

## Some initial projections under the OMP2014 rules averaged over all the Operating Models in the Reference Set

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### Summary

All the nine Operating Models in the Reference Set are projected forward under the rules of OMP2014, as well as variants of OMP2014 where the TAC cap and one of the tuning parameters are adjusted. A bias correction related to the stock-recruitment residual distribution has now been included in the projection code. The results suggest that there is scope for some increase in exploitation of the hake resource, pending results from the robustness tests. While long-term projections look largely positive, a key question is what changes should be made to the rules of OMP2014 in light of short-term projections of the TAC for the next few years.

### Introduction

The Reference Set (RS) Operating Models (OMs) are projected forward under the rules, and variants of the rules, of OMP2014. The approach is very similar to FISHERIES/2018/SEP/SWG-DEM/43, except that a bias correction for the skew distribution of the stock-recruitment residuals has been included as described below.

As for FISHERIES/2018/SEP/SWG-DEM/43, the modifications to OMP2014 that are being explored are: alternatives to the TAC cap of 150 000t and adjustments to the tuning parameter  $b$ , which determines the extent to which the TAC changes in response to changes in future abundance indices. Details of OMP2014 can be viewed in FISHERIES/2017/OCT/SWG-DEM/41, but for the purposes of this document, the relevant equation is:

$$C_{y+1}^s = b^s (J_y^s - J_0^s) \quad (1)$$

where  $C_{y+1}^s$  is the TAC in year  $y+1$ ,  $J_y^s$  is a measure of the immediate past level of the abundance indices for species  $s$  that are available for calculations in year  $y$ , and  $b^s$  and  $J_0^s$  are tuning parameters. It is the  $b^s$  parameters that have been adjusted in the results presented in this document. The values of the tuning parameters for OMP2014 are:

	<i>M. paradoxus</i>	<i>M. capensis</i>
$J_0$	0.132	0.240
$b$	83.83	33.33

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### Stock-recruitment bias

The new recruits in year  $y$  in the assessment OM are given by

$$R_{s,y} = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\zeta_y - \sigma_R^2/2)} \quad (2)$$

for the Beverton-Holt stock-recruitment relationship and

$$R_{s,y} = \alpha B_y^{sp} \exp\left(-\beta (\alpha B_y^{sp})^\gamma\right) e^{(\zeta_y - \sigma_R^2/2)} \quad (3)$$

for the modified Ricker relationship, where

- $\zeta_y$  reflects fluctuation about the expected recruitment in year  $y$ ;
- $\sigma_R$  is the standard deviation of the log-residuals, which is input ( $\sigma_R = 0.45$  and is taken to decrease linearly from this value to 0.1 over the last five years to statistically stabilise estimates of recent recruitment), and
- $\alpha, \beta, \gamma$  are estimable parameters.

However, when the variance of the model estimates of recruitment were calculated, the following values for the effective standard deviation were found:

**Table 1:** The effective standard deviation of the model estimated stock-recruitment residuals.

RS model	<i>M. paradoxus</i>	<i>M. capensis</i>
RS01 (Ricker, CY=1952)	0.204	0.275
RS02 (Ricker, CY=1958)	0.198	0.292
RS03 (Ricker, CY=1963)	0.195	0.270
RS04a (B-H, h=0.9, CY=1952)	0.330	0.200
RS05a (B-H, h=0.9, CY=1958)	0.315	0.226
RS06a (B-H, h=0.9, CY=1963)	0.283	0.227
RS04b (B-H, h=0.7, CY=1952)	0.352	0.215
RS05b (B-H, h=0.7, CY=1958)	0.344	0.229
RS06b (B-H, h=0.7, CY=1963)	0.314	0.223

In other words, the effective standard deviation (denoted from here on as  $\sigma_R^{out}$ ) is smaller than what was assumed in fitting the assessment model. The question is then what value to use for the variation of future recruitment in the projections. From information available for other hake-like species internationally, the variation about the stock-recruitment curve in the projections would be expected to be of the order of 0.45 (for FISHERIES/2018/SEP/SWG-DEM/43 a value of 0.4 was assumed, but 0.45 has been the value used standardly in the past). However, the mean of the future recruits should match that of the past recruits estimated in the assessment OM, as the sustainable level of catch is proportional to mean recruitment. Remembering that recruitment is assumed to be log-normally distributed, i.e.  $\ln R \sim N(\ln R_{med}, (\sigma_R^{out})^2)$  where  $R_{med}$  is the median of the estimated recruits at a particular spawning biomass, statistically the mean of the recruitment distribution in normal space would be  $R_{med} e^{(\sigma_R^{out})^2/2}$ . The inclusion of the  $\sigma_R$  term in equations (1) and (2) means that the estimate of  $\alpha$  has been biased by a factor of  $e^{(-\sigma_R)^2/2}$ , i.e. if  $R_{mod}$  is the model estimate of recruitment from the stock-recruitment relationship, then  $R_{mod} = R_{med} e^{(-\sigma_R)^2/2}$ . Thus the desired mean of the future recruits is  $R_{med} e^{(\sigma_R^{out})^2/2 - (\sigma_R)^2/2}$  and future recruitment should be calculated as follows (using the Beverton-Holt stock-recruitment equation for illustration purposes).

$$R_{s,y} = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{(\sigma_R^{out})^2/2} e^{\zeta_y} \quad (4)$$

where  $\zeta_y \sim N(0, \sigma_R^2)$  and the value of  $\sigma_R^{out}$  is OM and species dependent as reported in Table 1. This process has been followed for the projections reported in this document.

### Autocorrelation in the stock-recruitment residuals

The OM- and species-dependent values of the autocorrelation in the model estimated stock-recruitment residuals were calculated and are reported in Table 2 below.

**Table 2:** The autocorrelation values calculated from the model estimated stock-recruitment residuals.

RS model	<i>M. paradoxus</i>	<i>M. capensis</i>
RS01 (Ricker, CY=1952)	0.05	0.77
RS02 (Ricker, CY=1958)	0.09	0.79
RS03 (Ricker, CY=1963)	0.13	0.77
RS04a (B-H, h=0.9, CY=1952)	-0.18	0.65
RS05a (B-H, h=0.9, CY=1958)	-0.12	0.70
RS06a (B-H, h=0.9, CY=1963)	0.00	0.70
RS04b (B-H, h=0.7, CY=1952)	-0.20	0.64
RS05b (B-H, h=0.7, CY=1958)	-0.16	0.71
RS06b (B-H, h=0.7, CY=1963)	-0.02	0.65

For the results reported in this document, a value of zero was assumed for autocorrelation in *M. paradoxus* recruitment as the values in the table are all close to zero and not significant at the 5% level, while OM-specific values were used for *M. capensis* which are significant.

### Results

Projections were conducted for all the RS OMs for:

- the rules of OMP2014,
- a variant of OMP2014 where the TAC cap is increased from 150 000t to 160 000t, and
- variants of OMP2014 with a cap of both 150 000t and 160 000t where the *b* parameters are decreased and increased by 10%, 25% and 50%.

Table 3 lists an unweighted average of key performance statistics across the nine RS OMs; these are evaluated by pooling the output from the 100 simulations for each RS OM and calculating the performance statistics from those 900 values. Figure 1 plots these graphically.

Figure 2: shows the equally-weighted trajectories for female spawning biomass relative to  $B_{MSY}$  and those for the species-combined offshore exploitable biomass. A measure of effort is also provided; the explanation from FISHERIES/2018/AUG/SWG-DEM/35 is repeated here:

The effort in year *y* is calculated as  $C(y)/J(y)$ , where  $C(y)$  is the total species combined catch in year *y* and  $J(y)$  a combination of the *M. paradoxus* WC and SC CPUE indices, weighted according to the OMP-2014 TAC formula:

$$J_y = (1.0J_y^{WC,para} + .075J_y^{SC,para})/1.75 \quad (5)$$

with

$$J_y^{WC/SC,para} = \frac{\sum_{y'=y-3}^{y-1} I_{y'}^{WC/SC,para}}{\sum_{y'=2010}^{2012} I_{y'}^{WC/SC,para}} \quad (6)$$

where  $I_{y'}^{WC/SC,para}$  is the CPUE index for year  $y$ .

$J(y)$  is normalised to the value of one in 2017, and is calculated from the *M. paradoxus* indices only as this species dominates the catch. This computation is provided to give some idea of the extent to which the existing fleet size may need to change for different future levels of utilisation; in the interests of speed, it has been carried out only approximately, and can be calculated more accurately in future.

Figure 2 also plots out the predicted catches, as well as a combined CPUE index. This CPUE index is calculated by weighting each of the four species- and coast-specific commercial CPUE indices by the expected catch for that species and coast.

Figure 3 shows a selection of worm plots for a random selection of spawning biomass and TAC trajectories from across the nine RS OMs under application of the OMP-2014 rules.

Figure 4 plots the median estimates and 90% probability intervals for the projected TAC for the next three years for four OMs based on OMP-14: a cross of 15 000t and 160 000t TAC caps, and the  $b$  parameter values as for OMP-14 or increased by 10%

The Appendix provides the performance statistics in table form and as Zeh plots for the individual RS OMs.

## Discussion

- In median terms and for an equal weighting across the RS OMs, both a TAC cap of 150 000t and of 160 000t seem compatible with an absence of conservation concern for the resource. In both cases, the TAC is likely drop slightly in the next year or so, but then steadily increase to the cap, with the median estimate reaching the 150 000t cap by about 2023 and the 160 000t cap a year or two later (see row IV of Figure 2). The 90% probability envelope is similar in both cases and spans quite a large range, with the lowest likely catch being around 110 000t before the steady increase in TAC commences.
- Increasing the  $b$  parameter by 10% predicts a sharp increase in TAC over the next few years, with the TAC caps being reached a few years earlier than would likely be the case if  $b$  is kept unchanged. The average expected catch over the 25-year projection period for a 150 000t TAC cap increases from 147 (140,149) to 149 (142,149) when the  $b$  parameter is increased by 10%. For a 160 000t TAC cap this increase in average expected catch is from 155 (145,158) to 157 (147,159). With this increase in  $b$ , the chance of a short term decrease in the TAC is greatly reduced (see Figure 2).
- A key point for discussion here is though whether, given the improvement in *M. paradoxus* status indicated by the most recent assessment, any immediate drop in the TAC is necessary. Should OMP-18 be adjusted to greatly reduce the possibility of this happening? See Figure 4 for the projected TAC values for the next three years.
- All of the above options seem defensible, although robustness testing still needs to be conducted.

**Further work**

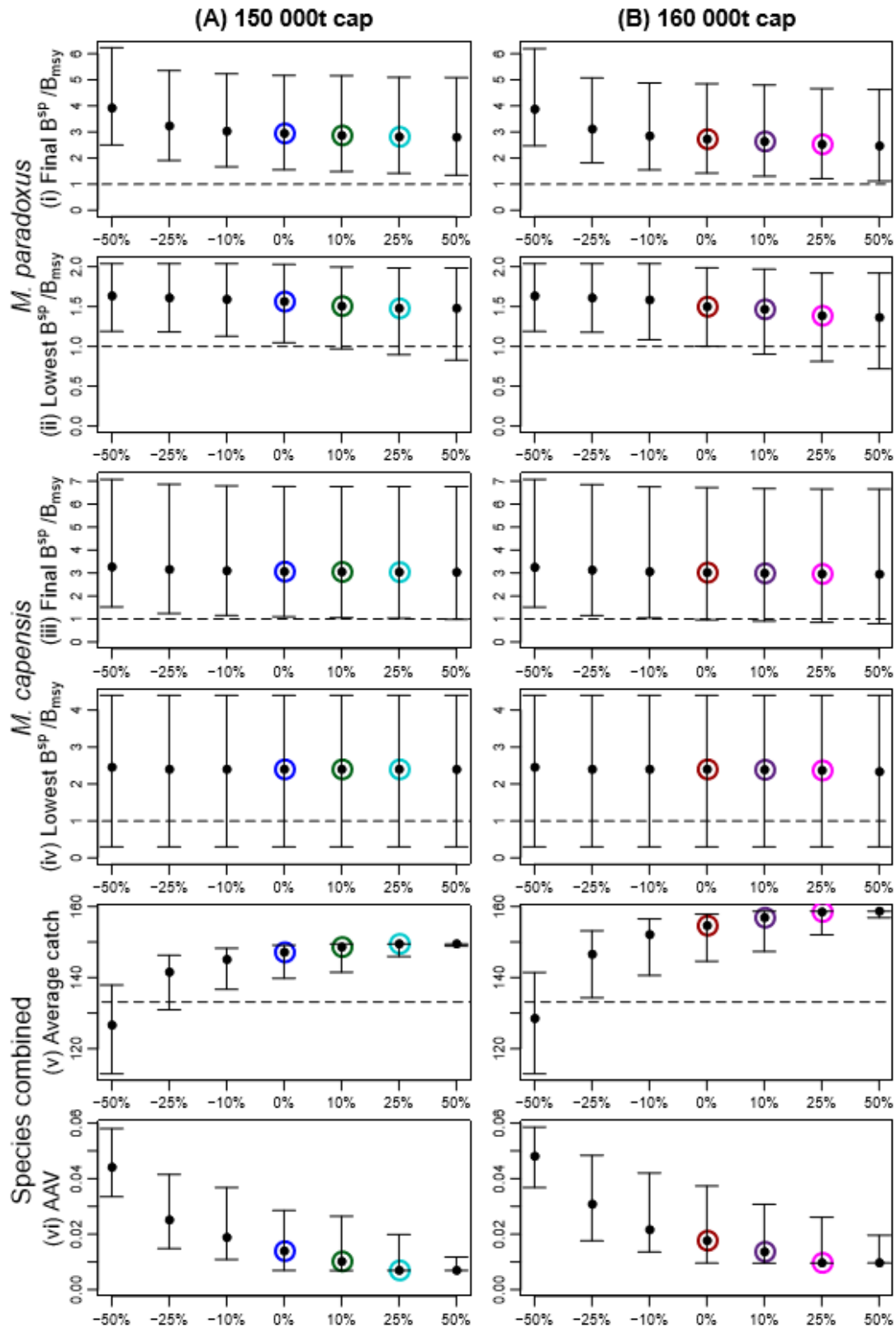
Further work planned for the hake 2018 OMP review entails the following.

1. Robustness tests, with first priority given to survey  $q$ 's.
2. Evaluate and (if deemed necessary) conduct sensitivity testing of other rules and tuning parameters of the OMP2014 formula, which include:
  - a. other tuning parameters (see Table 1 of FISHERIES/2017/OCT/SWG-DEM/41
  - b. maximum allowable annual TAC change
  - c. weighting of commercial and survey CPUE indices
3. Refine the method in which noise is added to the age 0-3 cohorts in the projections.
4. Refine the method for calculating effort.

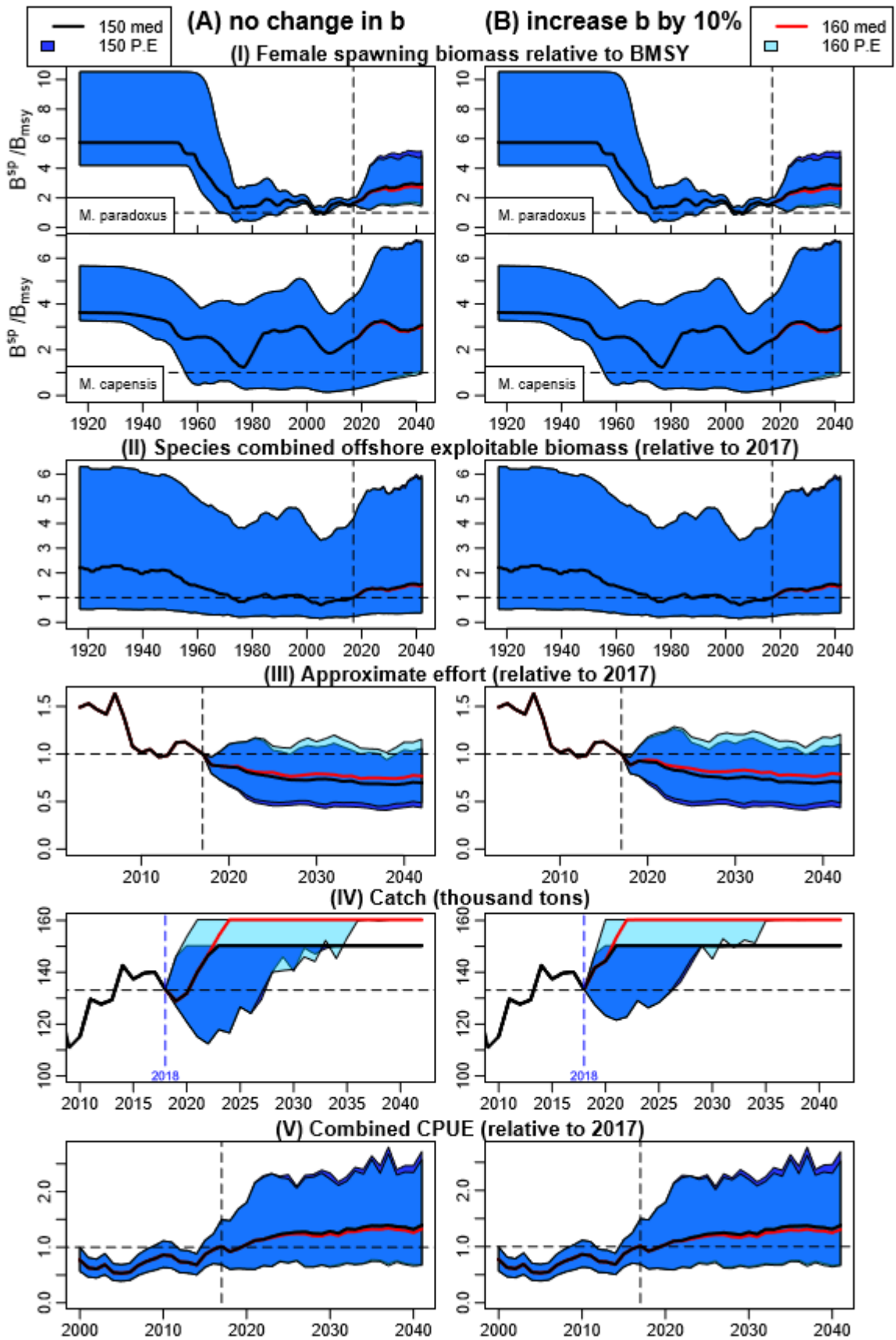
**Table 3:** Table of key performance statistics as medians with 90% probability intervals in parentheses for **an equally-weighted average across the nine RS OMs**. The equally-weighted performance statistics are calculated by pooling the output from the 100 simulations for each RS model and calculating the performance statistics from those 900 values. Results are reported for a cap of 150 000t and a cap of 160 000t, and for a range of more and less aggressive procedures than OMP2014 (results for which are highlighted by the bold text in the table below).

The performance statistics are  $B^{sp}/B_{MSY}$  final – the value of this statistic for the final year of the projection, i.e. 2042),  $B^{sp}/B_{MSY}$  lowest – the lowest value of this statistic in the projection period),  $C_{av}$  (the average catch over the projection period) and AAV (the average inter-annual proportional change in catch over the projection period).

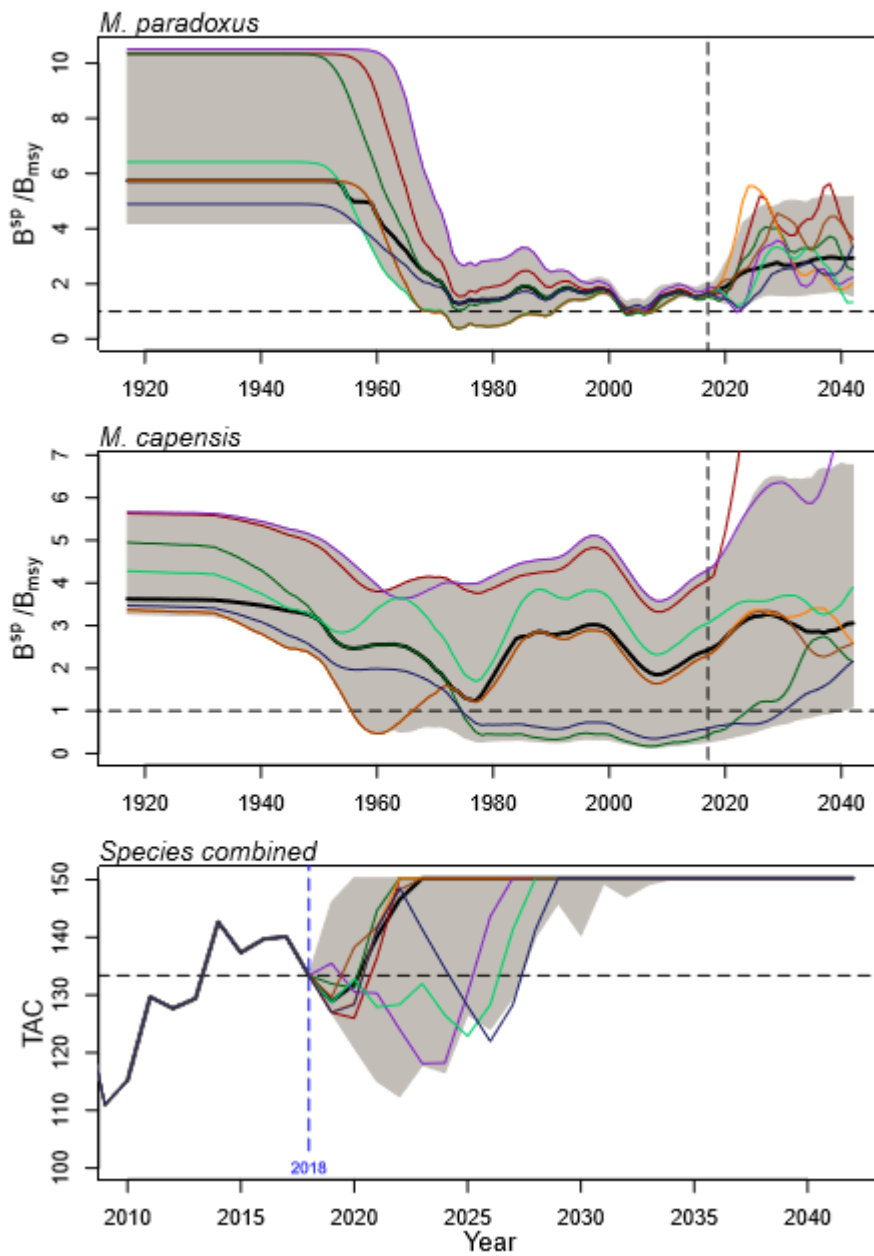
TAC cap	%change in b	<i>M. paradoxus</i>				<i>M. capensis</i>				(v) $C_{av}$	(vi) AAV
		(i) $B^{sp}/B_{MSY}$ final	(ii) $B^{sp}/B_{MSY}$ lowest	(iii) $B^{sp}/B_{MSY}$ final	(iv) $B^{sp}/B_{MSY}$ lowest						
150	-50%	3.91 (2.50,6.23)	1.63 (1.19,2.04)	3.26 (1.52,7.07)	2.45 (0.30,4.40)	126.60 (112.94,137.89)	0.04 (0.03,0.06)				
	-25%	3.22 (1.91,5.35)	1.61 (1.18,2.04)	3.15 (1.24,6.86)	2.39 (0.30,4.40)	141.51 (130.94,146.27)	0.03 (0.01,0.04)				
	-10%	3.02 (1.66,5.23)	1.59 (1.13,2.04)	3.09 (1.15,6.79)	2.39 (0.30,4.40)	145.03 (136.69,148.24)	0.02 (0.01,0.04)				
	<b>0%</b>	<b>2.94 (1.55,5.17)</b>	<b>1.56 (1.05,2.03)</b>	<b>3.06 (1.10,6.76)</b>	<b>2.39 (0.30,4.40)</b>	<b>147.07 (139.77,149.09)</b>	<b>0.01 (0.01,0.03)</b>				
	10%	2.86 (1.48,5.16)	1.50 (0.97,2.00)	3.04 (1.05,6.76)	2.39 (0.30,4.40)	148.56 (141.48,149.45)	0.01 (0.01,0.03)				
	25%	2.81 (1.41,5.10)	1.48 (0.90,1.98)	3.04 (1.03,6.76)	2.39 (0.30,4.40)	149.45 (145.90,149.45)	0.01 (0.01,0.02)				
	50%	2.79 (1.34,5.08)	1.48 (0.83,1.98)	3.03 (0.98,6.76)	2.39 (0.30,4.40)	149.45 (148.84,149.45)	0.01 (0.01,0.01)				
160	-50%	3.87 (2.47,6.19)	1.63 (1.19,2.04)	3.24 (1.51,7.07)	2.45 (0.30,4.40)	128.46 (112.94,141.44)	0.05 (0.04,0.06)				
	-25%	3.11 (1.82,5.07)	1.61 (1.18,2.04)	3.12 (1.15,6.85)	2.39 (0.30,4.40)	146.51 (134.34,153.15)	0.03 (0.02,0.05)				
	-10%	2.84 (1.55,4.88)	1.58 (1.08,2.04)	3.05 (1.05,6.75)	2.39 (0.30,4.40)	152.07 (140.60,156.50)	0.02 (0.01,0.04)				
	0%	2.72 (1.42,4.85)	1.50 (1.00,1.99)	3.01 (0.96,6.72)	2.39 (0.30,4.40)	154.58 (144.58,157.84)	0.02 (0.01,0.04)				
	10%	2.63 (1.30,4.80)	1.46 (0.90,1.97)	2.98 (0.91,6.67)	2.38 (0.30,4.40)	156.83 (147.34,158.65)	0.01 (0.01,0.03)				
	25%	2.52 (1.21,4.66)	1.38 (0.81,1.92)	2.95 (0.85,6.65)	2.36 (0.30,4.40)	158.43 (152.03,158.65)	0.01 (0.01,0.03)				
	50%	2.46 (1.11,4.63)	1.36 (0.72,1.92)	2.94 (0.80,6.65)	2.33 (0.30,4.40)	158.65 (156.84,158.65)	0.01 (0.01,0.02)				



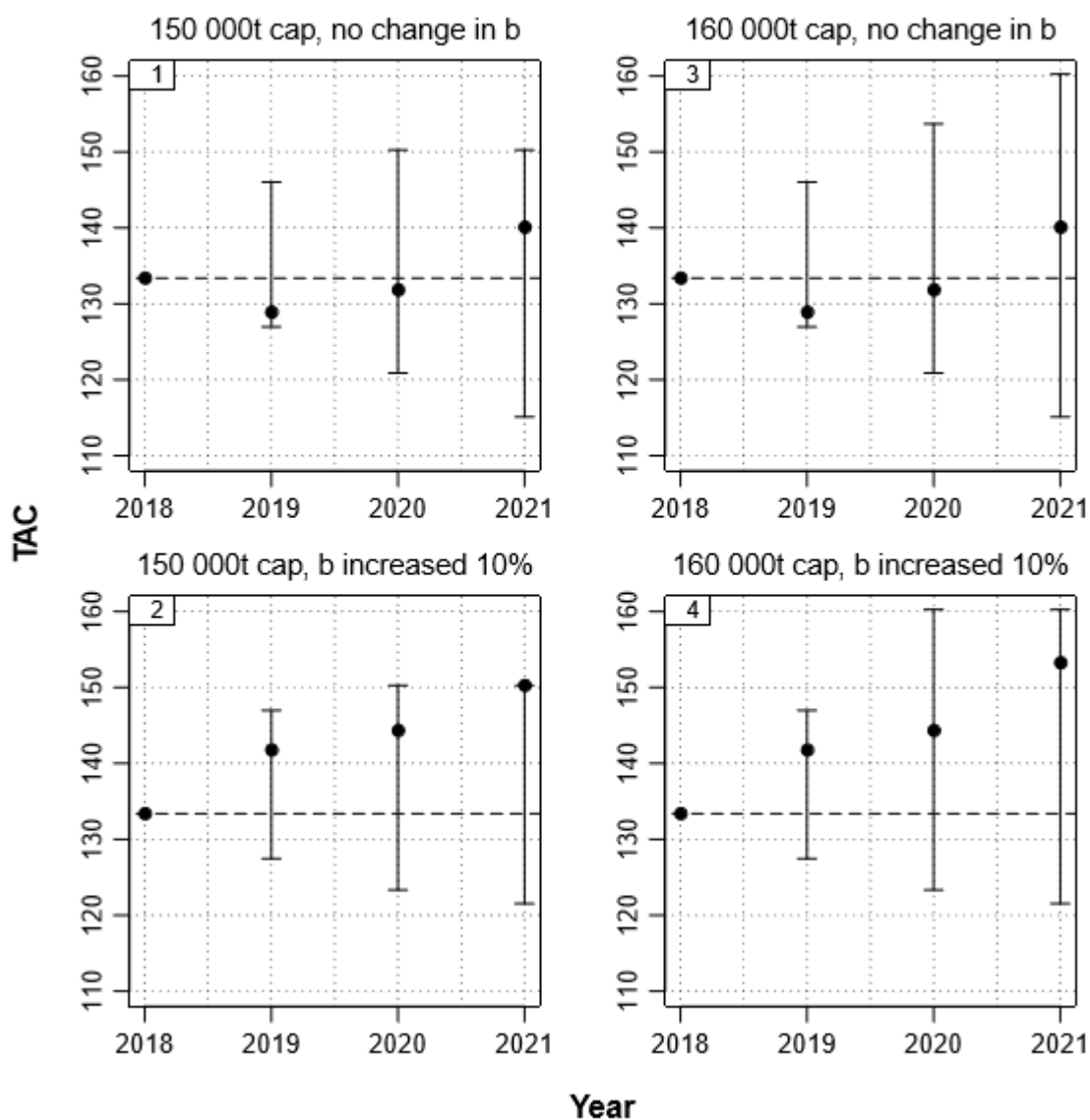
**Figure 1:** Zeh plots of the performance statistics in Table 3 for the **equally-weighted average across the nine RS OMs**, showing the median estimates and 90% probability intervals. The left column plots the statistics for a 150 000t cap, while the right column does the same for a 160 000t cap. In each plot, the performance statistics are shown for the range of more and less aggressive OMPs reported in this document. In the first four rows, the horizontal dashed line indicates  $B=B_{MSY}$ , while in row (v) the horizontal dashed line indicates the 2018 TAC of 133 119t. The coloured circles are purely to aid discussion. The statistics with the dark blue circle are for OMP2014 which has the 150 000t cap.



**Figure 2:** Various model outputs for an equal weighting across the nine RS OMs. For each plot, results are shown for a 150 000t cap (black lines for the median with dark blue shading for the 90% P.E.) and for a 160 000t cap (red lines for the median and light blue shading for the 90% P.E.). The left column shows these two TACs combined with the OMP2014  $b$  values, while the right column does the same for the OMP2014  $b$  values for *M. paradoxus* and *M. capensis* both increased by 10%.



**Figure 3:** Worm plots are shown for the projections under OMP2014 rules (i.e. cap of 150 000t with no change in  $b$ ), for female spawning biomass relative to  $B_{MSY}$  and for the projected TAC. The worm trajectories were drawn randomly from the 900 simulations from the nine RS OMs. The solid black line shows the equally-weighted median trajectories and the grey shaded area the 90% P.E.



**Figure 4:** Median estimates and 90% probability intervals for the predicted TAC for the next three years, for an equal weighting across the nine RS models. The horizontal dashed line is the 2018 TAC. Results are shown for TAC caps of 150 000t and 160 000t, and for no change in  $b$  as well as a 10% increase in  $b$ .

**APPENDIX – Results for the individual RS OMs**

**Table A. 1(i):** Performance statistic  $B^{SP}/B_{MSY}$  final for *M. paradoxus* for the nine RS OMs. This is the value of the  $B^{SP}/B_{MSY}$  statistic for the final year of the projection.

		Ricker						Beverton-Holt with h=0.90						Beverton-Holt with h=0.70					
		RS01		RS02		RS03		RS04a		RS05a		RS06a		RS04b		RS05b		RS06b	
150	-50%	3.75	(2.61,5.18)	3.63	(2.48,5.07)	3.07	(1.98,4.02)	4.70	(3.10,7.04)	4.97	(3.24,6.85)	5.21	(3.49,7.14)	3.29	(2.38,4.71)	3.43	(2.50,4.79)	3.68	(2.62,5.19)
	-25%	2.89	(1.80,4.40)	2.84	(1.78,4.35)	2.52	(1.56,3.58)	4.24	(2.66,6.81)	3.66	(2.18,5.81)	3.85	(2.34,6.06)	2.96	(1.92,4.45)	2.89	(1.95,4.36)	3.43	(2.40,5.00)
	-10%	2.59	(1.47,4.17)	2.55	(1.52,4.04)	2.25	(1.32,3.40)	4.15	(2.49,6.69)	3.28	(1.82,5.66)	3.46	(1.99,5.90)	2.93	(1.84,4.37)	2.76	(1.77,4.22)	3.38	(2.32,4.98)
	0%	2.43	(1.37,4.12)	2.44	(1.39,3.92)	2.15	(1.17,3.45)	4.10	(2.34,6.65)	3.17	(1.58,5.62)	3.33	(1.76,5.86)	2.85	(1.78,4.36)	2.75	(1.71,4.18)	3.35	(2.30,4.97)
	10%	2.40	(1.28,4.12)	2.35	(1.33,3.94)	2.03	(1.11,3.30)	4.08	(2.30,6.60)	3.07	(1.49,5.59)	3.28	(1.64,5.84)	2.82	(1.73,4.33)	2.72	(1.64,4.17)	3.32	(2.28,4.95)
	25%	2.39	(1.22,4.12)	2.30	(1.27,3.96)	1.94	(1.07,3.26)	4.06	(2.28,6.54)	2.96	(1.44,5.40)	3.21	(1.57,5.74)	2.78	(1.70,4.32)	2.66	(1.59,4.16)	3.29	(2.19,4.93)
	50%	2.32	(1.17,4.03)	2.26	(1.23,3.91)	1.91	(1.03,3.25)	4.04	(2.28,6.54)	2.94	(1.40,5.35)	3.20	(1.48,5.59)	2.76	(1.69,4.32)	2.66	(1.57,4.16)	3.28	(2.19,4.93)
160	-50%	3.75	(2.49,5.18)	3.62	(2.48,5.07)	3.07	(1.98,4.02)	4.52	(3.01,6.67)	4.94	(3.24,6.78)	5.21	(3.49,7.12)	3.28	(2.34,4.62)	3.43	(2.50,4.79)	3.64	(2.60,5.09)
	-25%	2.81	(1.69,4.23)	2.85	(1.75,4.25)	2.50	(1.44,3.57)	3.84	(2.36,6.30)	3.44	(2.09,5.43)	3.63	(2.22,5.65)	2.79	(1.81,4.31)	2.81	(1.90,4.22)	3.28	(2.27,4.85)
	-10%	2.48	(1.45,3.94)	2.47	(1.39,4.09)	2.23	(1.32,3.38)	3.64	(2.14,6.15)	3.03	(1.59,5.19)	3.23	(1.79,5.40)	2.71	(1.67,4.19)	2.66	(1.69,4.08)	3.23	(2.21,4.81)
	0%	2.31	(1.21,3.90)	2.33	(1.25,3.77)	2.09	(1.12,3.27)	3.59	(2.00,6.11)	2.83	(1.43,5.10)	2.97	(1.63,5.37)	2.70	(1.64,4.14)	2.55	(1.58,3.99)	3.18	(2.14,4.79)
	10%	2.19	(1.10,3.86)	2.18	(1.20,3.69)	1.98	(1.05,3.29)	3.51	(1.83,6.03)	2.71	(1.28,5.07)	2.91	(1.44,5.32)	2.63	(1.59,4.11)	2.52	(1.53,3.96)	3.14	(2.10,4.76)
	25%	2.13	(0.98,3.83)	2.10	(1.09,3.69)	1.81	(0.95,3.04)	3.47	(1.79,5.95)	2.56	(1.16,4.94)	2.79	(1.27,5.27)	2.54	(1.51,4.09)	2.49	(1.45,3.94)	3.07	(2.03,4.74)
	50%	2.04	(0.93,3.77)	2.06	(0.92,3.65)	1.76	(0.86,2.96)	3.46	(1.78,5.93)	2.41	(1.08,4.83)	2.68	(1.23,5.04)	2.50	(1.41,4.09)	2.43	(1.39,3.94)	3.06	(1.93,4.73)

**Table A. 1(ii):** Performance statistic  $B^{SP}/B_{MSY}$  lowest for *M. paradoxus* for the nine RS OMs. This is the lowest value of  $B^{SP}/B_{MSY}$  in the projection period.

		Ricker						Beverton-Holt with h=0.90						Beverton-Holt with h=0.70					
		RS01		RS02		RS03		RS04a		RS05a		RS06a		RS04b		RS05b		RS06b	
150	-50%	1.71	(1.34,1.71)	1.75	(1.41,1.75)	1.71	(1.39,1.71)	1.48	(1.04,1.48)	1.61	(1.03,1.61)	1.88	(1.32,1.88)	1.58	(1.12,1.59)	1.68	(1.20,1.70)	2.04	(1.56,2.04)
	-25%	1.71	(1.34,1.71)	1.75	(1.40,1.75)	1.60	(1.25,1.71)	1.48	(1.04,1.48)	1.61	(1.03,1.61)	1.88	(1.32,1.88)	1.58	(1.12,1.59)	1.68	(1.20,1.70)	2.04	(1.56,2.04)
	-10%	1.67	(1.14,1.71)	1.70	(1.23,1.75)	1.51	(1.14,1.71)	1.48	(1.00,1.48)	1.58	(0.99,1.61)	1.88	(1.32,1.88)	1.58	(1.12,1.59)	1.65	(1.20,1.70)	2.04	(1.41,2.04)
	0%	1.57	(1.04,1.71)	1.59	(1.10,1.75)	1.42	(1.05,1.71)	1.48	(0.91,1.48)	1.56	(0.99,1.61)	1.83	(1.14,1.88)	1.55	(1.00,1.59)	1.61	(1.05,1.70)	2.01	(1.36,2.04)
	10%	1.52	(0.94,1.71)	1.52	(0.99,1.75)	1.36	(0.99,1.71)	1.48	(0.83,1.48)	1.51	(0.84,1.61)	1.76	(1.10,1.88)	1.51	(0.96,1.59)	1.58	(1.05,1.70)	1.98	(1.36,2.04)
	25%	1.45	(0.89,1.71)	1.47	(0.94,1.75)	1.32	(0.91,1.67)	1.47	(0.75,1.48)	1.39	(0.74,1.61)	1.68	(0.99,1.88)	1.48	(0.88,1.59)	1.53	(0.97,1.70)	1.97	(1.27,2.04)
	50%	1.45	(0.81,1.71)	1.44	(0.89,1.75)	1.27	(0.86,1.67)	1.47	(0.73,1.48)	1.37	(0.68,1.61)	1.66	(0.86,1.88)	1.48	(0.83,1.59)	1.52	(0.92,1.70)	1.97	(1.26,2.04)
160	-50%	1.71	(1.34,1.71)	1.75	(1.41,1.75)	1.71	(1.39,1.71)	1.48	(1.04,1.48)	1.61	(1.03,1.61)	1.88	(1.32,1.88)	1.58	(1.12,1.59)	1.68	(1.20,1.70)	2.04	(1.56,2.04)
	-25%	1.71	(1.31,1.71)	1.75	(1.35,1.75)	1.58	(1.23,1.71)	1.48	(1.04,1.48)	1.61	(1.03,1.61)	1.88	(1.32,1.88)	1.58	(1.12,1.59)	1.68	(1.20,1.70)	2.04	(1.56,2.04)
	-10%	1.58	(1.12,1.71)	1.59	(1.10,1.75)	1.42	(1.08,1.71)	1.48	(1.00,1.48)	1.58	(0.99,1.61)	1.88	(1.32,1.88)	1.56	(1.12,1.59)	1.63	(1.20,1.70)	2.01	(1.41,2.04)
	0%	1.45	(1.00,1.71)	1.47	(0.98,1.75)	1.33	(0.98,1.68)	1.48	(0.91,1.48)	1.54	(0.91,1.61)	1.77	(1.14,1.88)	1.51	(1.00,1.59)	1.58	(1.05,1.70)	1.97	(1.36,2.04)
	10%	1.35	(0.84,1.71)	1.37	(0.88,1.75)	1.25	(0.90,1.60)	1.46	(0.83,1.48)	1.43	(0.83,1.61)	1.63	(1.10,1.88)	1.46	(0.96,1.59)	1.53	(1.05,1.70)	1.93	(1.34,2.04)
	25%	1.24	(0.75,1.71)	1.28	(0.84,1.75)	1.17	(0.82,1.55)	1.43	(0.68,1.48)	1.27	(0.74,1.61)	1.50	(0.89,1.88)	1.40	(0.88,1.59)	1.46	(0.92,1.70)	1.90	(1.25,2.04)
	50%	1.20	(0.66,1.71)	1.20	(0.77,1.75)	1.11	(0.72,1.53)	1.43	(0.68,1.48)	1.17	(0.65,1.61)	1.45	(0.75,1.88)	1.39	(0.81,1.59)	1.43	(0.89,1.70)	1.89	(1.20,2.04)

**APPENDIX – Results for the individual RS OMs**

**Table A. 1(iii):** Performance statistic  $B^{SP}/B_{MSY}$  final for *M. capensis* for the nine RS OMs.

		Ricker						Beverton-Holt with h=0.90						Beverton-Holt with h=0.70					
		RS01		RS02		RS03		RS04a		RS05a		RS06a		RS04b		RS05b		RS06b	
150	-50%	3.88	(2.55,5.50)	2.99	(1.87,4.60)	3.06	(2.04,4.38)	2.42	(1.58,3.70)	5.81	(4.25,8.28)	6.02	(4.42,8.50)	2.09	(1.38,3.11)	3.81	(2.76,5.47)	1.79	(1.12,2.65)
	-25%	3.70	(2.39,5.34)	2.92	(1.78,4.44)	2.96	(1.90,4.26)	2.14	(1.34,3.47)	5.66	(4.13,8.02)	5.90	(4.32,8.29)	1.83	(1.14,2.76)	3.72	(2.67,5.31)	1.54	(0.89,2.42)
	-10%	3.61	(2.39,5.20)	2.79	(1.78,4.37)	2.93	(1.85,4.15)	2.08	(1.18,3.30)	5.59	(4.07,7.92)	5.84	(4.28,8.21)	1.74	(1.05,2.66)	3.69	(2.64,5.25)	1.47	(0.76,2.35)
	0%	3.64	(2.36,5.12)	2.73	(1.71,4.28)	2.91	(1.84,4.07)	2.06	(1.11,3.19)	5.56	(4.06,7.87)	5.81	(4.26,8.17)	1.69	(0.97,2.60)	3.69	(2.63,5.23)	1.43	(0.71,2.32)
	10%	3.61	(2.34,5.08)	2.72	(1.68,4.20)	2.89	(1.83,4.05)	2.00	(1.05,3.14)	5.53	(4.05,7.85)	5.77	(4.26,8.14)	1.66	(0.91,2.56)	3.68	(2.62,5.21)	1.41	(0.67,2.31)
	25%	3.56	(2.35,5.03)	2.73	(1.65,4.16)	2.86	(1.82,4.03)	1.98	(1.04,3.14)	5.48	(4.05,7.84)	5.73	(4.25,8.11)	1.62	(0.88,2.54)	3.67	(2.62,5.21)	1.37	(0.63,2.31)
	50%	3.56	(2.35,5.03)	2.73	(1.62,4.12)	2.84	(1.81,4.03)	1.97	(0.98,3.14)	5.48	(4.04,7.82)	5.72	(4.25,8.10)	1.61	(0.81,2.54)	3.66	(2.62,5.21)	1.37	(0.59,2.31)
160	-50%	3.88	(2.55,5.52)	2.99	(1.87,4.64)	3.06	(2.04,4.38)	2.28	(1.53,3.41)	5.80	(4.23,8.28)	6.01	(4.42,8.50)	2.07	(1.34,3.10)	3.81	(2.76,5.47)	1.74	(1.08,2.60)
	-25%	3.70	(2.39,5.38)	2.93	(1.78,4.49)	2.96	(1.90,4.26)	1.92	(1.16,3.28)	5.63	(4.10,8.01)	5.87	(4.30,8.29)	1.75	(1.08,2.62)	3.71	(2.66,5.29)	1.46	(0.82,2.28)
	-10%	3.63	(2.38,5.23)	2.84	(1.73,4.38)	2.91	(1.85,4.17)	1.83	(1.05,3.01)	5.57	(4.04,7.88)	5.82	(4.25,8.18)	1.61	(0.98,2.47)	3.67	(2.62,5.22)	1.36	(0.71,2.19)
	0%	3.57	(2.33,5.15)	2.75	(1.72,4.30)	2.89	(1.82,4.11)	1.79	(0.92,2.90)	5.52	(4.01,7.82)	5.78	(4.23,8.13)	1.55	(0.92,2.40)	3.65	(2.60,5.18)	1.29	(0.62,2.14)
	10%	3.58	(2.31,5.07)	2.69	(1.66,4.23)	2.88	(1.79,4.09)	1.74	(0.86,2.83)	5.47	(3.99,7.77)	5.75	(4.21,8.09)	1.49	(0.84,2.35)	3.64	(2.59,5.15)	1.25	(0.55,2.12)
	25%	3.56	(2.29,4.97)	2.70	(1.61,4.17)	2.84	(1.78,4.06)	1.68	(0.75,2.81)	5.42	(3.97,7.72)	5.71	(4.20,8.04)	1.44	(0.73,2.32)	3.63	(2.58,5.14)	1.19	(0.52,2.11)
	50%	3.50	(2.30,4.93)	2.69	(1.59,4.13)	2.81	(1.77,4.02)	1.66	(0.69,2.81)	5.39	(3.97,7.67)	5.65	(4.19,8.00)	1.41	(0.65,2.32)	3.61	(2.58,5.13)	1.16	(0.44,2.11)

**Table A. 1(iv):** Performance statistic  $B^{SP}/B_{MSY}$  lowest for *M. capensis* for the nine RS OMs.

		Ricker						Beverton-Holt with h=0.90						Beverton-Holt with h=0.70					
		RS01		RS02		RS03		RS04a		RS05a		RS06a		RS04b		RS05b		RS06b	
150	-50%	3.15	(2.46,3.15)	2.36	(1.62,2.39)	2.49	(1.98,2.49)	0.50	(0.50,0.50)	4.17	(4.00,4.17)	4.40	(4.17,4.40)	0.62	(0.62,0.62)	2.69	(2.59,2.69)	0.30	(0.30,0.30)
	-25%	3.06	(2.34,3.15)	2.12	(1.53,2.39)	2.44	(1.83,2.49)	0.50	(0.50,0.50)	4.17	(3.87,4.17)	4.40	(4.07,4.40)	0.62	(0.62,0.62)	2.69	(2.52,2.69)	0.30	(0.30,0.30)
	-10%	3.04	(2.33,3.15)	2.11	(1.52,2.39)	2.41	(1.82,2.49)	0.50	(0.50,0.50)	4.17	(3.81,4.17)	4.40	(4.03,4.40)	0.62	(0.62,0.62)	2.69	(2.49,2.69)	0.30	(0.30,0.30)
	0%	3.02	(2.32,3.15)	2.12	(1.51,2.39)	2.39	(1.80,2.49)	0.50	(0.50,0.50)	4.17	(3.78,4.17)	4.40	(4.00,4.40)	0.62	(0.62,0.62)	2.69	(2.48,2.69)	0.30	(0.30,0.30)
	10%	3.01	(2.32,3.15)	2.10	(1.48,2.39)	2.38	(1.77,2.49)	0.50	(0.50,0.50)	4.17	(3.75,4.17)	4.40	(3.97,4.40)	0.62	(0.62,0.62)	2.69	(2.47,2.69)	0.30	(0.30,0.30)
	25%	3.00	(2.30,3.15)	2.07	(1.48,2.39)	2.36	(1.77,2.49)	0.50	(0.50,0.50)	4.17	(3.72,4.17)	4.40	(3.94,4.40)	0.62	(0.60,0.62)	2.69	(2.45,2.69)	0.30	(0.29,0.30)
	50%	2.97	(2.25,3.15)	2.05	(1.47,2.39)	2.34	(1.74,2.49)	0.50	(0.49,0.50)	4.17	(3.71,4.17)	4.40	(3.92,4.40)	0.62	(0.57,0.62)	2.69	(2.44,2.69)	0.30	(0.28,0.30)
160	-50%	3.15	(2.46,3.15)	2.36	(1.62,2.39)	2.49	(1.98,2.49)	0.50	(0.50,0.50)	4.17	(4.00,4.17)	4.40	(4.17,4.40)	0.62	(0.62,0.62)	2.69	(2.59,2.69)	0.30	(0.30,0.30)
	-25%	3.00	(2.27,3.15)	2.12	(1.53,2.39)	2.42	(1.82,2.49)	0.50	(0.50,0.50)	4.17	(3.87,4.17)	4.40	(4.07,4.40)	0.62	(0.62,0.62)	2.69	(2.52,2.69)	0.30	(0.30,0.30)
	-10%	2.97	(2.27,3.15)	2.05	(1.50,2.39)	2.35	(1.77,2.49)	0.50	(0.50,0.50)	4.17	(3.79,4.17)	4.40	(4.01,4.40)	0.62	(0.62,0.62)	2.69	(2.49,2.69)	0.30	(0.30,0.30)
	0%	2.97	(2.26,3.15)	2.05	(1.48,2.39)	2.34	(1.77,2.49)	0.50	(0.50,0.50)	4.17	(3.75,4.17)	4.40	(3.98,4.40)	0.62	(0.62,0.62)	2.69	(2.46,2.69)	0.30	(0.30,0.30)
	10%	2.93	(2.25,3.15)	2.08	(1.44,2.39)	2.34	(1.76,2.49)	0.50	(0.50,0.50)	4.17	(3.72,4.17)	4.40	(3.96,4.40)	0.62	(0.61,0.62)	2.69	(2.45,2.69)	0.30	(0.30,0.30)
	25%	2.93	(2.22,3.15)	2.03	(1.43,2.39)	2.32	(1.72,2.49)	0.50	(0.46,0.50)	4.17	(3.66,4.17)	4.40	(3.92,4.40)	0.62	(0.58,0.62)	2.69	(2.42,2.69)	0.30	(0.27,0.30)
	50%	2.88	(2.20,3.15)	1.99	(1.43,2.39)	2.30	(1.70,2.49)	0.50	(0.41,0.50)	4.17	(3.64,4.17)	4.40	(3.86,4.40)	0.62	(0.54,0.62)	2.69	(2.41,2.69)	0.30	(0.26,0.30)

**APPENDIX – Results for the individual RS OMs**

**Table A. 1(v):** Performance statistic **C<sub>av</sub>** (the average catch over the projection period) for the nine RS OMs.

		Ricker						Beverton-Holt with h=0.90						Beverton-Holt with h=0.70					
		RS01		RS02		RS03		RS04a		RS05a		RS06a		RS04b		RS05b		RS06b	
150	-50%	109	( 97,120)	106	( 96,118)	99	( 91,114)	133	(122,141)	113	(100,128)	110	( 99,126)	122	(108,135)	111	( 99,127)	127	(113,138)
	-25%	133	(121,141)	131	(121,139)	127	(116,135)	144	(134,147)	132	(121,143)	132	(120,143)	140	(127,146)	132	(118,143)	142	(131,146)
	-10%	141	(133,147)	140	(132,146)	137	(129,143)	146	(139,148)	141	(129,147)	141	(128,147)	144	(133,148)	141	(129,147)	145	(137,148)
	0%	145	(138,149)	144	(137,149)	142	(134,147)	148	(142,149)	144	(133,149)	144	(133,149)	146	(136,149)	144	(132,148)	147	(140,149)
	10%	148	(142,149)	147	(140,149)	145	(138,149)	149	(144,149)	146	(136,149)	147	(137,149)	148	(138,149)	147	(136,149)	149	(141,149)
	25%	149	(146,149)	149	(144,149)	148	(142,149)	149	(147,149)	149	(140,149)	149	(141,149)	149	(143,149)	149	(141,149)	149	(146,149)
	50%	149	(148,149)	149	(147,149)	149	(146,149)	149	(148,149)	149	(144,149)	149	(146,149)	149	(147,149)	149	(146,149)	149	(149,149)
160	-50%	109	( 97,122)	106	( 96,121)	99	( 91,114)	136	(122,146)	113	(100,130)	110	( 99,127)	123	(108,139)	111	( 99,129)	128	(113,141)
	-25%	135	(123,145)	133	(122,143)	128	(117,139)	150	(139,155)	135	(121,148)	135	(120,148)	143	(128,152)	135	(119,148)	147	(134,153)
	-10%	145	(134,153)	144	(134,152)	140	(130,149)	154	(144,157)	144	(132,154)	143	(130,154)	150	(136,156)	144	(130,154)	152	(141,156)
	0%	151	(141,157)	150	(140,156)	146	(138,153)	156	(148,158)	149	(136,157)	149	(134,157)	153	(140,157)	149	(135,157)	155	(145,158)
	10%	155	(147,159)	153	(145,158)	151	(143,157)	158	(150,159)	152	(140,158)	153	(139,158)	156	(143,158)	153	(140,158)	157	(147,159)
	25%	157	(152,159)	156	(150,159)	155	(148,158)	159	(154,159)	156	(144,159)	156	(145,159)	158	(147,159)	157	(146,159)	158	(152,159)
	50%	159	(154,159)	159	(153,159)	158	(153,159)	159	(155,159)	158	(150,159)	158	(151,159)	159	(152,159)	159	(151,159)	159	(157,159)

**Table A. 1(vi):** Performance statistic **AAV** (the average inter-annual proportional change in catch over the projection period) for the nine RS OMs.

		Ricker						Beverton-Holt with h=0.90						Beverton-Holt with h=0.70					
		RS01		RS02		RS03		RS04a		RS05a		RS06a		RS04b		RS05b		RS06b	
150	-50%	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.04	(0.03,0.05)	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.05	(0.03,0.06)	0.05	(0.04,0.06)	0.04	(0.03,0.06)
	-25%	0.04	(0.03,0.05)	0.05	(0.03,0.06)	0.05	(0.04,0.06)	0.02	(0.01,0.04)	0.04	(0.02,0.06)	0.04	(0.02,0.06)	0.03	(0.02,0.05)	0.04	(0.02,0.06)	0.03	(0.01,0.04)
	-10%	0.03	(0.02,0.05)	0.03	(0.02,0.05)	0.04	(0.03,0.05)	0.01	(0.01,0.03)	0.03	(0.01,0.05)	0.03	(0.01,0.05)	0.02	(0.01,0.04)	0.03	(0.01,0.05)	0.02	(0.01,0.04)
	0%	0.02	(0.01,0.04)	0.03	(0.01,0.04)	0.03	(0.02,0.04)	0.01	(0.01,0.03)	0.02	(0.01,0.04)	0.03	(0.01,0.05)	0.02	(0.01,0.03)	0.02	(0.01,0.04)	0.01	(0.01,0.03)
	10%	0.01	(0.01,0.03)	0.02	(0.01,0.03)	0.02	(0.01,0.04)	0.01	(0.01,0.03)	0.02	(0.01,0.04)	0.02	(0.01,0.04)	0.01	(0.01,0.03)	0.02	(0.01,0.04)	0.01	(0.01,0.03)
	25%	0.01	(0.01,0.03)	0.01	(0.01,0.03)	0.02	(0.01,0.03)	0.01	(0.01,0.02)	0.01	(0.01,0.03)	0.01	(0.01,0.04)	0.01	(0.01,0.03)	0.01	(0.01,0.03)	0.01	(0.01,0.02)
	50%	0.01	(0.01,0.02)	0.01	(0.01,0.02)	0.01	(0.01,0.02)	0.01	(0.01,0.02)	0.01	(0.01,0.03)	0.01	(0.01,0.03)	0.01	(0.01,0.02)	0.01	(0.01,0.03)	0.01	(0.01,0.01)
160	-50%	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.04	(0.03,0.06)	0.05	(0.04,0.06)	0.05	(0.05,0.06)	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.05	(0.04,0.06)
	-25%	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.05	(0.04,0.06)	0.03	(0.02,0.04)	0.05	(0.03,0.06)	0.05	(0.03,0.06)	0.04	(0.02,0.05)	0.05	(0.03,0.06)	0.03	(0.02,0.05)
	-10%	0.04	(0.03,0.05)	0.04	(0.03,0.05)	0.05	(0.04,0.06)	0.02	(0.01,0.04)	0.04	(0.02,0.06)	0.04	(0.02,0.06)	0.03	(0.01,0.05)	0.04	(0.02,0.05)	0.02	(0.01,0.04)
	0%	0.03	(0.01,0.05)	0.03	(0.02,0.05)	0.04	(0.03,0.05)	0.01	(0.01,0.03)	0.03	(0.02,0.05)	0.03	(0.01,0.05)	0.02	(0.01,0.04)	0.03	(0.01,0.05)	0.02	(0.01,0.04)
	10%	0.02	(0.01,0.04)	0.03	(0.01,0.04)	0.03	(0.02,0.04)	0.01	(0.01,0.03)	0.03	(0.01,0.05)	0.03	(0.01,0.05)	0.02	(0.01,0.04)	0.02	(0.01,0.05)	0.01	(0.01,0.03)
	25%	0.02	(0.01,0.03)	0.02	(0.01,0.04)	0.02	(0.01,0.04)	0.01	(0.01,0.03)	0.02	(0.01,0.04)	0.02	(0.01,0.05)	0.01	(0.01,0.04)	0.02	(0.01,0.04)	0.01	(0.01,0.03)
	50%	0.01	(0.01,0.03)	0.01	(0.01,0.03)	0.01	(0.01,0.03)	0.01	(0.01,0.02)	0.02	(0.01,0.04)	0.02	(0.01,0.04)	0.01	(0.01,0.03)	0.01	(0.01,0.04)	0.01	(0.01,0.02)

APPENDIX – Results for the individual RS OMs

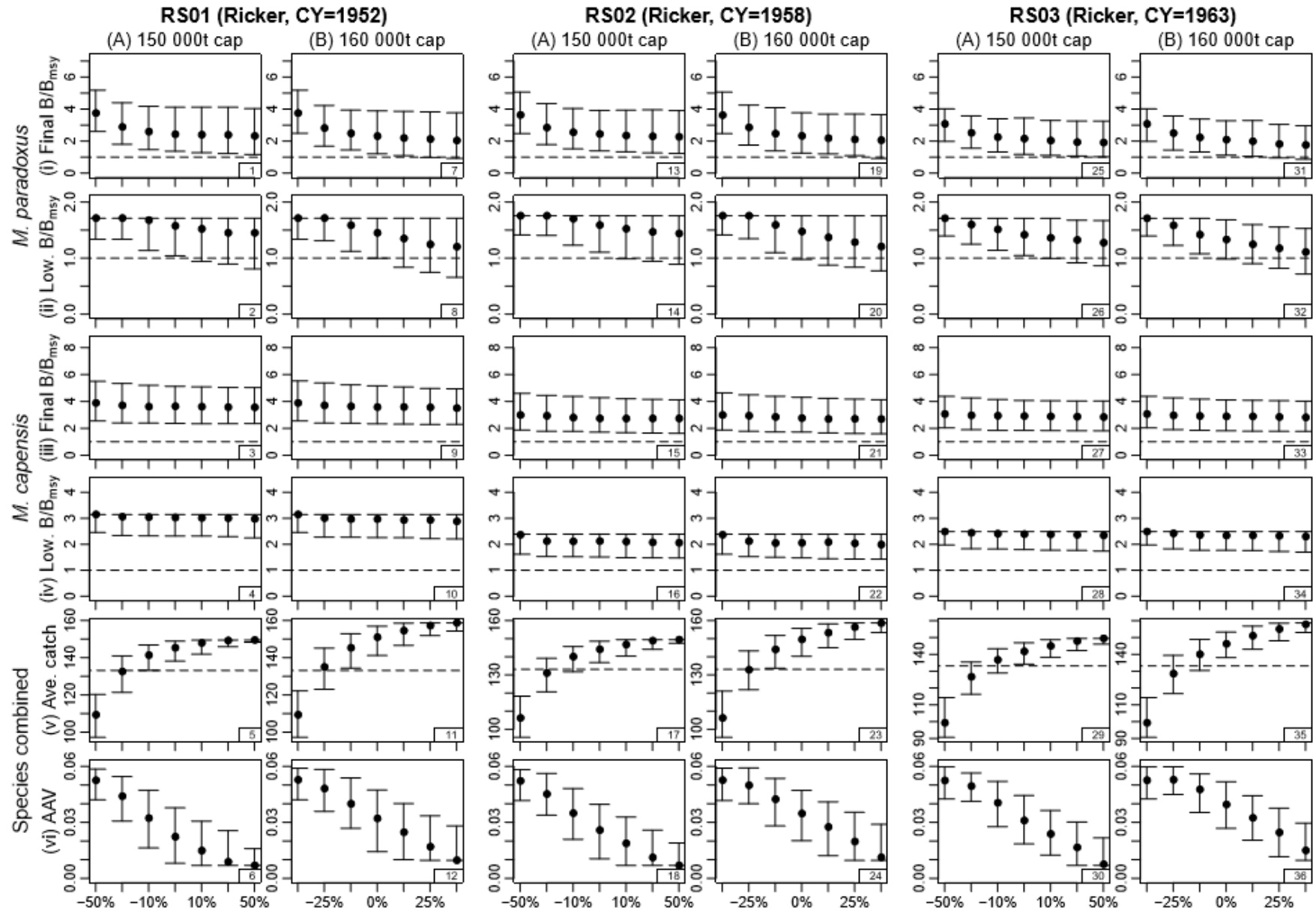


Figure A. 1(a): Zeh plots for the performance statistics for the first three RS OMs that assume a Ricker stock-recruitment relationship.

APPENDIX – Results for the individual RS OMs

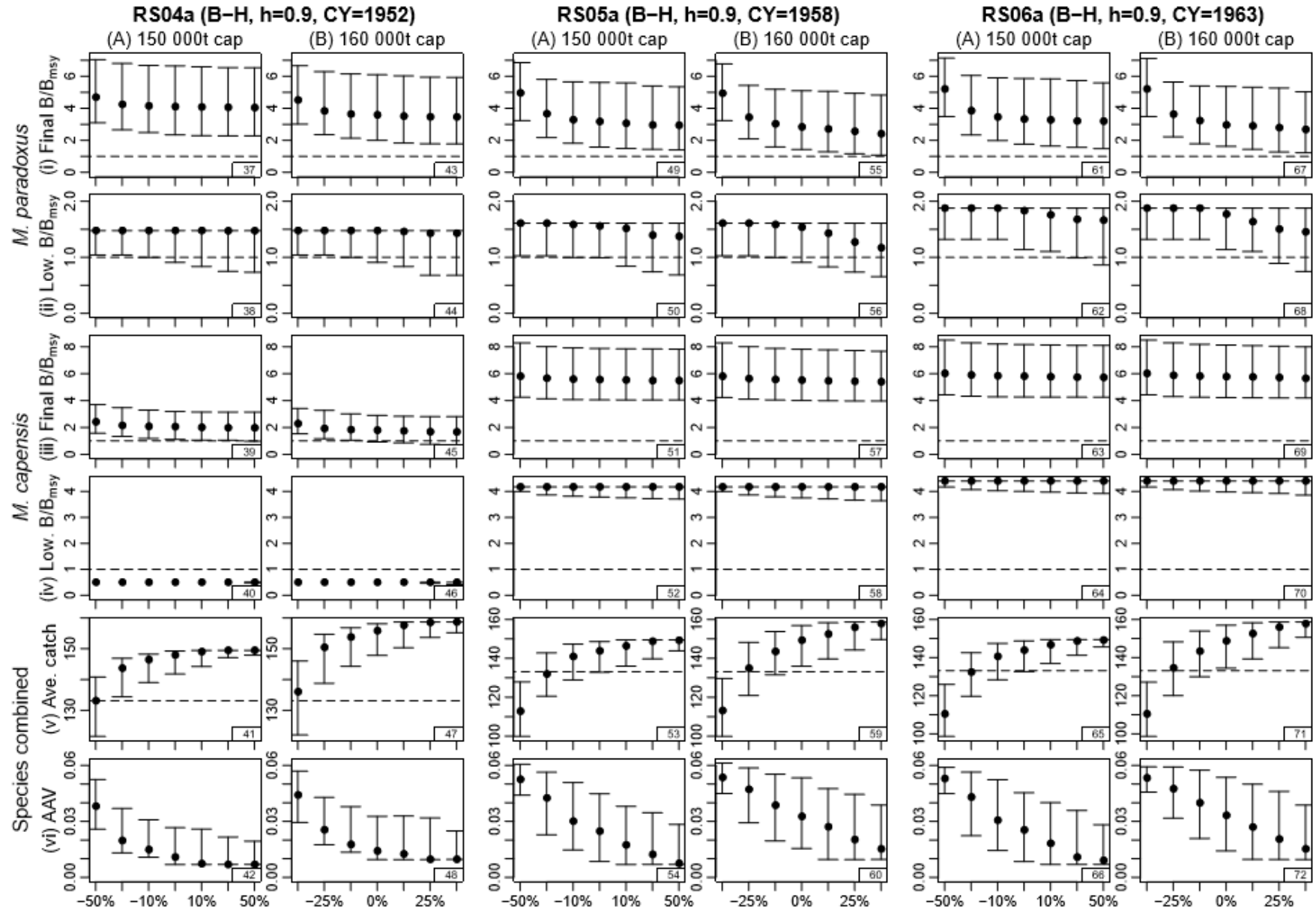


Figure A. 2(b): Zeh plots for the performance statistics for the middle three RS OMs that assume a Beverton-Holt stock-recruitment relationship with  $h$  fixed at 0.90.

APPENDIX – Results for the individual RS OMs

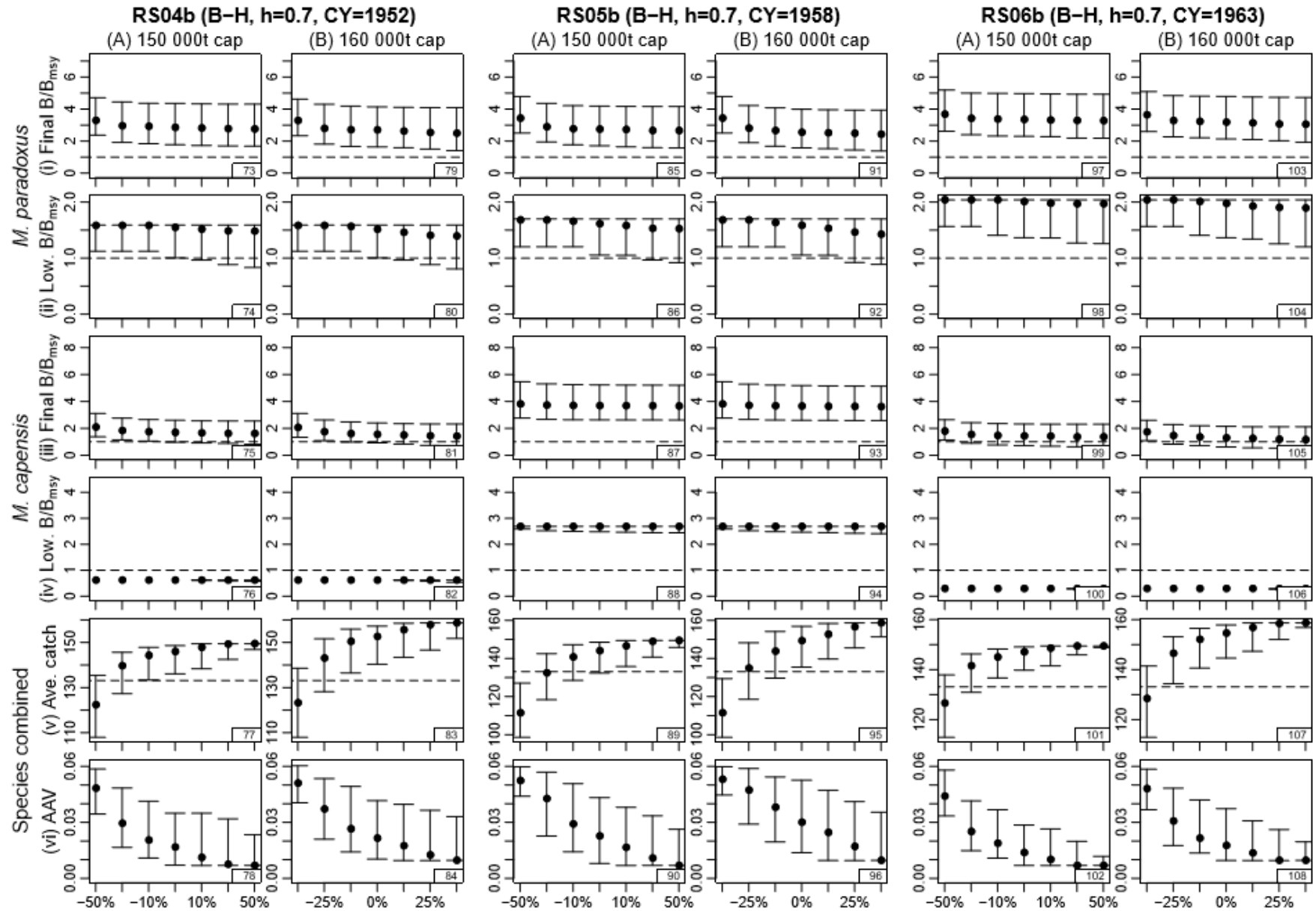


Figure A. 3(c): Zeh plots for the performance statistics for the last three RS OMs that assume a Beverton-Holt stock-recruitment relationship with  $h$  fixed at 0.70.