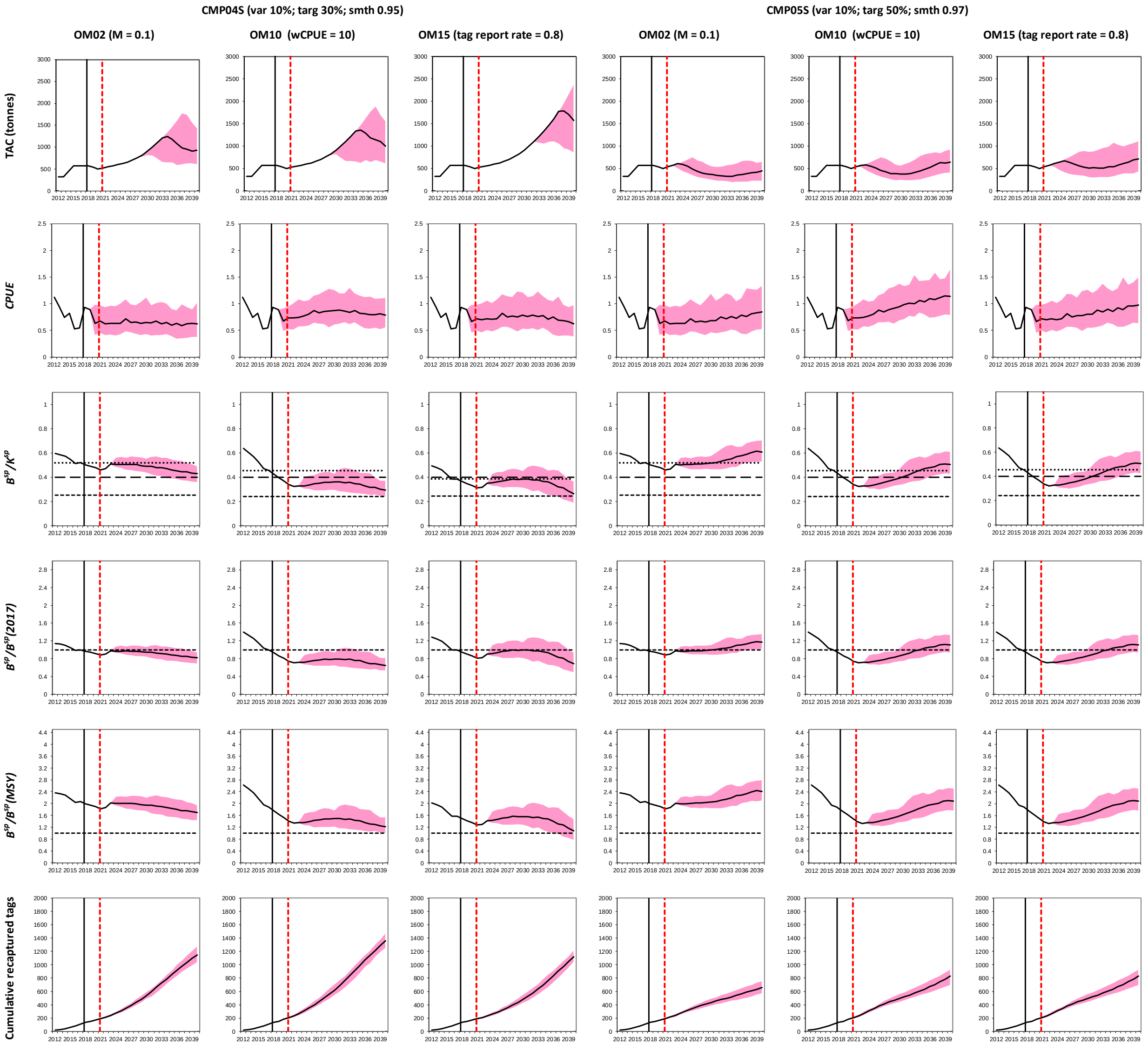

Figure I3.6b. Projection results as in Figure 6a, but here for **CMP04 to CMP05 with initial smoothing of TACs.**

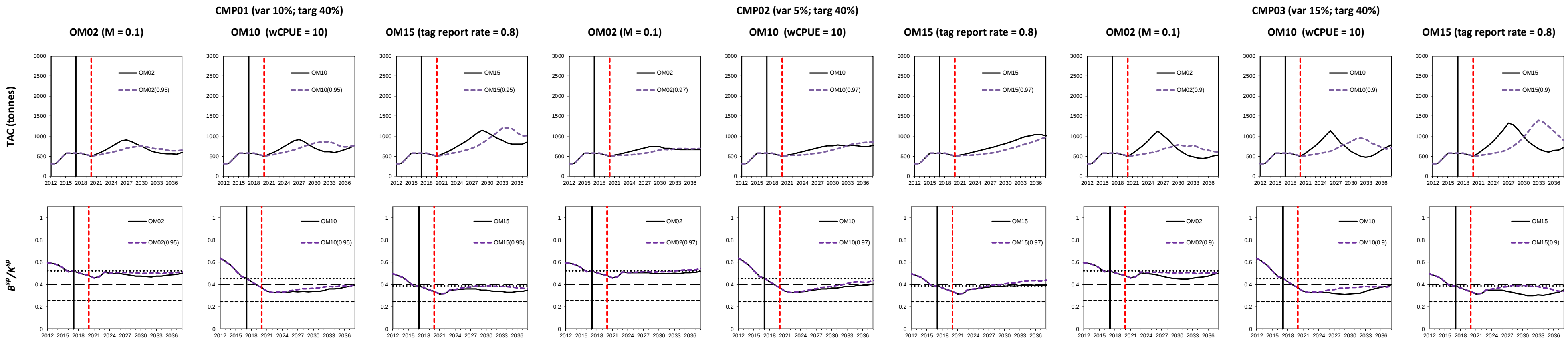

Figure I3.7a. Comparison of median trajectories of the TAC (in tonnes) and spawning biomass depletion, under **CMP01 to CMP03** for the selected **OMs** with and without adjusting the initial TACs. Projections commence to the right of the thick black vertical lines but with observed data until the red dashed vertical lines. For the bottom row of plots, the large dashed line is the value ($0.4K^{sp}$) to which the CMP was tuned under OM10 and the dotted line is the current (2018) spawning biomass depletion, while the small dash line is the MSYL (relative to K).

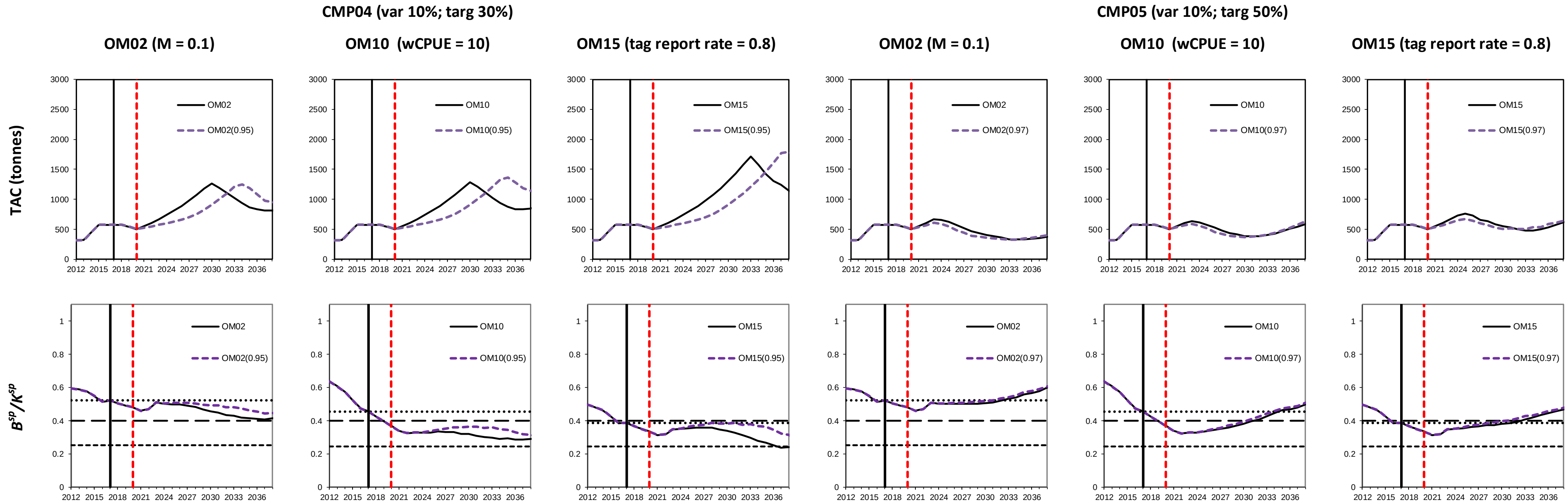

Figure I3.7b. Comparison of median trajectories of the TAC (in tonnes) and spawning biomass depletion as in Figure 7a but under **CMP04 and CMP05.**