Key aspects of the proposed Management Procedure for the Toothfish (*Dissostichus eleginoides*) Resource in the Prince Edward Islands vicinity

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ABSTRACT

This paper summarises the key aspects and results of analyses conducted to develop a Management Procedure (MP) for toothfish. This is to assist focus the discussion required in the Demersal Working Group to formulate and agree upon a recommendation for its adoption. All background details can be found in Brandão and Butterworth (2020). This MP inputs information on trends in the cumulative number of recaptured tags as well as the recent mean of the trotline CPUE, considers an initial smoothing of the TAC, is tuned to a target of 40% for the median final depletion under toothfish Operating Model 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 continue to increase and the median final depletion remains above the specified target value under OM10. The application of an initial TAC smoothing mechanism largely eliminates an earlier problematic pattern of an initial increase before a later drop in TACs fairly soon thereafter.

INTRODUCTION

Brandão and Butterworth (2020) provides a complete description and results of the process undergone to arrive at the selection of a proposed simple empirical Management Procedures (MP) for computing future TAC recommendations for toothfish in the Prince Edward Islands region. This paper summarises the key aspects and results of that paper to focus discussion on the formulation of a recommendation for adoption of this MP by the Demersal Working Group. All background details can be found in Brandão and Butterworth (2020). This MP inputs information on trends in the cumulative number of recaptured tags as well as the recent mean of the trotline CPUE, considers an initial smoothing of the TAC, is tuned to a target of 40% for the median final depletion under toothfish Operating Model OM10 and constrains the TAC to a maximum inter-annual change of 10%.

OPERATING MODELS AND PROJECTIONS

Assessment component

Brandão and Butterworth (2019) presents 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 1 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 of Brandão and Butterworth (2020). Table 2 lists the Robustness tests (ROBs) suggested by the Task Team (see Brandão and Butterworth (2020) 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.

Projections component

The proposed MP assumes 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 MP requires 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 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:

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

[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*.

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 MP 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 MP.

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).

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, 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 for the projections.

The MP Proposed

The MP proposed 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:

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

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 available only 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.

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:

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

and x is chosen so 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 MP is tuned to achieve a target value of 40% for the median final depletion under OM10. OM10 was chosen for this purpose as it shows an improved fit to the recent trotline CPUE decline compared to OM1.

RESULTS AND DISCUSSION

The performance of the MP has been considered in terms of future projections over a 20-year period. A description of the performance statistics considered which are intended to capture key features of the trade-off choices to be made is given in Brandão and Butterworth (2020).

Figure 1 compares the performance of this MP under the Reference Set OMs. Median projections for some performance statistics under each individual selected OM are shown in Figures 2. The results in Figure 2 are restricted to OM01, OM02, OM10 and OM15, where the second and last were selected as they reflected the largest positive and negative median final depletions compared to that for OM10. Figure 3 shows results when combining all the outputs from the 14 OMs together, and calculating the performance statistics for the 14x100 simulations. Figure 3 also shows one randomly selected worm projection from each of the OMs.

A similar set of results for the MP but for the Robustness tests are shown in Figure 4. The MP performs satisfactorily under nearly all these Robustness tests. The exception is ROB02 which imposes the assumption of an extreme tag loss rate.

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 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 soon thereafter. 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.

REFERENCES

Brandão, A. and Butterworth, D.S. 2019. 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.

Brandão, A. and Butterworth, D.S. 2020. Results of the progression towards a proposed Management Procedures for the toothfish (*Dissostichus eleginoides*) resource in the Prince Edward Islands vicinity. Department of Agriculture, Forestry and Fisheries Document: FISHERIES/2020/OCT/SWG-DEM/22.

Table 1. 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 2. 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

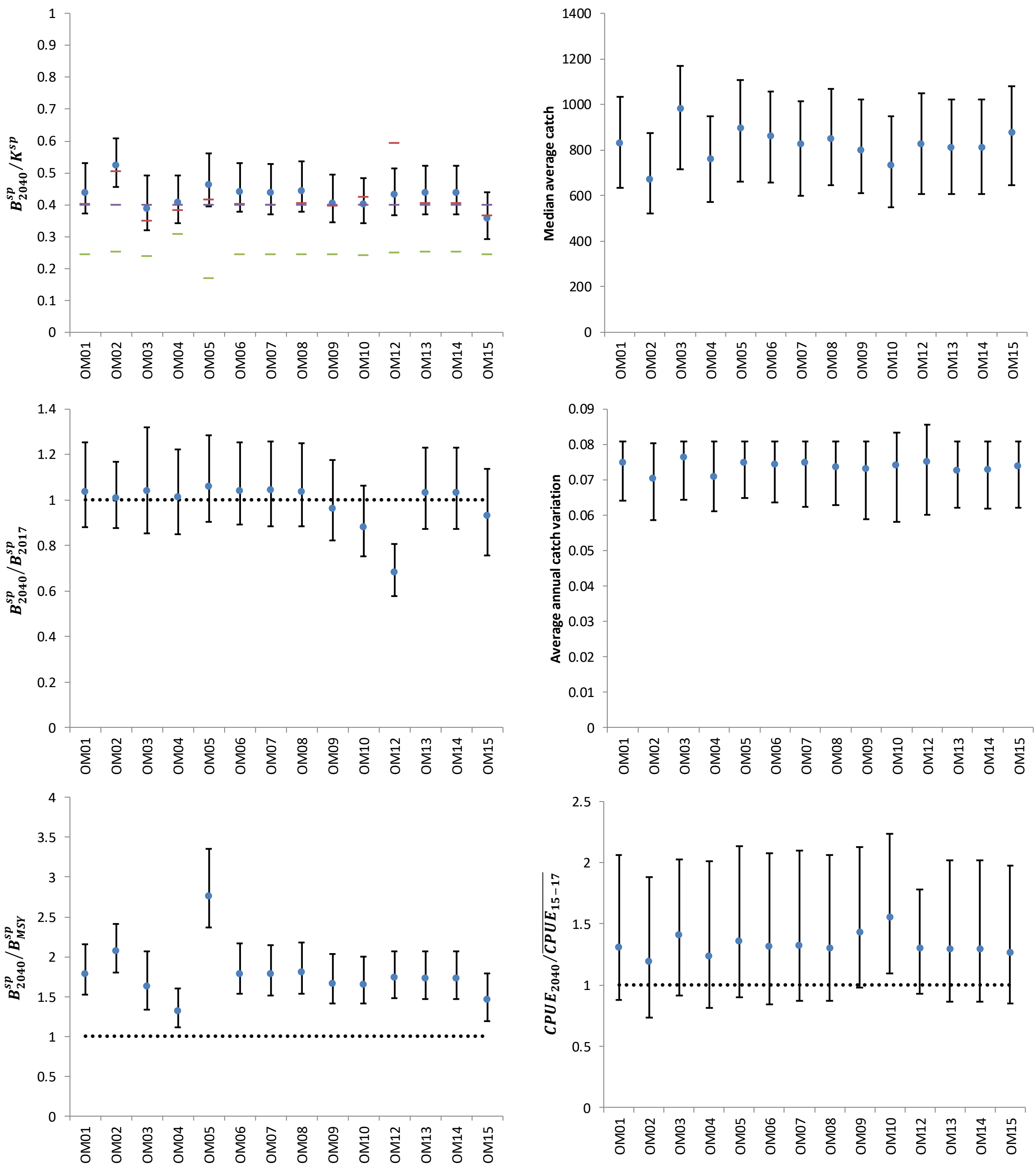

Figure 1. Zeh plots for some of the performance statistics reported in the Tables for each **OM** for the **MP**, which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2040 relative to K, to the spawning biomass in 2017 and 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 MP was tuned, and the green dashes represent the MSYL (relative to *K*).

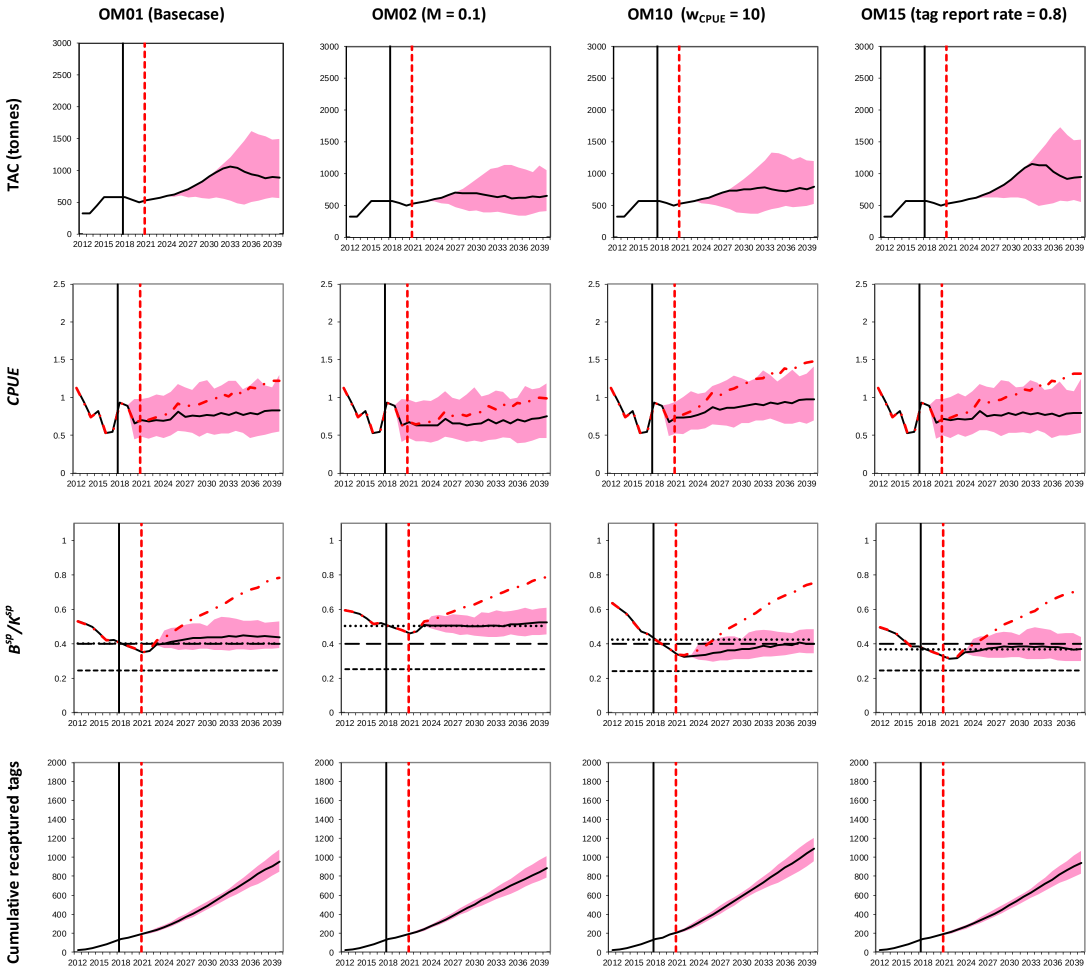

Figure 2. Median trajectories of the TAC (in tonnes), CPUE trend, spawning biomass depletion and the cumulative number of recaptured tags under the **MP**. The MP is based on the recent mean of the trotline CPUE and the recent trend in the cumulative number of recaptured tags, and applied to **OM01, OM02, OM10 and OM15**. 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 second from 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 red dot-dash lines represent the median trajectories under a zero-catch scenario.

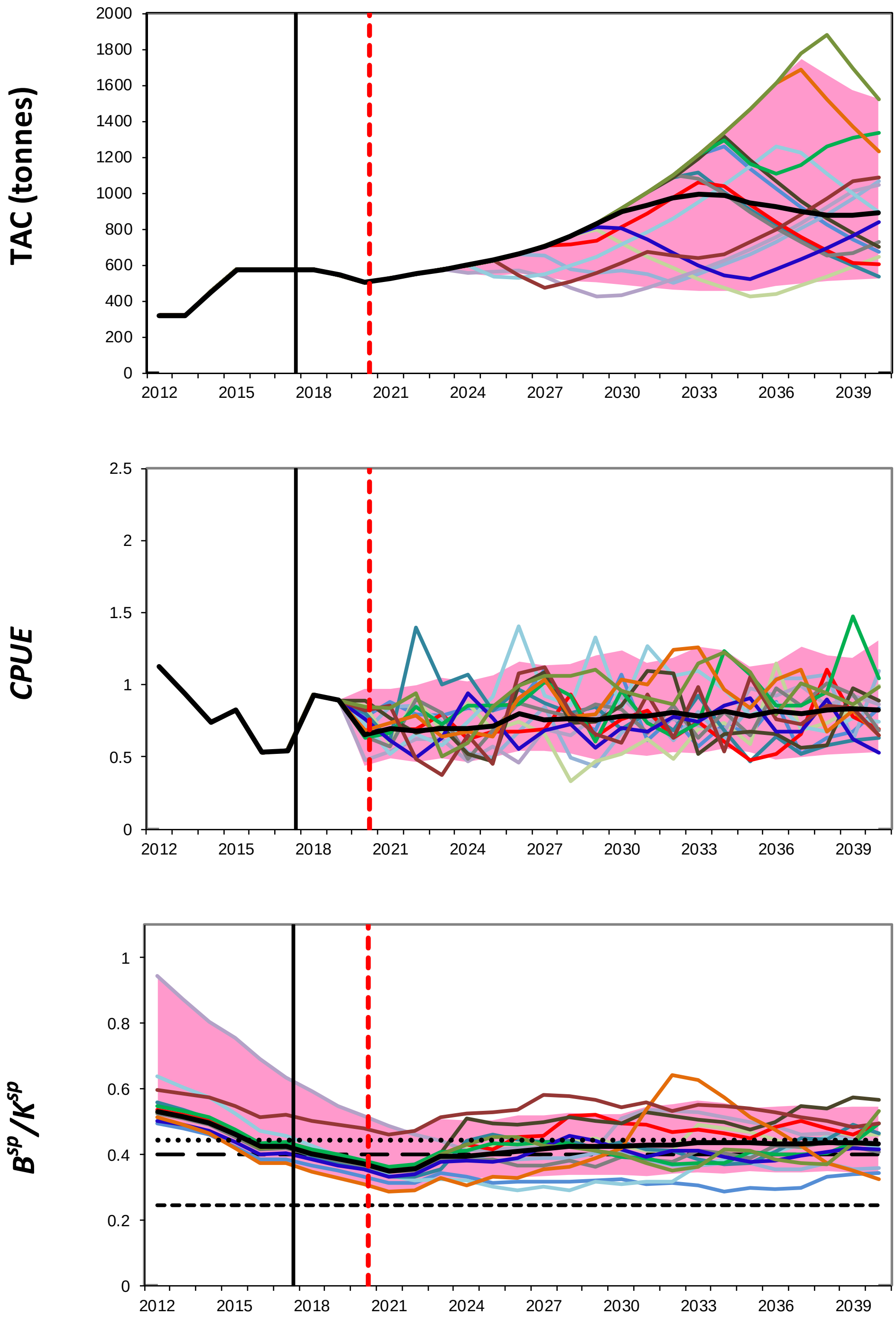

Figure 3. Median trajectories (thick black lines) of the TAC (in tonnes), CPUE trends and spawning biomass depletion under the **MP** across all simulations for all 14 **RS OMs**, giving equal weight to each OM. Projections commence to the right of the thick black vertical lines but with observed data 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 bottom plot, the large dashed line is the value ($0.4K^{sp}$) to which this MP 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.

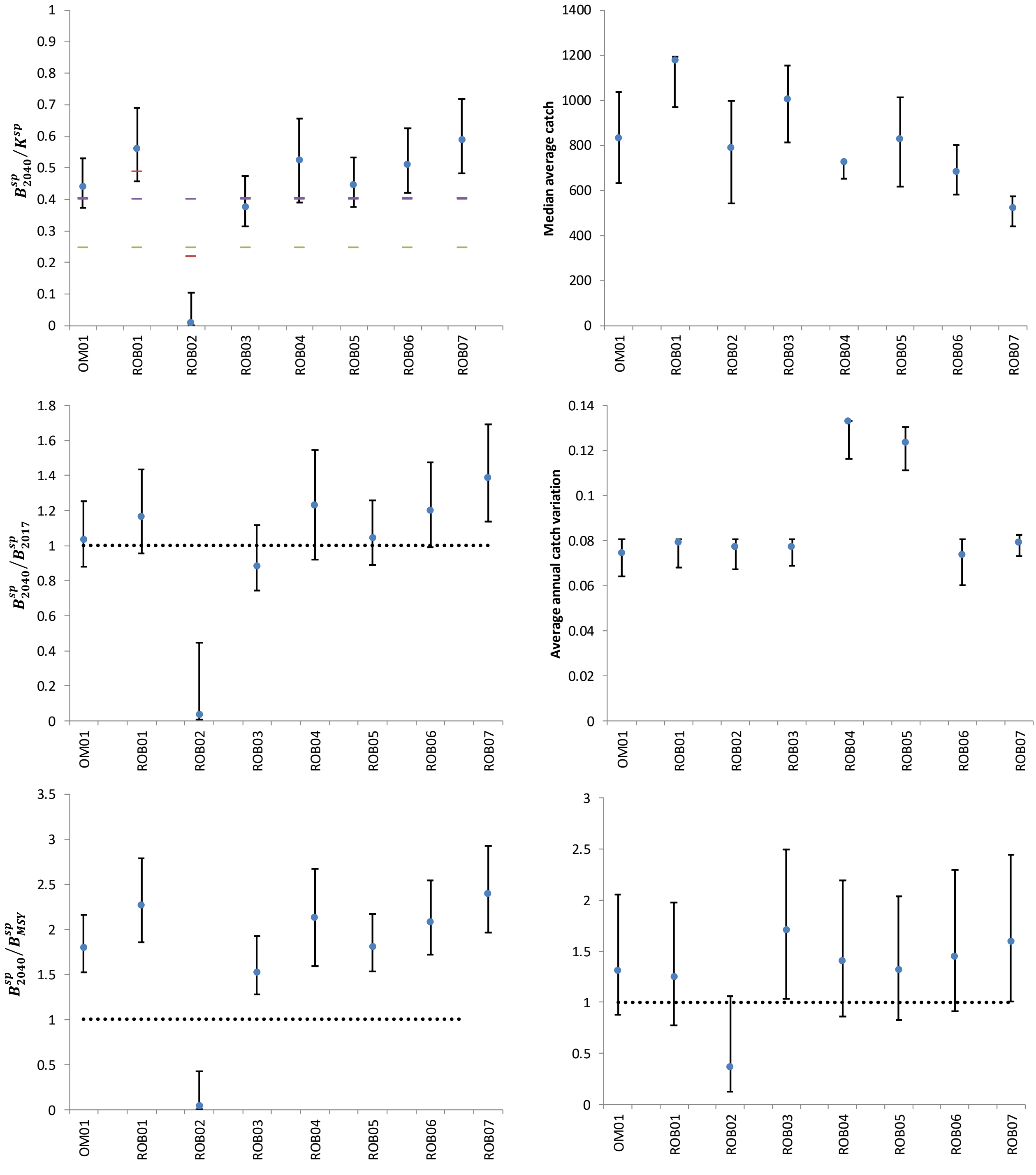

Figure 4. Zeh plots for some of the performance statistics reported in the Tables for each **Robustness test** for the **MP**, which has been tuned to achieve a median final depletion of 40% under OM10. These are the spawning biomass depletion at the start of 2040 relative to K, to the spawning biomass 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 MP was tuned, and the green dashes represent the MSYL (relative to *K*). For comparison, the results for OM01 are also shown.