

Updated specifications, conditioning results and projections for the Hake OMP2018 Reference Set models

A. Ross-Gillespie and D. S Butterworth

Summary

The 2018 Reference Set of Operating Models used for testing OMP2018 was not fully endorsed by the Panel for the 2018 International Stock Assessment workshop. This document provides results for an updated RS that take account of the recommendations made by the Panel to address the reasons why they did not fully endorse these OMs, and projects them forward under the rules of OMP2018. There are some substantial changes to certain of the Beverton-Holt models (primarily as a result of finding improved minima for model fits rather than of correcting other of the issues identified by the Panel). These reflect more instances of an *M. capensis* population currently below its MSY level, but this status is not well determined in terms of the likelihood; furthermore, arguably these results are less plausible than those for the Ricker model, the fits for which have an appreciably better likelihood and reflect this population to be above its MSY level at present. This uncertainty about the status of the *M. capensis* population notwithstanding, projections for the updated Reference Set under OMP2018 indicate that the performance of this OMP remains fully adequate.

Contents

Introduction	1
The RS OMs	2
Results	2
Discussion.....	3
Acknowledgements	5
References.....	5
Appendix A: Re-parameterisation of the hake growth curves following recommendations made at IWS 2018	20
Appendix B: Details of changes that have been made to the Reference Set that was originally proposed by the Panel for the 2017 International Stock Assessment Workshop.....	25
Appendix C: Detailed assessment results for the nine Reference Set Operating Models	26
Appendix D: Restricting the survey q values for the central year OMs.....	40
Appendix E: Convergence statistics for the RC OM.....	45

Introduction

The Reference Set (RS) of Operating Models (OMs) used for testing OMP2018 (Ross-Gillespie and Butterworth, 2018) was not endorsed by the Panel for the 2018 International Stock Assessment workshop owing to concerns about model convergence and unrealistic estimates of growth curves estimated in some of the Beverton-Holt models (Cox *et al.* 2018). The Panel recommended that efforts be made to obtain a positive definite Hessian matrix for the RS OMs as this will increase the confidence that the parameter estimates correspond to the true minimum of the objective function. The Panel made the following recommendations to aid this exercise.

1. Reparameterize the growth curves from von Bertalanffy curves to two-parameter linear models, where the parameters are the lengths corresponding to two reference ages for which there are reliable data on length-at-age.
2. If necessary, fix some parameters (e.g. the observation error sigmas) and use analytical solutions for others (e.g. the survey catchability coefficients) to obtain a positive definite Hessian matrix.
3. Implement the Baranov formulation for the catch equation using the Hybrid method.

4. Increase the amount of standard assessment output that is plotted to ensure that all results conform to biological realism.

These points have all been addressed, with a few modifications. For (1), a two-straight-line growth curve has been fit, as there is evidence in the age-length key data that growth slows for older hake (see

Appendix A for more details). For (2) the survey q 's continue to be estimated in the non-linear minimisation rather than calculated analytically, as the analytic solutions often produce unrealistic results requiring penalties to be put in place.

In addition to the above, a further modification was made to the Ricker models to address the fact the BO parameter (i.e. the standard deviation for the length-at-age distribution of zero-year-old hake) for *M. paradoxus* females was being estimated at the bottom bound of 0.1. The reason for this is that the Ricker models estimate the *M. paradoxus* zero-year-olds to be very small (roughly 5-7cm at mid-year) and the standard deviation for the age-length distributions is calculated by dividing the BO parameter by the mean length-at-age; thus the BO parameter is estimated as small as possible to prevent that quotient from becoming too large. Since there are no age-length-key data for *M. paradoxus* females and only one data point for *M. paradoxus* males, the BO /mean-length quotients estimated for *M. capensis* males and females have respectively been used for *M. paradoxus* males and females. The Beverton-Holt models do not have this problem, as the size of the small *M. paradoxus* fish is estimated to be larger for these models, and the BO parameter was thus estimated for each species and gender.

The RS OMs

As was the case in 2018, there are nine models in the RS.

There are three options for the central year in the shift from predominantly *M. capensis* in the historical catch (for which no species information is available) to predominantly *M. paradoxus*.

1. Centre of the shift occurred in 1952¹.
2. Centre of the shift occurred in 1958.
3. Centre of the shift occurred in 1963.

A further three options for the form of the stock-recruitment function have been considered.

1. Modified Ricker²
2. Beverton-Holt (B-H) with h fixed at 0.90
3. Beverton-Holt (B-H) with h fixed at 0.70

Appendix B provides some further information on changes that have been made to the RS originally proposed by the Panel for the 2017 International Stock Assessment Workshop.

Each of the runs for which results have been reported in this document have undergone "jittering" whereby the starting parameters are jittered by a small percentage and the minimisation is restarted to try to ensure as best as possible that a global minimum has been found. This jittering process was repeated at least ten times for each RS OM.

Results

Conditioning results

Full and detailed assessment results for the nine RS OMs have been included in Appendix C.

Table 1a lists key parameter outputs for the nine updates RS OMs alongside the 2017 Reference Case (RC) OM. Table 1b reports the percentage by which these have changed from the 2018 RS results. Table 2a lists the values of the negative log-likelihood components in absolute terms, while Table 2b reports the difference in negative log-likelihood values for each model relative to the updated 2019 Reference Case OM (RS02; the model with the best negative log-likelihood).

¹ The central years tested for OMP2014 were 1950, 1958 and 1965. It was found, however, that the fits to the GLM CPUE data became markedly worse when the central year was later than 1963. Hence 1963 was taken as the third option instead of 1965, and 1950 was similarly adjusted to 1952 to maintain the same symmetry as for the previous set.

² The modified Ricker equation is given by $R_y^g = \alpha B_y^{\mathcal{Q},sp} \exp(-\beta (B_y^{\mathcal{Q},sp})^\gamma) e^{(\epsilon_y - \sigma_R^2/2)}$ with $\alpha = R_0 \exp(\beta (K^{\mathcal{Q},sp})^\gamma) / K^{\mathcal{Q},sp}$

$$\text{and } \beta = \frac{\ln(5h)}{(K^{\mathcal{Q},sp})^\gamma (1 - 5^{-\gamma})}.$$

Figure 1 shows the female spawning biomass trajectories for all nine models in blue (solid lines for Ricker models, dashed lines for Beverton-Holt models with $h=0.90$ and dotted lines for Beverton-Holt models with $h=0.70$), contrasted against the Oct 2017 Reference Case model in black. Figure 2 includes the female spawning biomass trajectories for the nine RS models only, showing the median and range for these models. Figure 3a and b also show the spawning biomass trajectories, but with these broken into smaller groups.

Figure 4a and b show the recruitment plots for *M. paradoxus* and *M. capensis* respectively, while Figure 5 shows the fits to the CPUE data.

Positive definite Hessians were obtained for all three Ricker models after the *M. capensis* h parameter (which is estimated at the upper bound of 2) was fixed. Convergence statistics for the Reference Case RS02 OM are reported in Appendix E, and provide no indication that convergence has not been achieved. Note that the parameters with the largest gradients and standard deviations correspond to commercial selectivity parameters, suggesting that some additional work might be pursued towards optimising these functions (for example one-sided selectivity functions that remain flat for older fish, such as the *M. paradoxus* South Coast offshore selectivities, do not need to be parameterised by a double normal function). The matter has, however, not been pursued further at this point in time given that a positive definite Hessian had been achieved. Positive definite Hessians were not obtained immediately for the Beverton-Holt models, but there was insufficient time to explore this matter further for these models.

Projection results

Figure 6 and Figure 7 compare the projections of the original and updated RS under OMP2018: Figure 6 shows the trajectories and probability envelopes of biomass, exploitable biomass, TAC, effort and CPUE, while Figure 7 shows Zeh plots of the standard performance statistics that have been reported previously. Figure 9a and b repeat the trajectories of Figure 6 for the updated RS only and include some worm plots to illustrate individual possible future scenarios.

Discussion

Conditioning results

The most substantial change with the updated Reference Sets is that all the Beverton-Holt OMs estimate the *M. capensis* population to be depleted below B_{MSY} , whereas the old RS had a mixture of results for these Beverton-Holt OMs with three OMs estimating a pessimistic status for *M. capensis* and three an optimistic status. This is likely because: (a) greater time was invested for the updated RS to ensure as best as possible that a true minimum was found, and (b) a substantial update to the $h=0.70$ OMs occurred as a result of the correction made to the growth curves (the issue identified by the IWS Panel).

One possible point of contention, particularly regarding the Beverton-Holt models, is that the estimates of the survey catchability coefficients q are hardly seem realistic (for example the 1958 Beverton-Holt run with $h=0.90$ estimates that the autumn survey *M. capensis* biomass estimates are six times the actual exploitable biomass available to the survey – these q values are reported in Table C. 1a-c of Appendix C). In order to address this, variants on the central year OMs (i.e. 1958 for Ricker, Beverton-Holt with $h=0.90$ and $h=0.70$) were reconditioned with restrictions on q in place. More details about this are reported in Appendix D, but a brief summary is included here. As would be expected, in all cases the negative log-likelihoods are worse when bounds are placed on the q values. In some cases, contrary to expectation, reduction of the q values does not result in an appreciable change to the estimated biomass in absolute terms. The reason for this is that the model ameliorates the impact of the restriction by adjusting the selectivity functions (in particular the summer survey selectivities) in a direction that relatively more older fish are exploited by the surveys, i.e. an increase in exploitable biomass and a decrease in cryptic biomass. In other cases, the results switched to solutions where the *M. capensis* population is much less depleted. This reflects an indication of a multi-modal likelihood surface – for most of the Beverton-Holt models there appear to be at least two modes, one with an appreciably depleted *M. capensis* population and one where this is estimated to be less depleted (and well above B_{MSY}). While the mode corresponding to the more depleted status generally has a somewhat better negative log-likelihood, instances have occurred during various stages of the RS conditioning where the likelihoods were very similar,

suggesting that the *M. capensis* depletion level is not very well-defined. This multi-modality is also largely responsible for the biggest differences between the original 2018 RS and the updated set, in that the Beverton-Holt OMs in the original RS that estimated a less depleted *M. capensis* population likely corresponded to alternative modes with slightly worse likelihoods.

It should be noted, however, that the negative log-likelihood for the Beverton-Holt OMs are substantially worse than for the Ricker OMs (17 to 37 points worse) for which the *M. capensis* population is estimated to be well above B_{MSY} , and for which the estimation of the *M. capensis* population status appears to be more stable.

The table below lists the original discussion points from MARAM/IWS/DEC2018/Hake/P3 in the left column, while the right column reports if and how these comments have changed for the updated RS.

Observations made for the 2018 RS in MARAM/IWS/DEC2018/Hake/P3.	Updated 2019 RS
Current depletion for <i>M. paradoxus</i> ranges from 0.26 to 0.39 for (generalised) Ricker, and from 0.15 to 0.41 for Beverton Holt stock-recruitment models.	Current depletion for <i>M. paradoxus</i> ranges from 0.24 to 0.36 for (generalised) Ricker, and from 0.15 to 0.39 for Beverton Holt stock-recruitment models.
Current depletion for <i>M. capensis</i> ranges from 0.68 to 0.74 for Ricker, and from 0.08 to 0.76 for Beverton-Holt models (note the very wide range in this case).	Current depletion for <i>M. capensis</i> ranges from 0.68 to 0.74 for Ricker, and from 0.03 to 0.16 for Beverton-Holt models.
The Beverton-Holt based OMs generally reflect worse fits than the Ricker-based OMs in terms of the negative log-likelihood, and many of the Beverton-Holt models show little effect of changes in spawning biomass on expected recruitment.	This is still the case, except that all of the Beverton-Holt models show little effect of changes in spawning biomass on expected recruitment.
Beverton-Holt models with $h=0.9$ result in B_{MSY}/K^{SP} estimates that are very low (~10% for <i>M. paradoxus</i>). Fixing h at 0.7 has the effect of increasing these estimates (to ~20%). Beverton-Holt fits with $h=0.9$ are generally better in terms of the total negative log-likelihood.	This is still the case, barring the RS06a OM where the negative log-likelihood is worse than for the $h=0.70$ OMs. It is possible that the results for this OM reflect a local minimum, but despite extensive efforts and jittering a better minimum has not been found to date.
<i>M. paradoxus</i> is consistently estimated to be above B_{MSY} . <i>M. capensis</i> is above B_{MSY} except for the runs Beverton-Holt that produce a very flat biomass trajectory where biomass has little impact on recruitment.	This is still the case for <i>M. paradoxus</i> , but in the updated RS <i>M. capensis</i> is estimated to be below B_{MSY} for all the Beverton-Holt OMs.
Models RS02 (the Ricker model with central year 1958) and RS03 (the Ricker model with central year 1963) are the best in terms of the total negative log-likelihood.	This is still the case.

Projection results

Despite the difference in the Beverton-Holt results between the original and updated Reference Sets, the performance of OMP2018 remains fully adequate and comparable with the performance evaluated using the old RS. As might be expected, the upper bound and median estimates of the *M. capensis* biomass trajectories are much lower for the updated RS, but the lower bound (which is the important aspect in terms of possible conservation concerns) is similar to what was estimated before. More importantly, both the median biomass trajectories and the lower bounds of the probability envelopes are projected to increase steadily for management under OMP2018. Projections for *M. paradoxus* are slightly more optimistic with the updated RS, and consequently projected catch, effort and CPUE are slightly more favourable than for the old 2018 RS.

In general, the results provide no evidence that OMP2018 would not perform adequately despite the revision of the Reference Set. This also holds true for projections for the OMs with restricted survey q values (see Appendix

D). A selection of robustness tests still needs to be re-computed for the updated RS - priority will be given to those testing the impact of future recruitment failure and other robustness tests that previously indicated greater concern for the conservation of the hake resource (including those related to changes to the vessels used for, or absence of some future surveys).

Acknowledgements

Computations were performed using facilities provided by the University of Cape Town's ICTS High Performance Computing team: hpc.uct.ac.za.

References

- Cox, S., Howell, D. and Punt, A.E. 2017. International Review Panel Report for the 2017 International Fisheries Stock Assessment Workshop, 27 November – 1 December 2017, University of Cape Town.
- Cox, S., Gaichas. S., Haddon, M. and Punt, A.E. 2018. International Review Panel Report for the 2017 International Fisheries Stock Assessment Workshop, 26-30 November 2018, University of Cape Town.
- Ross-Gillespie, A. and Butterworth, D.S. 2018. Specification and Conditioning of the Hake OMP2018 Reference Set models. Paper MARAM/IWS/2018/Hake/P3rev submitted to the Panel for the International Stock Assessment Workshop, Cape Town, November 2018.

Table 1a: Key parameter estimates for the updated RS models (biomass units are thousand tons). Cases where the current spawning biomass is below its MSY value are highlighted in yellow.

Model name	Central Year	Stock Recruit	<i>M. paradoxus</i>								<i>M. capensis</i>							
			K^{sp}	B_{MSY}^{sp}	B_{2017}^{sp}	B_{2017}^{tot}	B_{2017}^{sp}/K^{sp}	$B_{2017}^{sp}/B_{MSY}^{sp}$	B_{MSY}^{sp}/K^{sp}	MSY	K^{sp}	B_{MSY}^{sp}	B_{2017}^{sp}	B_{2017}^{tot}	B_{2017}^{sp}/K^{sp}	$B_{2017}^{sp}/B_{MSY}^{sp}$	B_{MSY}^{sp}/K^{sp}	MSY
(0) Oct 2017	1958	Ricker	515	115	127	245	0.25	1.11	0.22	137	196	63	141	334	0.72	2.23	0.32	81
(1) RS01	1952	Ricker	306	49	74	172	0.24	1.52	0.16	143	379	88	268	587	0.71	3.04	0.23	110
(2) RS02	1958		294	51	78	181	0.27	1.55	0.17	144	272	81	186	415	0.68	2.30	0.30	84
(3) RS03	1963		245	58	89	201	0.36	1.53	0.24	146	437	134	323	701	0.74	2.41	0.31	106
(4) RS04a	1952	Beverton-Holt (h=0.9)	443	42	65	164	0.15	1.54	0.10	142	410	80	31	90	0.08	0.39	0.19	54
(5) RS05a	1958		435	42	68	172	0.16	1.65	0.10	141	483	97	24	75	0.05	0.25	0.20	63
(6) RS06a	1963		457	44	86	206	0.19	1.96	0.10	144	584	121	18	60	0.03	0.15	0.21	83
(7) RS04b	1952	Beverton-Holt (h=0.7)	751	170	233	474	0.31	1.37	0.23	122	514	146	82	195	0.16	0.56	0.28	48
(8) RS05b	1958		739	167	222	456	0.30	1.33	0.23	121	579	166	66	164	0.11	0.40	0.29	55
(9) RS06b	1963		820	186	321	658	0.39	1.73	0.23	134	718	206	55	140	0.08	0.27	0.29	70

Table 1b: Percentage difference between estimates reported in Table 1a for the updated RS and Table 1a of the 2018 RS in MARAM/IWS/DEC2018/Hake/P3. A negative value indicates that the estimates for the updated RS are lower than previously.

Model name	Central Year	Stock Recruit	<i>M. paradoxus</i>								<i>M. capensis</i>							
			K^{sp}	B_{MSY}^{sp}	B_{2017}^{sp}	B_{2017}^{tot}	B_{2017}^{sp}/K^{sp}	$B_{2017}^{sp}/B_{MSY}^{sp}$	B_{MSY}^{sp}/K^{sp}	MSY	K^{sp}	B_{MSY}^{sp}	B_{2017}^{sp}	B_{2017}^{tot}	B_{2017}^{sp}/K^{sp}	$B_{2017}^{sp}/B_{MSY}^{sp}$	B_{MSY}^{sp}/K^{sp}	MSY
(0) Oct 2017	1958	Ricker	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(1) RS01	1952	Ricker	-10	-8	-16	-12	-7	-8	-1	-1	-8	-8	-9	-9	0	-1	1	-2
(2) RS02	1958		-8	-8	-16	-12	-8	-7	1	0	-6	-6	-6	-7	0	0	-1	0
(3) RS03	1963		-8	-8	-14	-10	-7	-6	-1	0	-6	-6	-6	-7	0	0	-1	0
(4) RS04a	1952	Beverton-Holt (h=0.9)	-15	-16	-16	-9	-2	0	-5	1	-2	-5	-11	-13	-5	-7	-3	2
(5) RS05a	1958		-17	-18	-18	-11	-2	0	-4	1	-60	-55	-97	-96	-93	-94	12	-53
(6) RS06a	1963		-15	-14	-10	-6	4	6	-4	1	-62	-56	-98	-98	-96	-97	16	-51
(7) RS04b	1952	Beverton-Holt (h=0.7)	875	963	795	187	-9	-18	13	-20	-4	-5	-9	-10	-7	-4	-2	1
(8) RS05b	1958		802	884	641	157	-17	-25	13	-22	-60	-58	-94	-93	-84	-85	2	-54
(9) RS06b	1963		832	932	791	205	-5	-17	13	-19	-4	-5	-7	-8	-5	-2	-1	1

Table 2a: Negative log-likelihood components are shown for the Reference Case from October 2017 (a Ricker model) and updated RS models. Grey italic text and a star have been used to show values that are not comparable between the Oct 2017 model and the updated RS, as a result of the treatment of the catch-at-length data. The Reference Case of the updated RS remains RS02 (the OM corresponding to the best negative log-likelihood) and has been highlighted by using bold text. For the updated RS OMs (which use the Baranov formulation for the catch equation), the penalty column corresponds to the catch penalty for when the model-predicted catches do not match the observed catches perfectly. The total in the last column excludes this penalty.

Run	GLM CPUE	ICSEAF CPUE	Survey abund.	Comm. CAL	Survey CAL	Recruit. resid.	ALKs	Penalties	Total (w/o pen.)
<i>Oct 2017</i>	<i>-191.43</i>	<i>-40.76</i>	<i>-35.11</i>	<i>-2441.14*</i>	<i>-2678.00*</i>	<i>10.39</i>	<i>124.53</i>	<i>0.00*</i>	<i>-5251.52*</i>
RS01 (1952, Ricker)	-202.14	-37.38	-34.63	-1507.03	-1503.31	8.82	123.82	0.05	-3151.85
RS02 (1958, Ricker)	-203.88	-37.74	-34.69	-1508.45	-1502.68	9.37	123.55	0.06	-3154.52
RS03 (1963, Ricker)	-203.40	-36.44	-34.50	-1506.53	-1503.54	8.46	123.00	0.17	-3152.96
RS04a (1952, B-H, h=0.90)	-184.37	-40.61	-33.42	-1509.62	-1505.34	12.53	123.40	0.01	-3137.45
RS05a (1958, B-H, h=0.90)	-180.99	-40.19	-33.23	-1508.94	-1504.12	12.68	124.12	0.02	-3130.66
RS06a (1963, B-H, h=0.90)	-175.72	-38.26	-31.97	-1505.20	-1502.64	10.66	125.82	0.61	-3117.33
RS04b (1952, B-H, h=0.70)	-180.26	-26.16	-32.05	-1509.08	-1503.93	8.52	122.20	0.01	-3120.77
RS05b (1958, B-H, h=0.70)	-179.00	-28.72	-31.80	-1510.69	-1503.82	8.58	122.00	0.24	-3123.43
RS06b (1963, B-H, h=0.70)	-179.84	-33.66	-31.58	-1511.38	-1503.35	8.47	121.98	0.32	-3129.36

Table 2b: Negative log-likelihoods expressed relative to the updated Reference Case OM (RS02, highlighted by using bold text in the table). Cells highlighted in grey indicate a worse negative log-likelihood.

Run	GLM CPUE	ICSEAF CPUE	Survey abund.	Comm. CAL	Survey CAL	Recruit. resid.	ALKs	Penalties	Total (w/o pen.)
<i>Oct 2017</i>	<i>12.45</i>	<i>-3.02</i>	<i>-0.42</i>	<i>-932.69*</i>	<i>-1175.32*</i>	<i>1.02</i>	<i>0.98</i>	<i>-0.06*</i>	<i>-2097.00*</i>
RS01 (1952, Ricker)	1.74	0.35	0.06	1.43	-0.63	-0.55	0.27	-0.02	2.68
RS02 (1958, Ricker)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RS03 (1963, Ricker)	0.48	1.30	0.19	1.92	-0.86	-0.91	-0.55	0.10	1.57
RS04a (1952, B-H, h=0.90)	19.51	-2.87	1.27	-1.17	-2.66	3.16	-0.15	-0.06	17.08
RS05a (1958, B-H, h=0.90)	22.89	-2.45	1.46	-0.48	-1.44	3.31	0.58	-0.05	23.87
RS06a (1963, B-H, h=0.90)	28.16	-0.53	2.72	3.25	0.04	1.29	2.27	0.55	37.19
RS04b (1952, B-H, h=0.70)	23.62	11.57	2.63	-0.62	-1.25	-0.84	-1.35	-0.05	33.75
RS05b (1958, B-H, h=0.70)	24.88	9.02	2.89	-2.23	-1.13	-0.79	-1.54	0.18	31.09
RS06b (1963, B-H, h=0.70)	24.04	4.08	3.11	-2.93	-0.67	-0.90	-1.56	0.26	25.16

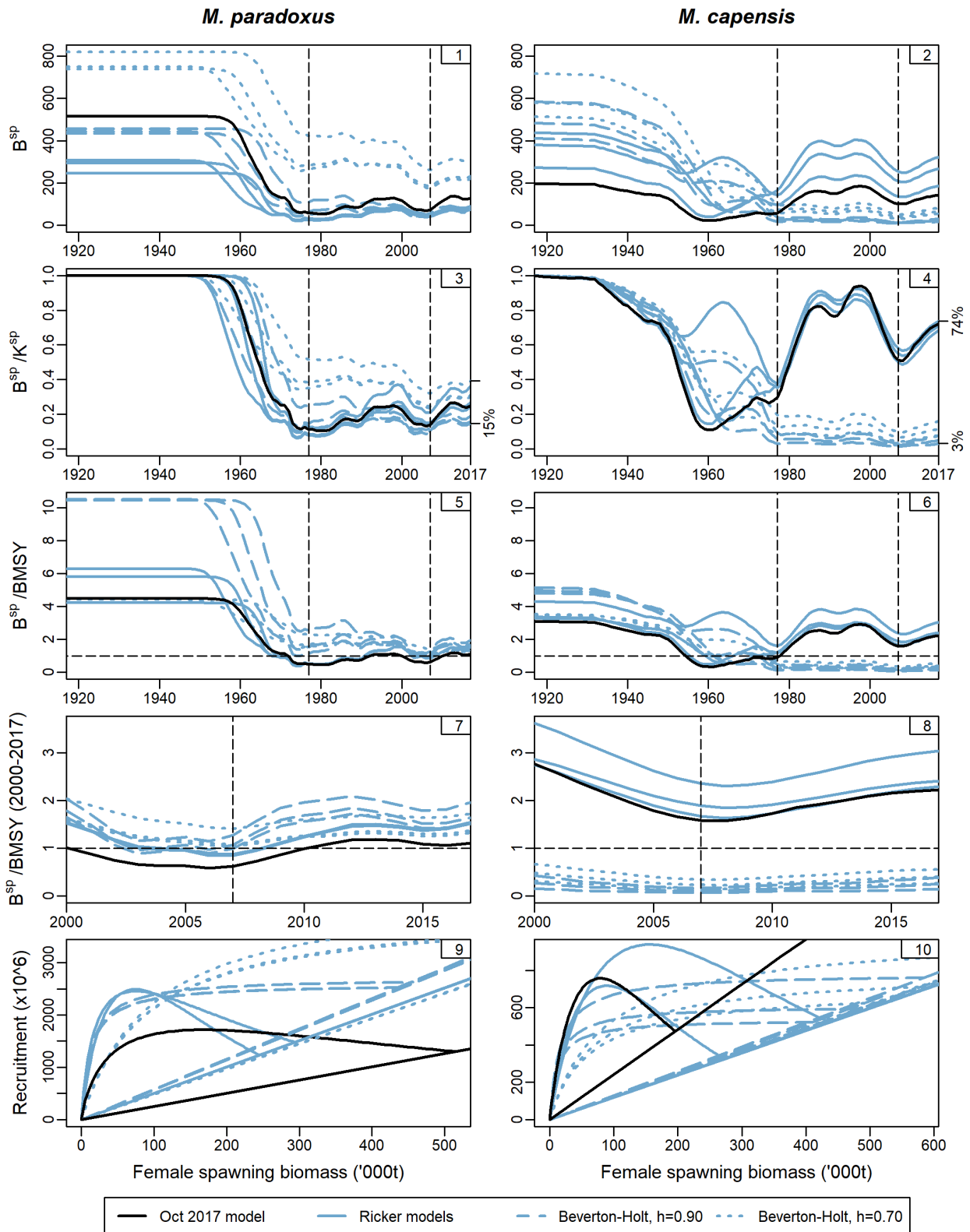


Figure 1: Female spawning biomass trajectories are shown for all the nine models reported on here with the purpose of comparing the 2017 model (black curves) with the 2019 RS models (blue curves). Recruitment is also shown plotted against spawning biomass.

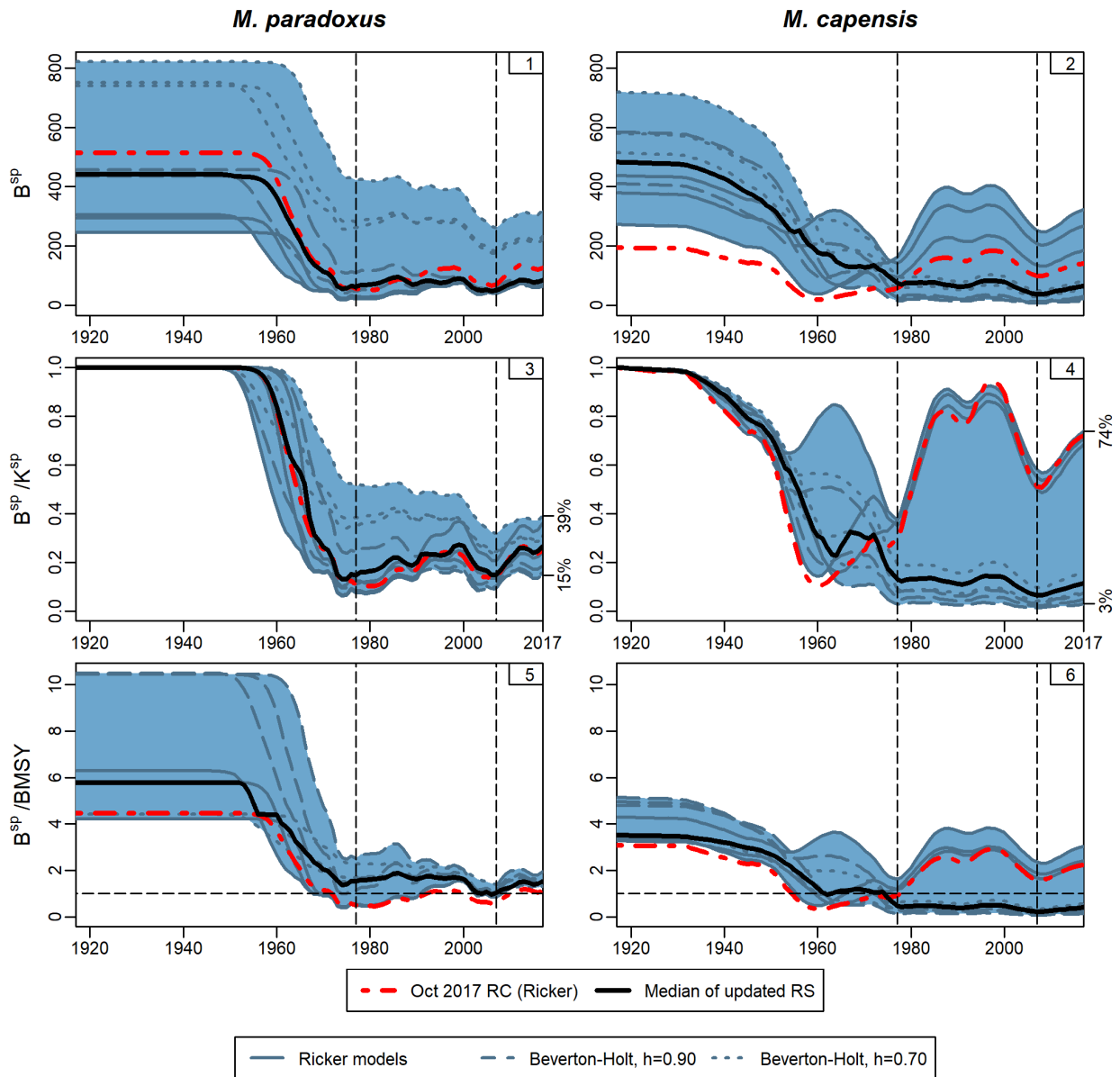


Figure 2: Female spawning biomass trajectories are shown for all the nine updated RS models (blue curves) with the purpose of comparing the updated RS with the 2017 Reference Case Ricker model (red dashed curves). The black solid line shows the **median** across the nine models for each year and the blue shaded area shows the range (min to max).

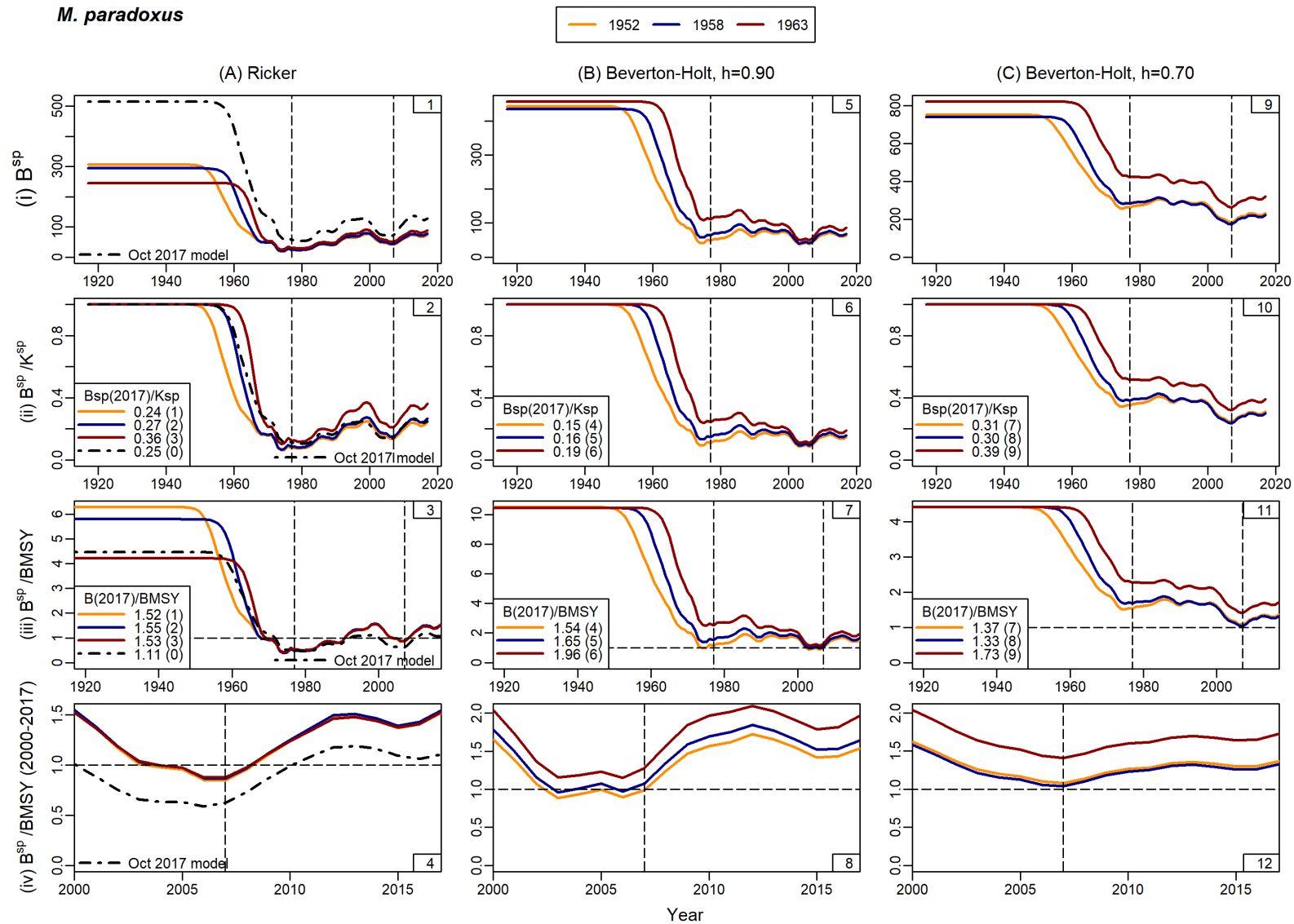


Figure 3a: Female spawning biomass trajectories are shown for *M. paradoxus* for smaller groupings of models. In the plots, yellow lines have been used for the models with the central year of shift occurring in 1952, blue lines for the 1958 models and red lines for the 1963 models. The corresponding Oct 2017 model has been included in the first column with the RS Ricker models (black dash-dot lines).

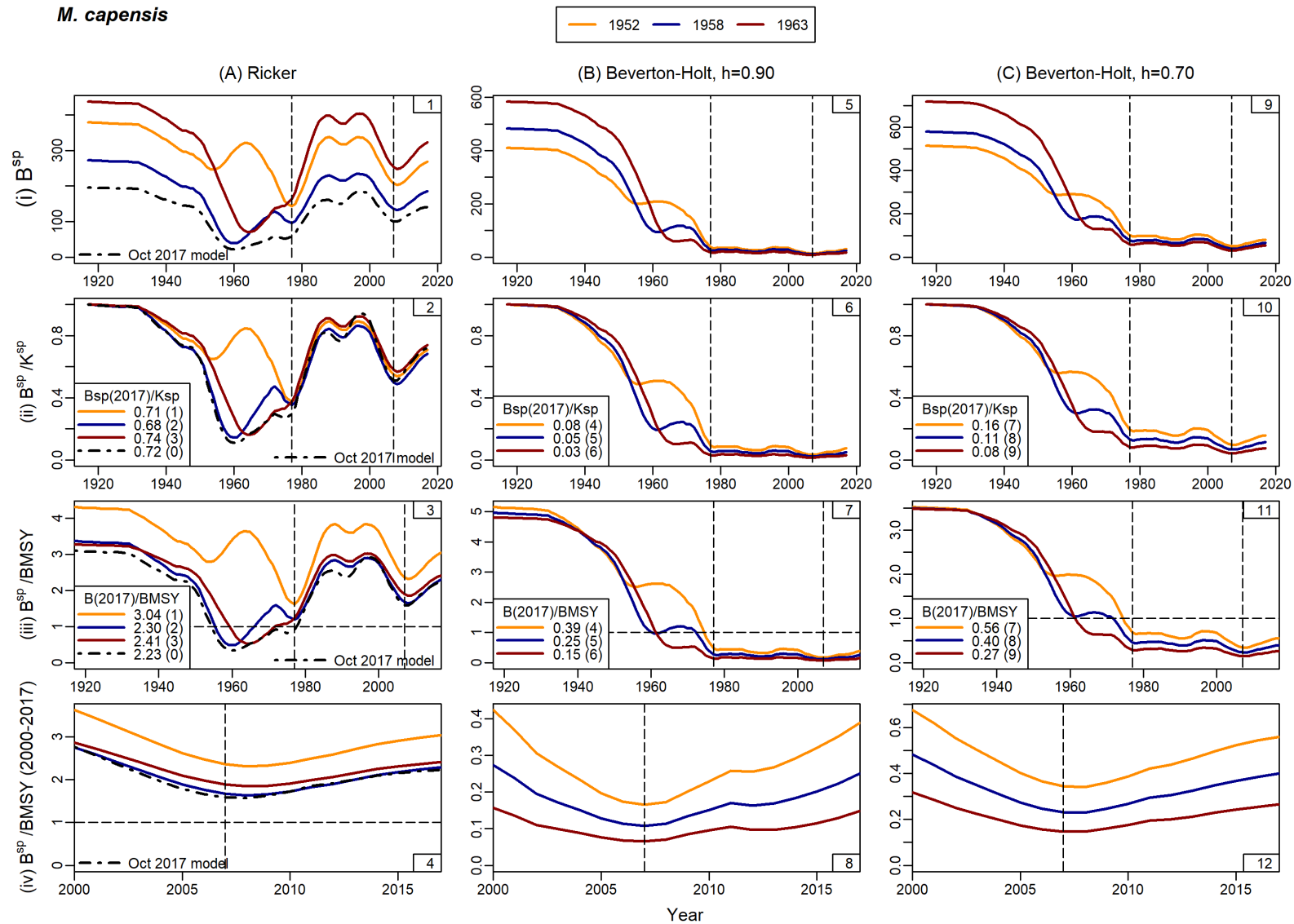


Figure 3b: Female spawning biomass trajectories are shown for *M. capensis* for the smaller groupings of models (as in Figure 3a).

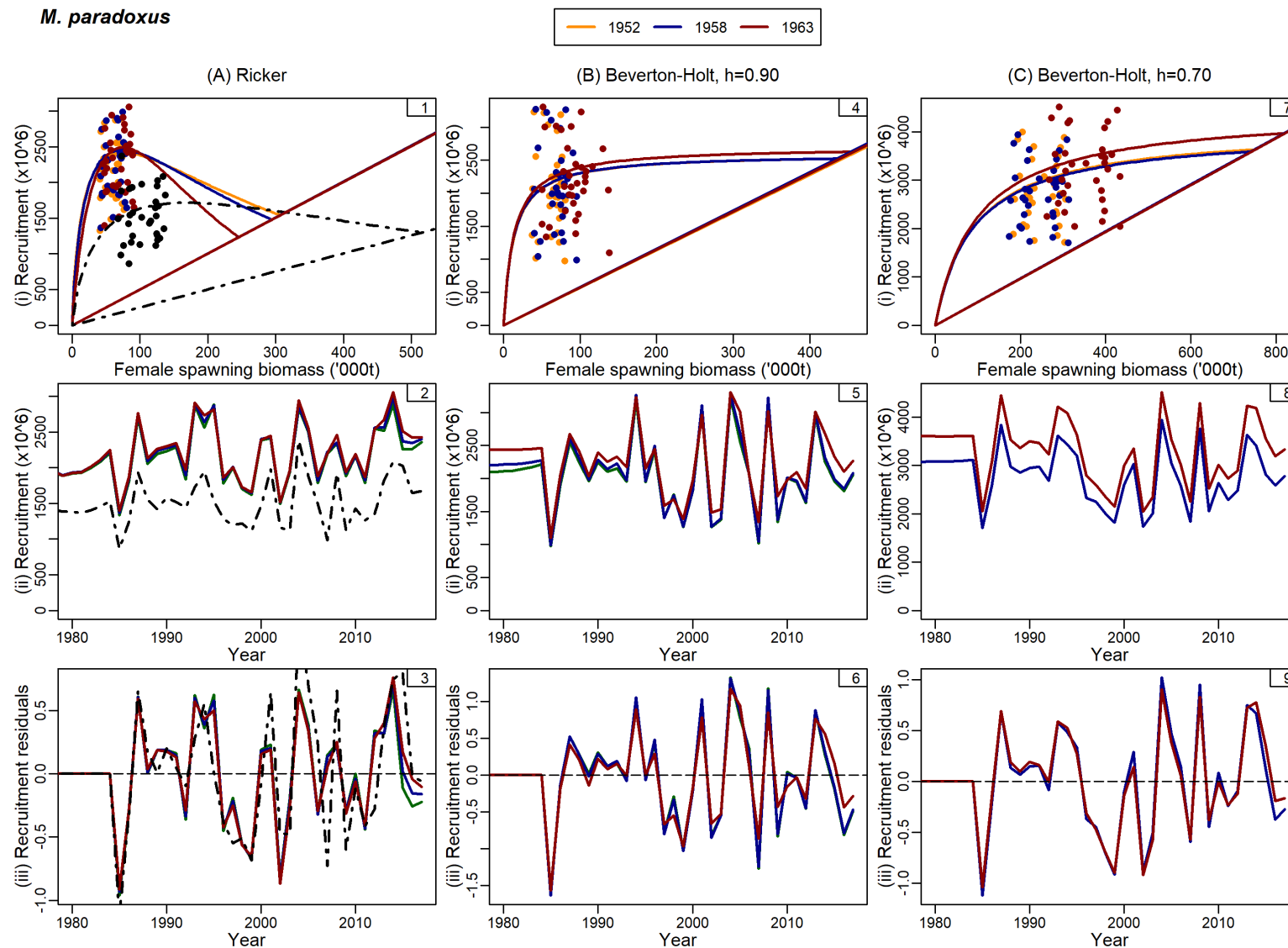


Figure 4a: Stock-recruitment plots together with recruitment time series and residuals about the stock-recruitment curves are shown for *M. paradoxus* for the smaller groupings of models. In the interest of clarity, the “data” are shown for a selection of models only. The straight lines through the origin in the stock-recruitment plots are replacement lines.

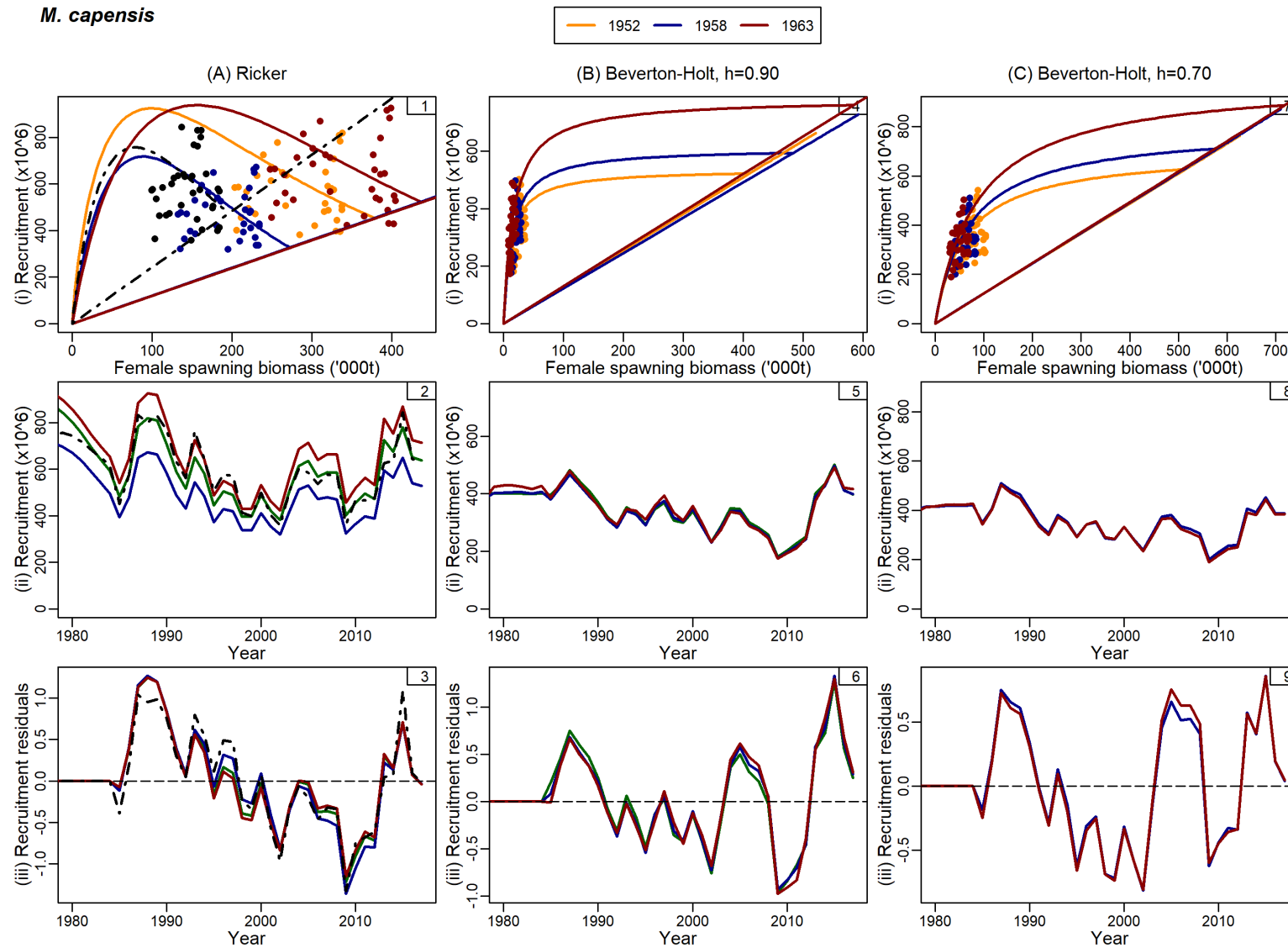


Figure 4b: Stock recruitment plots are shown for *M. capensis* for the smaller groupings of models (as in Figure 4a).

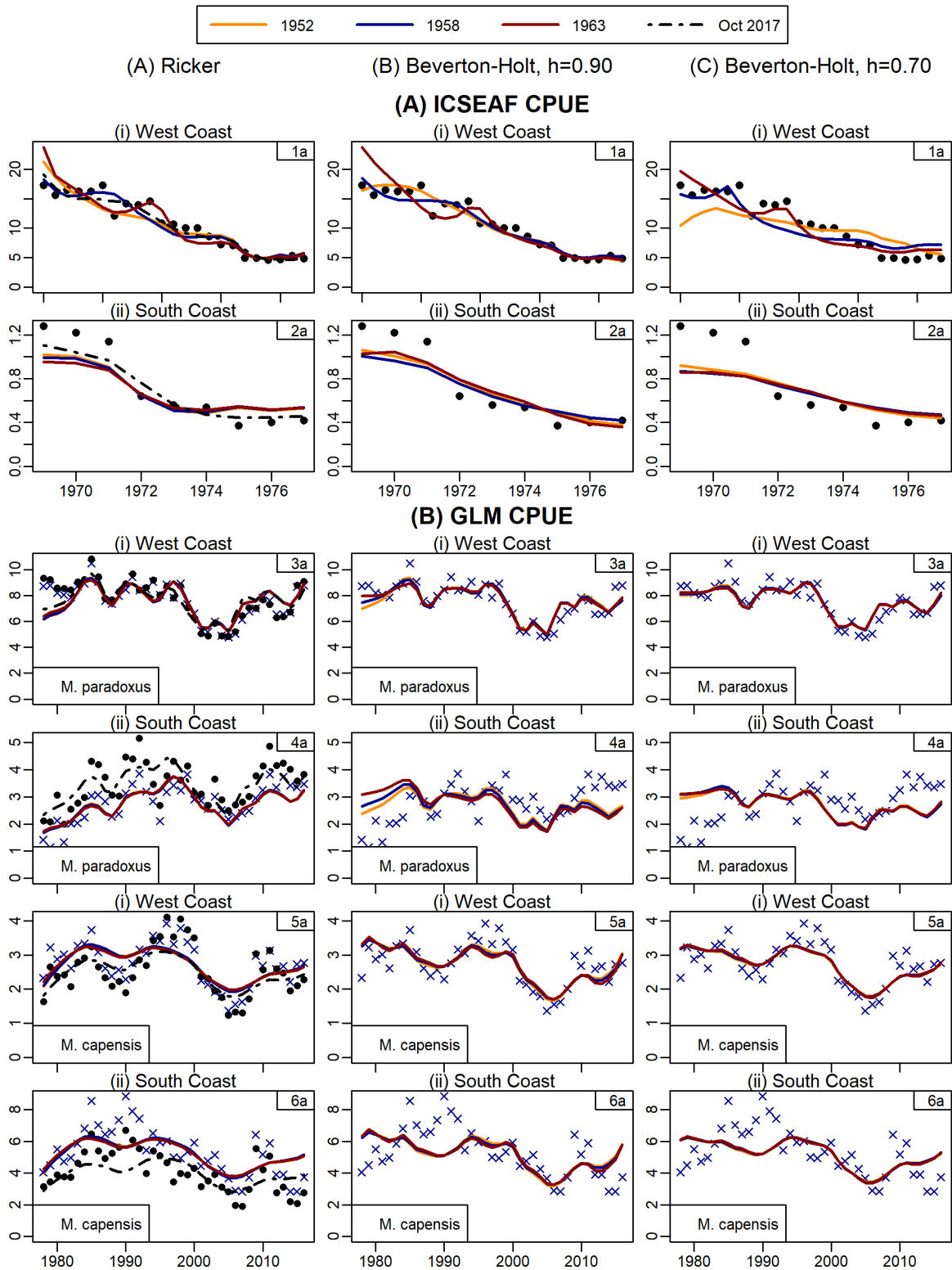


Figure 5: Fits to the ICSEAF and commercial CPUE data. All three columns show the new data for the GLM CPUE. The first column, which shows the Ricker models including the Oct 2017 model, additionally indicates the old data with the black circles.

Equal weighting across Whole RS

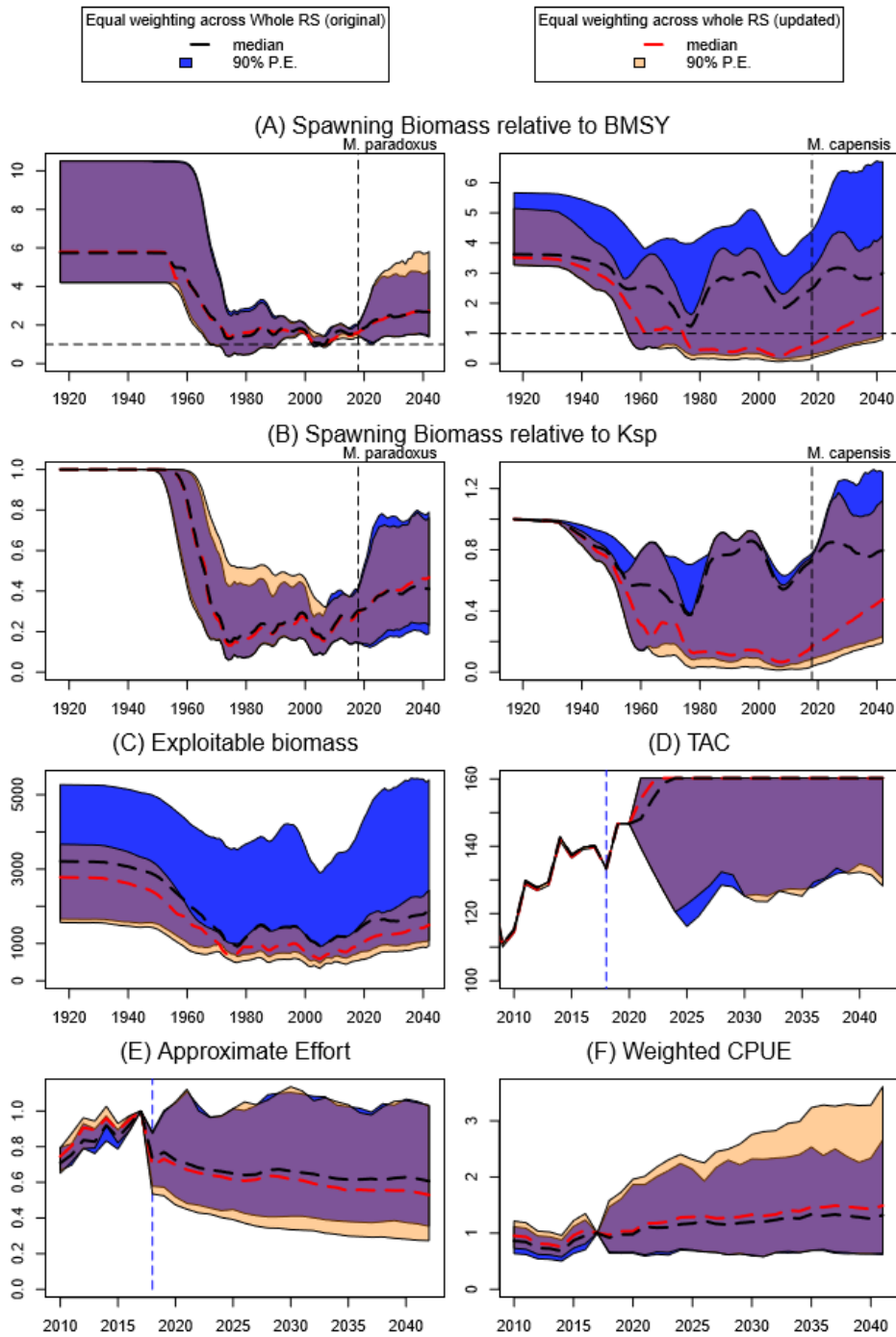


Figure 6: Comparison of median trajectories and 90% probability envelopes (calculated as an equal weighting across the nine RS OMs) for projections under OMP2018 for the old 2018 and the updated RS. The median and 90% probability envelope for the original RS are shown respectively by black dashed lines and blue shading, while the updated RS is shown by red dashed lines and orange shading. The purple areas mark the overlap between the intervals for the two Reference Sets.

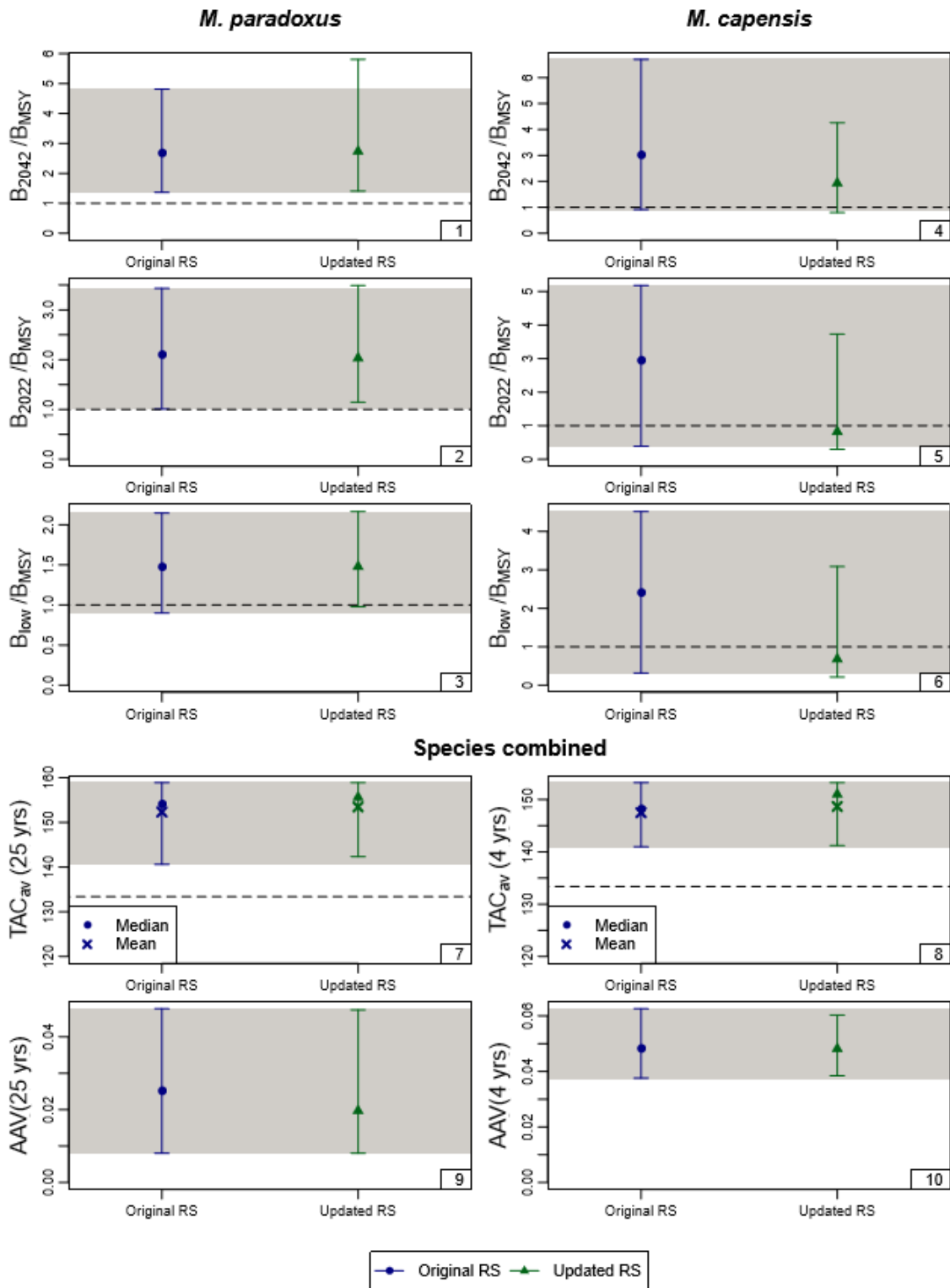


Figure 7: Zeh plots comparing the performance statistics for the old 2018 RS projected under OMP2018 with the projections for the updated RS. The statistics are B^{sp}/B_{MSY} for 2042 and 2022 (i.e. at the planned end of OMP2018 application), $B^{sp}(low)/B_{MSY}$ (the lowest value of this statistic in the projection period to 2042), TAC_{av} (the average catch over the projection period (25 years) and over the next four years) and AAV (the average inter-annual proportional change in catch over the projection period (25 years) and over the next four years). Medians and 90% probability intervals are shown. For TAC_{av} , the means are also shown, by crosses.

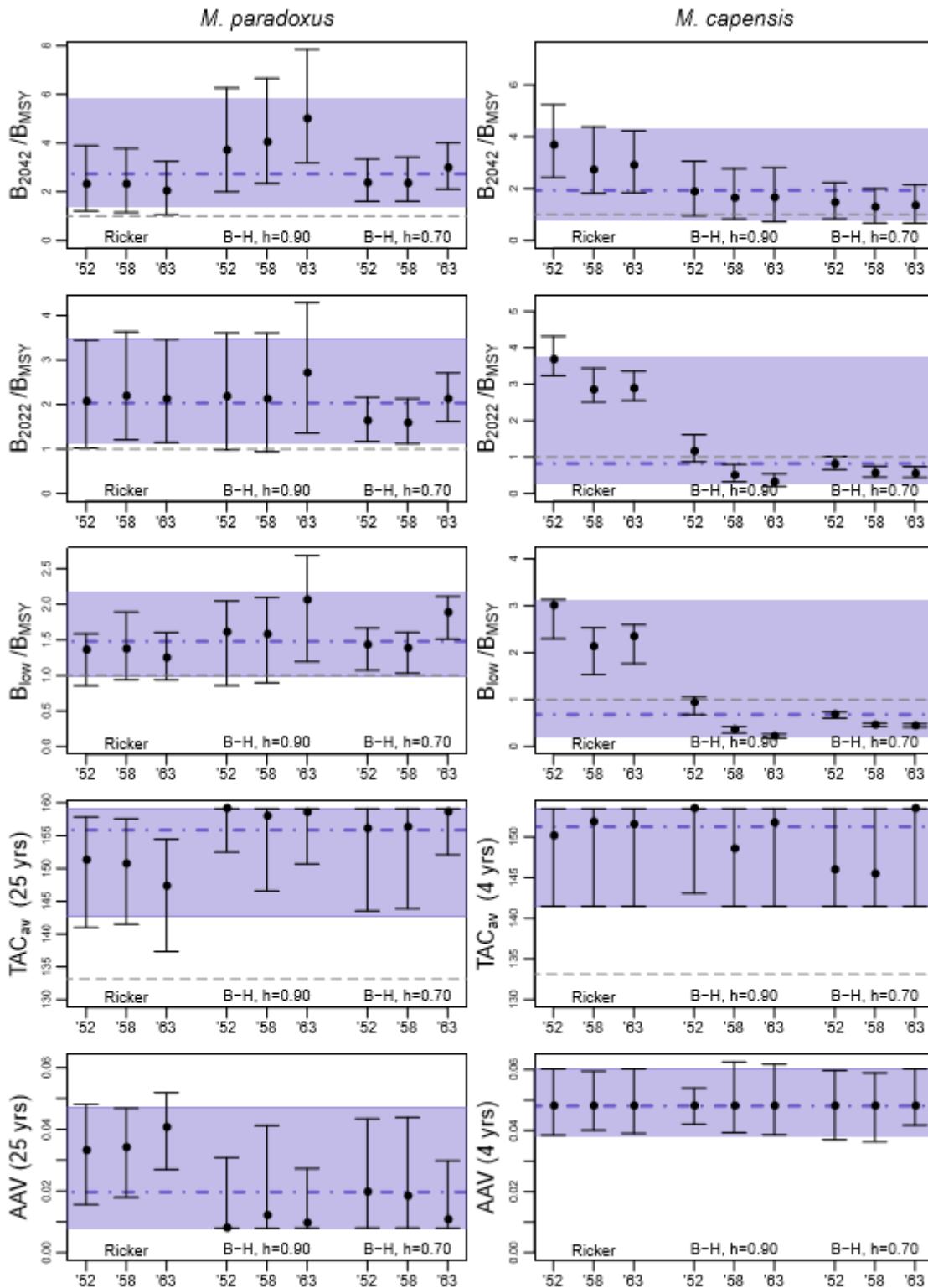


Figure 8: Zeh plots comparing the individual performance statistics across the nine OMs in the updated RS. The median and 90% probability intervals for the equal weighting across the RS are shown by the blue dash-dot lines and shaded areas.

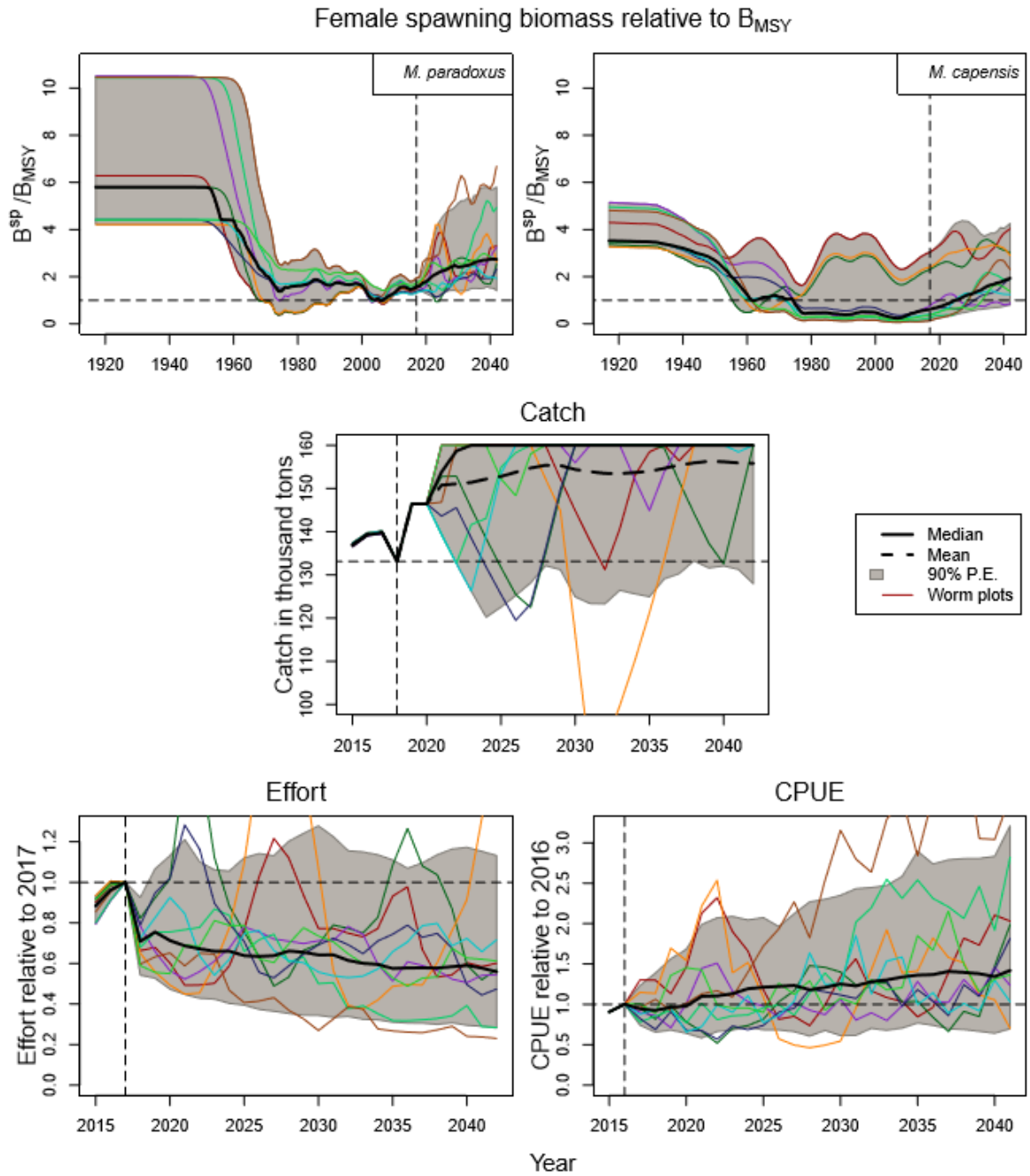


Figure 9a: Trajectories are shown for the updated RS projected under OMP2018 for an equal weighting across the nine RS OMs. Results are shown for female spawning biomass relative to B_{MSY} , catch, effort (taken to be proportional to the estimated *M. paradoxus* WC offshore fishing mortality rate, and normalised to be one in the last year of the OM, i.e. 2017) and CPUE (normalised to be one in the last year for which data are available for the OM, i.e. 2016). In each case the median trajectories are shown by the black solid lines, the 90% probability envelopes are shown by the grey shaded area, and a selection of worm plots are shown by the coloured lines, consisting of one random simulation drawn from the set of 100 simulations for each RS OM. The mean catch trajectory has also been included.

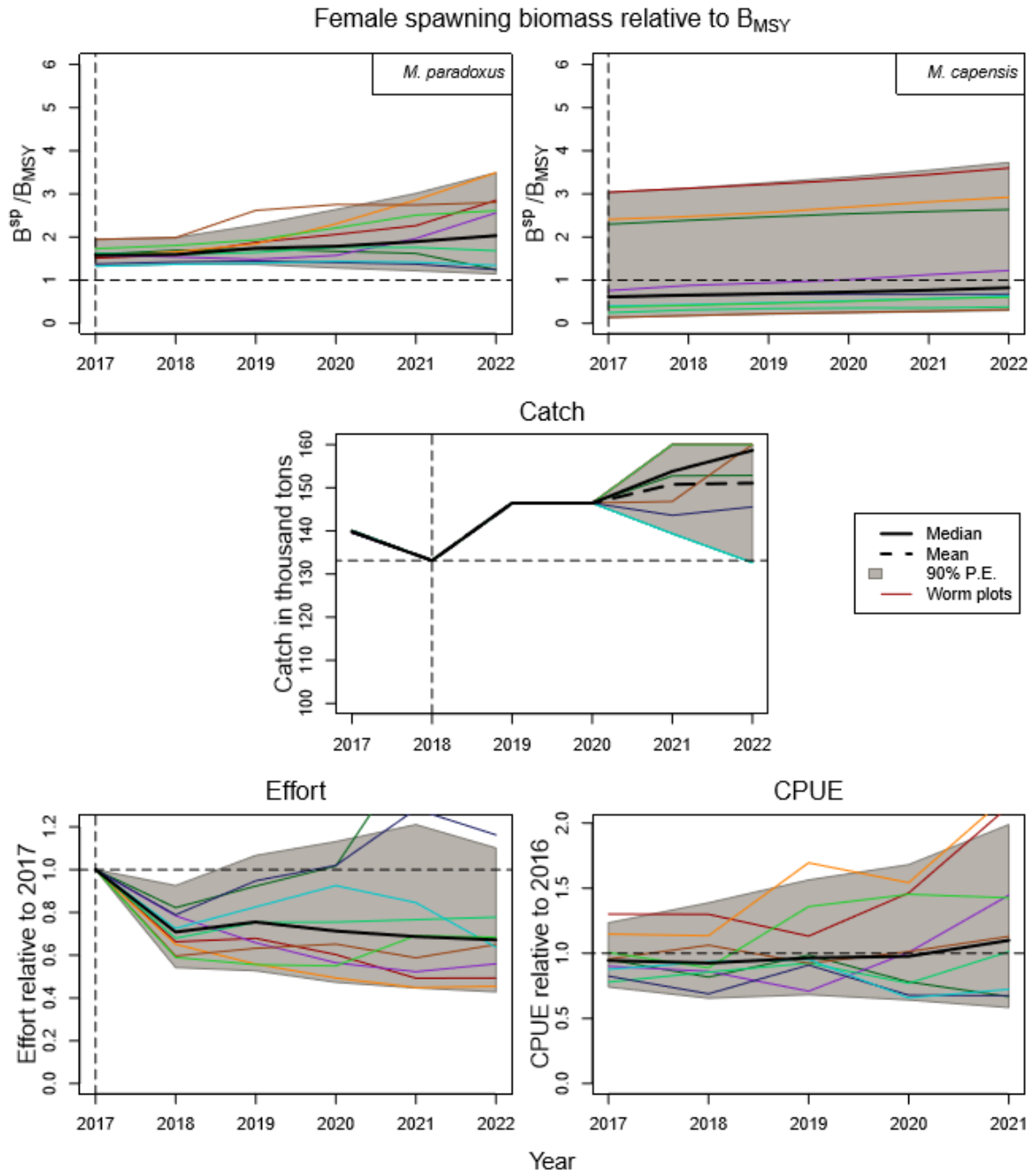


Figure 9b: Repeat of Figure 9a, but with the year-axis restricted to the lifespan of OMP2018.

Appendix A: Re-parameterisation of the hake growth curves following recommendations made at IWS 2018

The Panel for the 2018 International Stock Assessment Workshop (IWS 2018) recommended that the growth curves be re-parameterised as straight lines (rather than using the standard von Bertalanffy growth curves) given that the models consistently estimated straight lines for these growth curves (Cox *et al.* 2018). Subsequent graphical illustration of the age-length key data suggest that growth might in fact slow for older fish (see Figure A. 1; note that data for fish older than 9 years are available only for the females of each species). A growth curve was thus investigated whereby a straight line is fit for fish up to age 9, and after age 9 the slope is multiplicatively adjusted by a value of X , where X can take on values between 0 and 1. Though varying by species, X is considered to be independent of gender (the data plots make clear that there are insufficient data to estimate X separately for males anyway).

This X parameter was estimated for three of the RS models: central year of 1958 for the Ricker stock recruitment relationship, Beverton-Holt with $h=0.90$ and Beverton-Holt with $h=0.70$. For the Ricker model, the X parameters were consistently estimated at one for both species, which is somewhat surprising given the distribution of lengths for females of large age. More in-depth investigation revealed that it is the presence of outliers in larger length and age groups (where there are a small number of data points available) that is influencing the estimation process. For the Beverton-Holt models (with $h=0.90$ and with $h=0.70$), the models consistently estimated $X=1$ for *M. capensis* and $X=0$ for *M. paradoxus*.

In light of this, a value of $X=0.50$ seems a biologically plausible intermediate choice. In order to check this, the three OMs were run with (a) X estimated for each species, (b) $X=1$ for both species and (c) $X=0.5$ for both species. Table A. 1 lists key parameter outputs for these models, while Table A. 2 reports the negative log-likelihood components. The length-at-age distributions from the age-length-key data sets are plotted in Figure A. 1a and b. The estimated growth curves have been superimposed on these distributions. Note that these Figures do not strictly speaking show assessment model fits to the data: the age-length-key data are incorporated into the negative log-likelihood by comparing observed age-at-length distributions with those estimated by the model, and the model-estimated distributions are derived from the predicted catches-at-length. The Figures on the other hand show the observed length-at-age distributions and the empirical growth curves. The reason for plotting the data in this way is that the length-at-age distributions allow a more intuitive interpretation than the age-at-length distributions, particularly as there are often only one or two age readings per length class.

In all cases, estimating the X parameter freely for each species results in the best negative log-likelihood (although this difference is minimal for the Ricker model - the difference in negative log-likelihood points between fixing X at 1 and X at 0.5 was only 0.79). However, given that the Ricker models estimate $X=1$ for both species, and the Beverton-Holt $X=1$ for *M. capensis* and $X=0$ for *M. paradoxus*, fixing X at 0.5 for all models seems a biologically plausible compromise – some slowing of growth at large ages would be expected. The impact of choice of X on key assessment outputs is not substantial, though for lower X the value of K^{sp} does drop as only the near-unexploited spawning biomass contains a relatively large number of the oldest age hake.

Table A. 1: Key parameter estimates for the Ricker and Beverton-Holt (B-H) models, with the X parameters (a) estimated separately for each species, (b) fixed at 1 for both species and (c) fixed at 0.5 for both species. Pristine spawning biomass K^{sp} is reported for both the female and male component of the population, and the $B^{sp}(2017)$ relative to B^{MSY} and to K^{sp} values are reported for the female component and the total (male and female) component of the population. Other estimates correspond to the female component of the population. The estimates for the stock-recruitment parameters h and γ have been included, as well as estimates of the X parameter and the total negative log-likelihood.

<i>M. par</i>		K^{sp} (f)	K^{sp} (m)	B^{MSY}	MSY	$B^{sp}(2017)$	$B^{tot}(2017)$	$B^{sp}(2017)/B^{MSY}$	B_{MSY}/K^{sp}	h	γ	X	-lnL
Ricker	(a) X est.	289	333	53	144	83	193	1.56	0.18	1.66	0.48	1.0	-3152.41
	(b) X=1	289	333	53	144	83	193	1.56	0.18	1.66	0.48	1.0	-3152.41
	(c) X=0.50	274	321	52	144	81	191	1.55	0.19	1.66	0.50	0.5	-3151.62
B-H (h=0.90)	(a) X est.	374	401	38	142	66	168	1.76	0.10	0.90	NA	0.0	-3120.54
	(b) X=1	466	482	44	137	73	177	1.63	0.10	0.90	NA	1.0	-3118.35
	(c) X=0.50	412	441	40	139	66	166	1.67	0.10	0.90	NA	0.5	-3117.61
B-H (h=0.70)	(a) X est.	636	659	145	121	192	399	1.32	0.23	0.70	NA	0.0	-3118.25
	(b) X=1	707	675	162	120	200	388	1.23	0.23	0.70	NA	1.0	-3107.26
	(c) X=0.50	656	632	148	119	186	368	1.25	0.23	0.70	NA	0.5	-3110.87
<i>M. cap</i>		K^{sp} (f)	K^{sp} (m)	B_{MSY}	MSY	$B^{sp}(2017)$	$B^{tot}(2017)$	$B^{sp}(2017)/B^{MSY}$	B_{MSY}/K^{sp}	h	γ	X	-lnL
Ricker	(a) X est.	277	297	84	84	191	428	2.27	0.30	2.00	0.90	1.0	-3152.41
	(b) X=1	277	297	84	84	191	428	2.27	0.30	2.00	0.90	1.0	-3152.41
	(c) X=0.50	266	281	81	84	183	409	2.25	0.31	2.00	0.91	1.0	-3151.62
B-H (h=0.90)	(a) X est.	1257	1347	219	142	921	1962	4.21	0.17	0.90	NA	1.0	-3120.54
	(b) X=1	1271	1361	221	144	933	1987	4.22	0.17	0.90	NA	1.0	-3118.35
	(c) X=0.50	1158	1226	203	136	840	1782	4.15	0.17	0.90	NA	0.5	-3117.61
B-H (h=0.70)	(a) X est.	586	631	170	55	70	174	0.41	0.29	0.70	NA	1.0	-3118.25
	(b) X=1	586	631	170	55	70	174	0.41	0.29	0.70	NA	1.0	-3107.26
	(c) X=0.50	559	593	163	55	67	166	0.41	0.29	0.70	NA	0.5	-3110.87

Table A. 2: Negative log-likelihood components are listed (A) in absolute terms and (B) relative to run (a) in each group (where X is estimated).

(A)		GLM CPUE	ICSEAF	Surv. Abun.	Comm. CAL	Surv. CAL	Rec. resid.	ALKs	Total
Ricker	(a) X est.	-203.94	-37.04	-34.65	-1506.53	-1503.74	9.60	122.71	-3152.41
	(b) X=1	-203.94	-37.04	-34.65	-1506.53	-1503.74	9.60	122.71	-3152.41
	(c) X=0.50	-203.94	-37.13	-34.69	-1506.55	-1503.56	9.67	123.40	-3151.62
B-H (h=0.90)	(a) X est.	-172.66	-37.14	-32.86	-1504.42	-1512.09	12.74	125.42	-3120.54
	(b) X=1	-172.11	-36.94	-32.75	-1503.85	-1512.40	13.41	125.85	-3118.35
	(c) X=0.50	-174.27	-36.40	-33.35	-1504.32	-1511.93	15.16	127.09	-3117.61
B-H (h=0.70)	(a) X est.	-179.01	-29.58	-31.96	-1508.96	-1504.40	9.10	123.15	-3118.25
	(b) X=1	-176.52	-29.95	-32.34	-1501.47	-1506.29	11.24	124.72	-3107.26
	(c) X=0.50	-177.77	-29.24	-32.25	-1505.28	-1506.46	11.39	125.38	-3110.87
(B)		GLM CPUE	ICSEAF	Surv. Abun.	Comm. CAL	Surv. CAL	Rec. resid.	ALKs	Total
Ricker	(a) X est.	-203.94	-37.04	-34.65	-1506.53	-1503.74	9.60	122.71	0.00
	(b) X=1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(c) X=0.50	0.00	-0.09	-0.05	-0.03	0.18	0.07	0.68	0.79
B-H (h=0.90)	(a) X est.	-172.66	-37.14	-32.86	-1504.42	-1512.09	12.74	125.42	0.00
	(b) X=1	0.55	0.20	0.11	0.57	-0.31	0.67	0.44	2.19
	(c) X=0.50	-1.61	0.74	-0.50	0.10	0.16	2.42	1.67	2.93
B-H (h=0.70)	(a) X est.	-179.01	-29.58	-31.96	-1508.96	-1504.40	9.10	123.15	0.00
	(b) X=1	2.49	-0.36	-0.38	7.49	-1.89	2.14	1.58	10.99
	(c) X=0.50	1.24	0.34	-0.30	3.68	-2.06	2.29	2.24	7.38

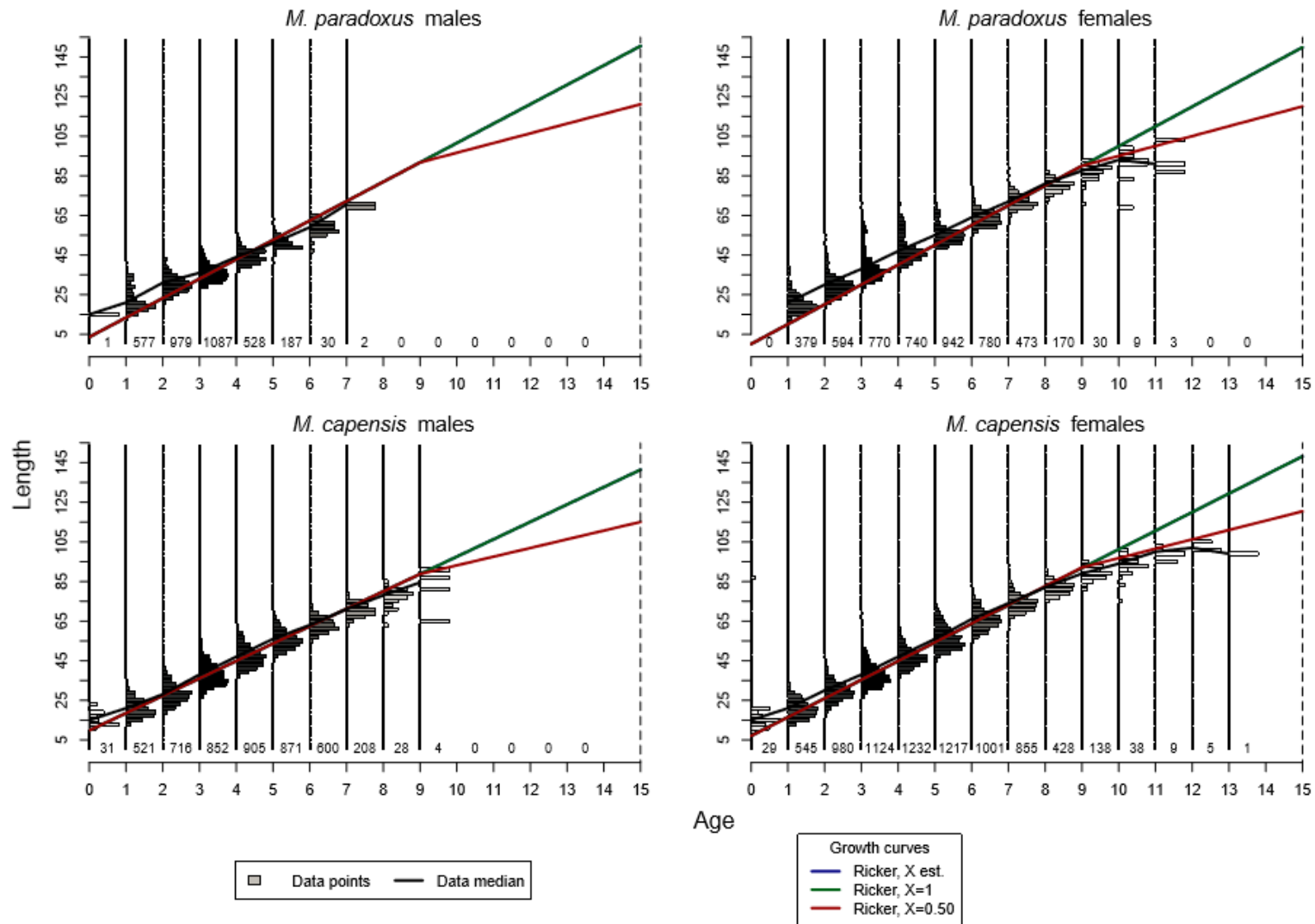


Figure A. 1a: Growth curves estimated for the Ricker models are superimposed onto the length-at-age distributions from the age-length keys. The colours of the data bars are indicative of the sample size (white for small, black for large sample sizes) and the actual sample sizes for each age class are reported by the small numbers at the bottom of the graph.

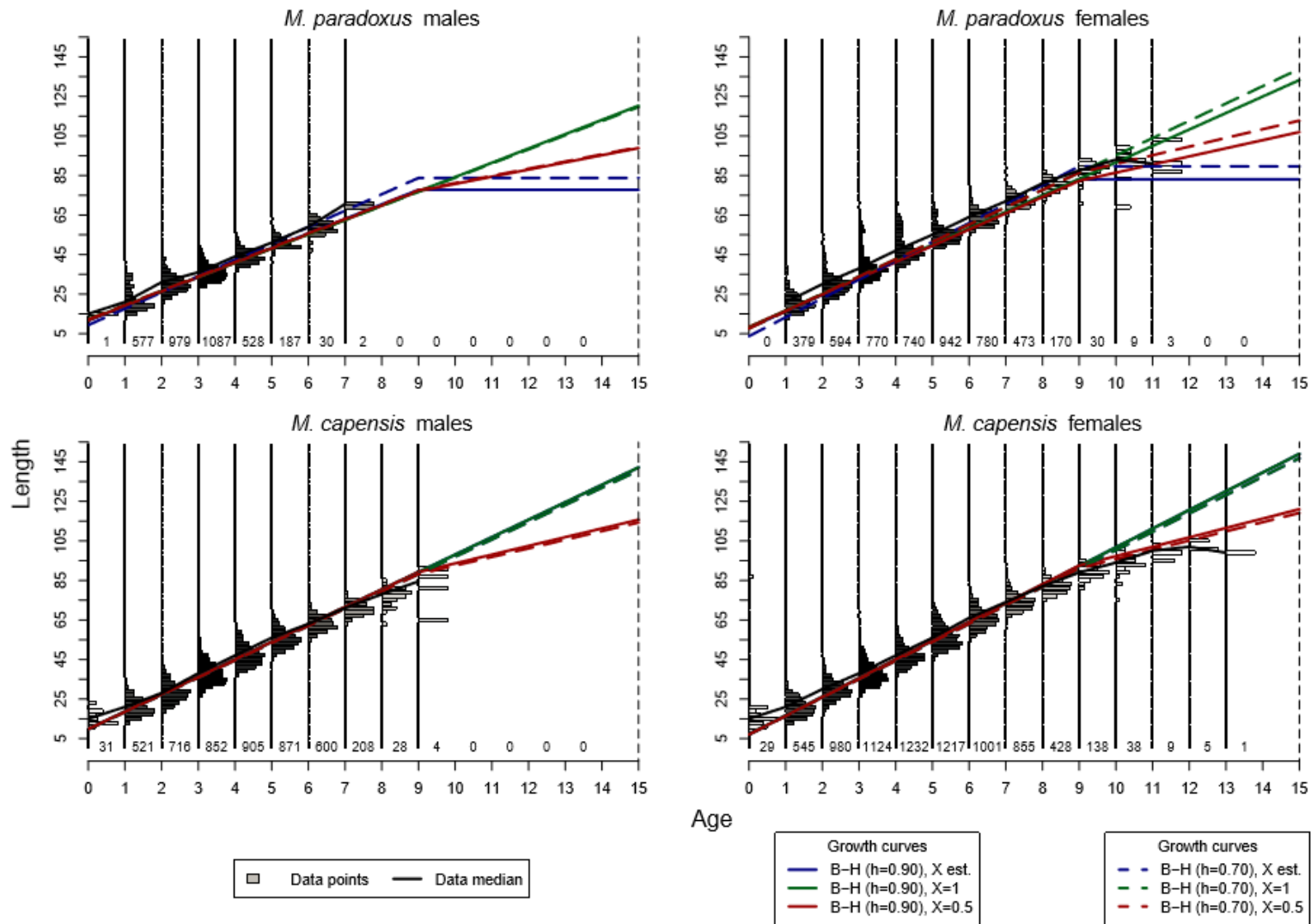


Figure A. 1b: Repeat of Figure A. 1a for the Beverton-Holt models.

Appendix B: Details of changes that have been made to the Reference Set that was originally proposed by the Panel for the 2017 International Stock Assessment Workshop.

The text in this Appendix has been reproduced from MARAM/IWS/2018/Hake/P3 for reference purposes.

The Panel for the 2017 International Stock Assessment Workshop (Cox *et al.* 2017) recommended that the RS should consist of eight models spanning two axes of uncertainty: the central year in which the catch shifted from primarily *M. capensis* to *M. paradoxus* (including a model starting in 1978 which avoids the need for specifying this shift in the pre-1978 catches), and the form of the stock recruitment function. The Panel recommended that the natural mortality-at-age be removed as an axis of uncertainty in the RS, and that the mortality-at-age vectors estimated in the hake predation model (MARAM/IWS/2018/Hake/BG7) be used.

However, several difficulties were experienced with the models starting in 1978 (e.g. certain parameters needing to be fixed owing to estimation instability), which led to the decision to remove this scenario from the Reference Set and to consider its inclusion instead under robustness tests.

Furthermore, the estimation of the h parameter Beverton-Holt models proved challenging as the models tended to provide estimates for h at its upper boundary. Because of this, the h parameter was fixed at two values: 0.70 (roughly the median meta-analyses of demersal stocks) and 0.90 (a value closer to the upper bound of 0.98 that is imposed on h in the assessment model if it is freely estimated).

Therefore, there are nine models in the RS considered in the development of OMP2018.

There are three options for the central year.

4. Centre of the shift occurred in 1952.
5. Centre of the shift occurred in 1958.
6. Centre of the shift occurred in 1963.

A further three options for the form of the stock-recruitment function have been considered.

4. Modified Ricker
5. Beverton-Holt (B-H) with h fixed at 0.90
6. Beverton-Holt (B-H) with h fixed at 0.70

When the Ricker Models were originally run, the stock recruitment h parameter was estimated at the upper bound of 1.5 for both species. The upper bound was then increased to 3 to see what the unconstrained estimate for h would be. While the *M. paradoxus* estimate for the stock recruitment h and γ parameters remained reasonable (h generally between 1.5 and 1.7 and γ between 0.3 and 0.5), the *M. capensis* estimates for h tended to increase to very high values (i.e. well above 2) and in some cases the γ estimate was extremely low (below 0.1), resulting in unrealistically heavily domed plots of recruitment against spawning biomass. Jittering also yielded very different results with virtually the same negative log-likelihood, suggesting that the *M. capensis* stock recruitment parameters h and γ are not very well determined by the data available. Remembering that h is the proportion of pristine recruitment that occurs when the biomass is at 20% of K , an upper limit of 2 was imposed on h , which seemed to result in more stable estimation of the *M. capensis* h and γ parameters.

Appendix C: Detailed assessment results for the nine Reference Set Operating Models

This Appendix contains the detailed assessment results for the nine RS OMs. Each figure contains three panels, the first with plots for the three Ricker models, the second with plots for the Beverton-Holt models with $h=0.90$ and the third for Beverton-Holt with $h=0.70$.

The table below provides a summary of the plots that have been included.

Reference	Description
Table C. 1a-c	Parameter estimates for the nine RS OMs
Figure C. 1	Recruitment plots
Figure C. 2	Yield curves
Figure C. 3	Fits to CPUE data
Figure C. 4	Fits to survey relative abundance indices
Figure C. 5	Fits to commercial and survey catch-at-length data
Figure C. 6a	Commercial selectivity-at-length functions
Figure C. 6b	Commercial selectivity-at-age functions
Figure C. 8a	Survey selectivity-at-length functions
Figure C. 8b	Survey selectivity-at-age functions
Figure C. 10	Estimated growth curves

Table C. 1a: Parameter estimates for the **three Ricker models**: yellow for the model with central year 1952, blue for the model with central year 1958 and red for the model with central year 1963. The first block reports the estimates for pristine spawning biomass, the stock recruitment h parameter and the Ricker γ parameter. The second block (“Zeta”) reports estimates of the stock-recruitment residuals. The third block the five parameters starting with “sig” reports the standard deviations for the CPUE series residuals, while the fourth block reports the values relating to the treatment of the historical ICSEAF CPUE data. The second to last block reports the estimates of the survey catchability coefficient in log space, and the last block lists the estimates relating to the growth curves.

<i>M. paradoxus</i>				<i>M. capensis</i>			
-lnL	-3151.80	-3154.46	-3152.79				
K^{sp} (f)	306	294	245	K^{sp} (f)	379	272	437
K^{sp} (m)	356	340	280	K^{sp} (m)	401	287	463
B_{MSY}	49	51	58	B_{MSY}	88	81	134
MSY	143	144	146	MSY	110	84	106
B^{sp}_{2017}	74	78	89	B^{sp}_{2017}	268	186	323
B^{tot}_{2017}	172	181	201	B^{tot}_{2017}	587	415	701
B^{sp}_{2017}/K^{sp}	0.24	0.27	0.36	B^{sp}_{2017}/K^{sp}	0.71	0.68	0.74
B^{sp}_{2017}/B_{MSY}	1.52	1.55	1.53	B^{sp}_{2017}/B_{MSY}	3.04	2.30	2.41
B_{MSY}/K^{sp}	0.16	0.17	0.24	B_{MSY}/K^{sp}	0.23	0.30	0.31

			<i>M. paradoxus</i>			<i>M. capensis</i>		
ln(K)	(3.50,10.00)		5.72	5.68	5.50	5.94	5.61	6.08
h	(0.50,2.00)		1.56	1.64	1.91	2.00	2.00	1.60
gamma	(0.00,2.00)		0.38	0.44	0.73	0.60	0.88	0.82
Zeta	(-5.00,5.00)	1985	-0.43	-0.42	-0.41	-0.04	-0.05	-0.03
		1986	-0.13	-0.13	-0.13	0.17	0.18	0.18
		1987	0.27	0.27	0.27	0.51	0.52	0.51
		1988	0.00	0.01	0.02	0.56	0.57	0.56
		1989	0.08	0.08	0.08	0.54	0.54	0.54
		1990	0.08	0.08	0.08	0.38	0.38	0.37
		1991	0.07	0.06	0.06	0.18	0.18	0.17
		1992	-0.16	-0.15	-0.13	0.03	0.04	0.02
		1993	0.28	0.27	0.26	0.27	0.28	0.25
		1994	0.16	0.17	0.19	0.18	0.20	0.16
		1995	0.28	0.26	0.22	-0.07	-0.03	-0.09
		1996	-0.20	-0.19	-0.19	0.07	0.14	0.05
		1997	-0.09	-0.10	-0.11	0.04	0.12	0.02
		1998	-0.25	-0.25	-0.25	-0.18	-0.10	-0.20
		1999	-0.30	-0.30	-0.29	-0.19	-0.12	-0.21
		2000	0.08	0.08	0.07	-0.01	0.04	-0.04
		2001	0.10	0.09	0.09	-0.21	-0.18	-0.23
		2002	-0.37	-0.37	-0.39	-0.37	-0.37	-0.38
		2003	-0.09	-0.10	-0.13	-0.14	-0.16	-0.14
		2004	0.30	0.29	0.29	-0.00	-0.03	0.00
		2005	0.17	0.16	0.15	-0.02	-0.05	-0.00
		2006	-0.14	-0.14	-0.13	-0.17	-0.20	-0.15
		2007	0.07	0.06	0.02	-0.16	-0.22	-0.13
		2008	0.11	0.09	0.11	-0.18	-0.24	-0.15
		2009	-0.13	-0.13	-0.14	-0.55	-0.61	-0.52
		2010	-0.00	-0.02	-0.03	-0.41	-0.47	-0.38
		2011	-0.20	-0.19	-0.18	-0.30	-0.36	-0.27
		2012	0.15	0.14	0.13	-0.32	-0.36	-0.31
		2013	0.14	0.14	0.18	0.13	0.10	0.15
		2014	0.24	0.26	0.28	0.06	0.05	0.06
		2015	-0.03	0.00	0.05	0.20	0.19	0.20
		2016	-0.05	-0.03	-0.01	0.01	0.01	0.01
		2017	-0.02	-0.02	-0.01	-0.00	-0.00	-0.00
sig_add	(0.00,0.50)		0.18	0.18	0.18	0.14	0.14	0.14
sig_ICSEAF	(0.25,1.00)	0.25						
sig_ICSEAF	(0.25,1.00)	0.25						
sig_GLM	(0.15,1.00)		0.15	0.15	0.15	0.17	0.16	0.16
sig_GLM	(0.15,1.00)		0.16	0.16	0.17	0.22	0.22	0.22
qWCz1	(0.00,10.00)					9.99	0.12	0.07
qWCz2	(0.00,10.00)					6.65	9.81	0.32
qWCpar	(0.00,10.00)		0.04	0.04	0.03			
r	(0.00,10.00)		0.08	0.07	0.08			
gamma	(0.00,1.00)					0.02	0.00	0.11
lnq WC sum	(-5.00,2.00)		Old gear		New gear	Old gear		New gear
lnq WC win	(-5.00,2.00)		0.69	0.67	0.60	-0.13	0.06	-0.24
lnq SC spr	(-5.00,2.00)		0.28	0.26	0.18	-0.07	0.13	-0.19
lnq SC aut	(-5.00,2.00)		0.08	0.06	-0.02	-0.33	-0.07	-0.45
			0.19	0.17	0.08	-0.06	0.18	-0.20
AL theta0	(0.10,100.00)		Males		Females	Males		Females
theta1	(0.01,20.00)		4.68	4.68	4.74	2.37	2.36	2.40
theta14	(0.01,20.00)		9.00	8.59	7.04	4.65	4.53	4.65
L2	(5.00,50.00)		22.1	22.0	22.5	6.26	6.77	6.20
L4	(20.00,70.00)		42.5	42.4	42.3	27.4	27.4	27.4
X	(0.00,1.00)		0.50	0.50	0.50	45.0	44.9	45.0
						0.50	0.50	0.50

Table C. 1b: Parameter estimates for the three Beverton-Holt models with $h=0.90$.

<i>M. paradoxus</i>				<i>M. capensis</i>			
-lnL	-3137.44	-3130.64	-3116.72				
K^{sp} (f)	443	435	457	K^{sp} (f)	410	483	584
K^{sp} (m)	452	444	424	K^{sp} (m)	428	482	640
B_{MSY}	42	42	44	B_{MSY}	80	97	121
MSY	142	141	144	MSY	54	63	83
B^{sp}_{2017}	65	68	86	B^{sp}_{2017}	31	24	18
B^{tot}_{2017}	164	172	206	B^{tot}_{2017}	90	75	60
B^{sp}_{2017}/K^{sp}	0.15	0.16	0.19	B^{sp}_{2017}/K^{sp}	0.08	0.05	0.03
B^{sp}_{2017}/B_{MSY}	1.54	1.65	1.96	B^{sp}_{2017}/B_{MSY}	0.39	0.25	0.15
B_{MSY}/K^{sp}	0.10	0.10	0.10	B_{MSY}/K^{sp}	0.19	0.20	0.21

		<i>M. paradoxus</i>			<i>M. capensis</i>				
ln(K)	(3.50,10.00)		6.09	6.07	6.12		6.02	6.18	6.37
h	(0.50,2.00)		0.90	0.90	0.90		0.90	0.90	0.90
gamma	(0.00,2.00)		0.34	0.34	0.34		0.79	0.79	0.79
Zeta	(-5.00,5.00)	1985	-0.73	-0.74	-0.71		0.09	0.04	-0.00
		1986	-0.07	-0.06	-0.08		0.20	0.18	0.17
		1987	0.24	0.24	0.19		0.34	0.31	0.30
		1988	0.12	0.12	0.09		0.27	0.23	0.22
		1989	0.01	-0.01	-0.06		0.21	0.17	0.17
		1990	0.14	0.13	0.10		0.11	0.10	0.08
		1991	0.06	0.06	0.04		-0.03	-0.05	-0.05
		1992	0.07	0.09	0.07		-0.14	-0.17	-0.15
		1993	-0.03	-0.03	-0.00		0.03	-0.01	-0.01
		1994	0.46	0.48	0.40		-0.07	-0.10	-0.12
		1995	-0.02	-0.03	0.00		-0.22	-0.24	-0.23
		1996	0.20	0.22	0.13		-0.06	-0.06	-0.09
		1997	-0.35	-0.36	-0.30		0.02	0.03	0.05
		1998	-0.13	-0.15	-0.25		-0.16	-0.14	-0.10
		1999	-0.46	-0.46	-0.44		-0.19	-0.18	-0.20
		2000	-0.09	-0.09	-0.08		-0.06	-0.04	-0.05
		2001	0.46	0.47	0.35		-0.19	-0.18	-0.16
		2002	-0.37	-0.38	-0.30		-0.34	-0.33	-0.31
		2003	-0.25	-0.25	-0.24		-0.09	-0.07	-0.07
		2004	0.60	0.59	0.53		0.16	0.17	0.20
		2005	0.35	0.38	0.43		0.23	0.26	0.28
		2006	0.16	0.14	0.06		0.14	0.18	0.21
		2007	-0.57	-0.56	-0.39		0.10	0.15	0.17
		2008	0.53	0.52	0.39		-0.01	0.03	0.02
		2009	-0.38	-0.36	-0.19		-0.43	-0.42	-0.44
		2010	0.02	0.01	-0.07		-0.38	-0.37	-0.41
		2011	-0.02	-0.02	-0.01		-0.30	-0.31	-0.37
		2012	-0.21	-0.20	-0.14		-0.21	-0.20	-0.18
		2013	0.40	0.40	0.35		0.25	0.26	0.25
		2014	0.10	0.12	0.20		0.26	0.28	0.32
		2015	-0.05	-0.05	0.04		0.35	0.37	0.36
		2016	-0.15	-0.15	-0.08		0.10	0.12	0.13
		2017	-0.05	-0.05	-0.03		0.02	0.03	0.03
sig_add	(0.00,0.50)		0.19	0.20	0.20		0.14	0.14	0.14
sig_ICSEAF	(0.25,1.00)	0.25							
sig_ICSEAF	(0.25,1.00)	0.25							
sig_GLM	(0.15,1.00)		0.15	0.15	0.15		0.15	0.15	0.15
sig_GLM	(0.15,1.00)		0.29	0.33	0.38		0.27	0.26	0.26
qWCz1	(0.00,10.00)						0.03	0.05	0.22
qWCz2	(0.00,10.00)						0.06	9.73	0.04
qWCpar	(0.00,10.00)		0.02	0.02	0.01				
r	(0.00,10.00)		0.16	0.12	0.11				
gamma	(0.00,1.00)						0.19	0.00	0.84
lnq WC sum	(-5.00,2.00)		Old gear		New gear		Old gear		New gear
lnq WC win	(-5.00,2.00)		0.13	0.11	-0.03		0.28	0.38	0.49
lnq SC spr	(-5.00,2.00)		-0.10	-0.14	-0.26		0.75	0.79	0.84
lnq SC aut	(-5.00,2.00)		-0.38	-0.40	-0.45		1.04	1.20	1.56
			-0.17	-0.19	-0.29		1.07	1.19	1.39
AL theta0	(0.10,100.00)		Males		Females		Males		Females
theta1	(0.01,20.00)		2.30	2.32	2.29		2.31	2.31	2.25
theta14	(0.01,20.00)		4.08	4.04	3.88		4.17	4.10	4.77
L2	(5.00,50.00)		11.1	12.2	14.0		8.71	8.60	3.14
L4	(20.00,70.00)		26.3	26.4	26.5		27.0	26.8	26.6
X	(0.00,1.00)		40.6	40.4	39.5		44.0	43.8	43.7
			0.50	0.50	0.50		0.50	0.50	0.50

Table C. 1c: Parameter estimates for the three Beverton-Holt models with $h=0.70$.

<i>M. paradoxus</i>				<i>M. capensis</i>			
-lnL	-3120.76	-3123.19	-3129.04				
K^{SP} (f)	751	739	820	K^{SP} (f)	514	579	718
K^{SP} (m)	786	775	859	K^{SP} (m)	538	611	761
B_{MSY}	170	167	186	B_{MSY}	146	166	206
MSY	122	121	134	MSY	48	55	70
B^{SP}_{2017}	233	222	321	B^{SP}_{2017}	82	66	55
B^{tot}_{2017}	474	456	658	B^{tot}_{2017}	195	164	140
B^{SP}_{2017}/K^{SP}	0.31	0.30	0.39	B^{SP}_{2017}/K^{SP}	0.16	0.11	0.08
B^{SP}_{2017}/B_{MSY}	1.37	1.33	1.73	B^{SP}_{2017}/B_{MSY}	0.56	0.40	0.27
B_{MSY}/K^{SP}	0.23	0.23	0.23	B_{MSY}/K^{SP}	0.28	0.29	0.29

		<i>M. paradoxus</i>			<i>M. capensis</i>				
ln(K)	(3.50,10.00)		6.62	6.61	6.71		6.24	6.36	6.58
h	(0.50,2.00)		0.70	0.70	0.70		0.70	0.70	0.70
gamma	(0.00,2.00)		0.46	0.46	0.34		0.87	0.87	0.79
Zeta	(-5.00,5.00)	1985	-0.50	-0.51	-0.47		-0.04	-0.08	-0.11
		1986	-0.09	-0.09	-0.06		0.12	0.09	0.09
		1987	0.32	0.31	0.31		0.37	0.34	0.33
		1988	0.07	0.06	0.08		0.34	0.29	0.27
		1989	0.04	0.03	0.04		0.32	0.27	0.25
		1990	0.07	0.07	0.09		0.18	0.15	0.14
		1991	0.08	0.07	0.07		0.02	-0.01	-0.02
		1992	-0.03	-0.04	-0.00		-0.11	-0.13	-0.14
		1993	0.27	0.26	0.27		0.09	0.06	0.04
		1994	0.22	0.22	0.24		-0.03	-0.07	-0.09
		1995	0.16	0.15	0.12		-0.26	-0.28	-0.30
		1996	-0.17	-0.17	-0.14		-0.12	-0.14	-0.16
		1997	-0.19	-0.20	-0.21		-0.10	-0.11	-0.11
		1998	-0.31	-0.31	-0.31		-0.31	-0.31	-0.31
		1999	-0.41	-0.41	-0.40		-0.32	-0.32	-0.33
		2000	-0.04	-0.05	-0.06		-0.14	-0.14	-0.15
		2001	0.12	0.13	0.06		-0.27	-0.26	-0.26
		2002	-0.41	-0.40	-0.41		-0.38	-0.37	-0.36
		2003	-0.23	-0.23	-0.26		-0.07	-0.06	-0.05
		2004	0.45	0.46	0.41		0.18	0.20	0.23
		2005	0.20	0.21	0.17		0.26	0.30	0.34
		2006	0.05	0.06	0.03		0.18	0.23	0.28
		2007	-0.27	-0.27	-0.26		0.19	0.24	0.28
		2008	0.43	0.43	0.37		0.15	0.18	0.22
		2009	-0.21	-0.20	-0.17		-0.31	-0.28	-0.27
		2010	0.04	0.04	-0.00		-0.21	-0.20	-0.20
		2011	-0.11	-0.11	-0.10		-0.15	-0.15	-0.16
		2012	-0.04	-0.04	-0.05		-0.18	-0.15	-0.15
		2013	0.34	0.34	0.33		0.25	0.26	0.25
		2014	0.23	0.24	0.28		0.12	0.15	0.15
		2015	0.02	0.03	0.10		0.22	0.24	0.24
		2016	-0.07	-0.07	-0.04		0.02	0.04	0.04
		2017	-0.03	-0.03	-0.02		-0.00	0.00	0.00
sig_add	(0.00,0.50)		0.21	0.22	0.22		0.14	0.14	0.14
sig_ICSEAF	(0.25,1.00)	0.25							
sig_ICSEAF	(0.25,1.00)	0.25							
sig_GLM	(0.15,1.00)		0.15	0.15	0.15		0.15	0.15	0.15
sig_GLM	(0.15,1.00)		0.34	0.36	0.35		0.26	0.26	0.25
qWCz1	(0.00,10.00)						0.01	0.03	0.03
qWCz2	(0.00,10.00)						6.74	7.68	0.21
qWCpar	(0.00,10.00)		0.02	0.02	0.01				
r	(0.00,10.00)		0.21	0.07	0.08				
gamma	(0.00,1.00)						0.00	0.00	0.12
lnq WC sum	(-5.00,2.00)		Old gear		New gear		Old gear		New gear
lnq WC win	(-5.00,2.00)		0.03	0.04	-0.16		-0.08	-0.07	-0.27
lnq SC spr	(-5.00,2.00)		-0.40	-0.39	-0.59		0.30	0.35	0.37
lnq SC aut	(-5.00,2.00)		-0.67	-0.67	-0.90		0.27	0.33	0.35
			-0.54	-0.53	-0.76		0.41	0.51	0.59
			-0.69	-0.69	-0.92		0.62	0.72	0.79
AL theta0	(0.10,100.00)		Males		Females		Males		Females
theta1	(0.01,20.00)		2.33	2.31	2.24		2.35	2.35	2.35
theta14	(0.01,20.00)		4.45	4.44	4.47		4.37	4.36	4.33
L2	(5.00,50.00)		7.47	7.43	6.70		7.49	7.46	7.55
L4	(20.00,70.00)		25.7	25.8	26.0		27.3	27.2	27.2
X	(0.00,1.00)		42.6	42.6	42.7		44.6	44.6	44.6
			0.50	0.50	0.50		0.50	0.50	0.50

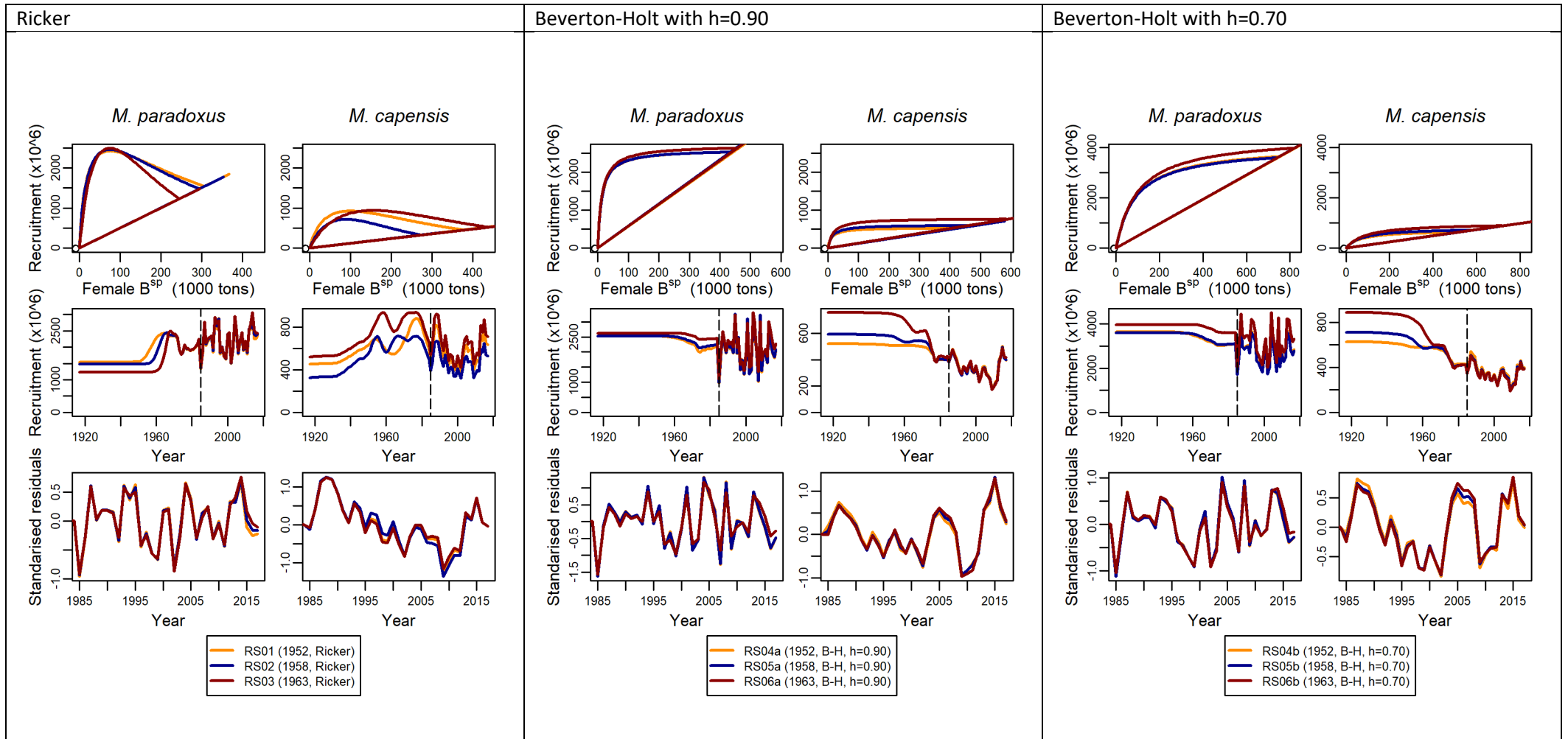


Figure C. 1: Recruitment in absolute terms is plotted against female spawning biomass (top row of each panel) and against time (middle panel). The bottom panel shows plots of standardised recruitment residuals plotted against time for the years for which recruitment residuals are estimated.

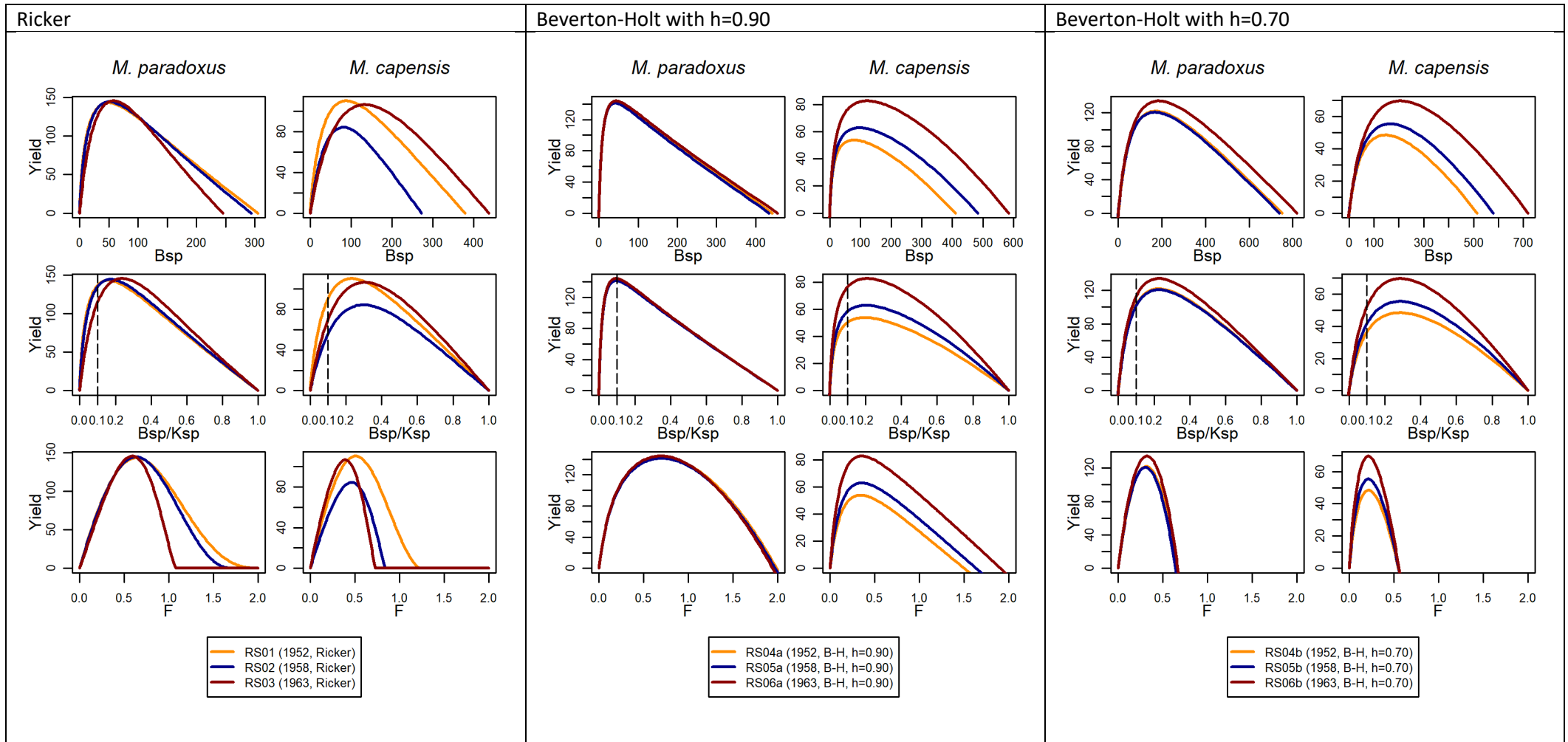


Figure C. 2: The estimated yield curve (yield in thousand tons) is plotted against female spawning biomass (top panel), female spawning biomass relative to pristine levels (middle panel) and fishing mortality rate F (bottom panel).

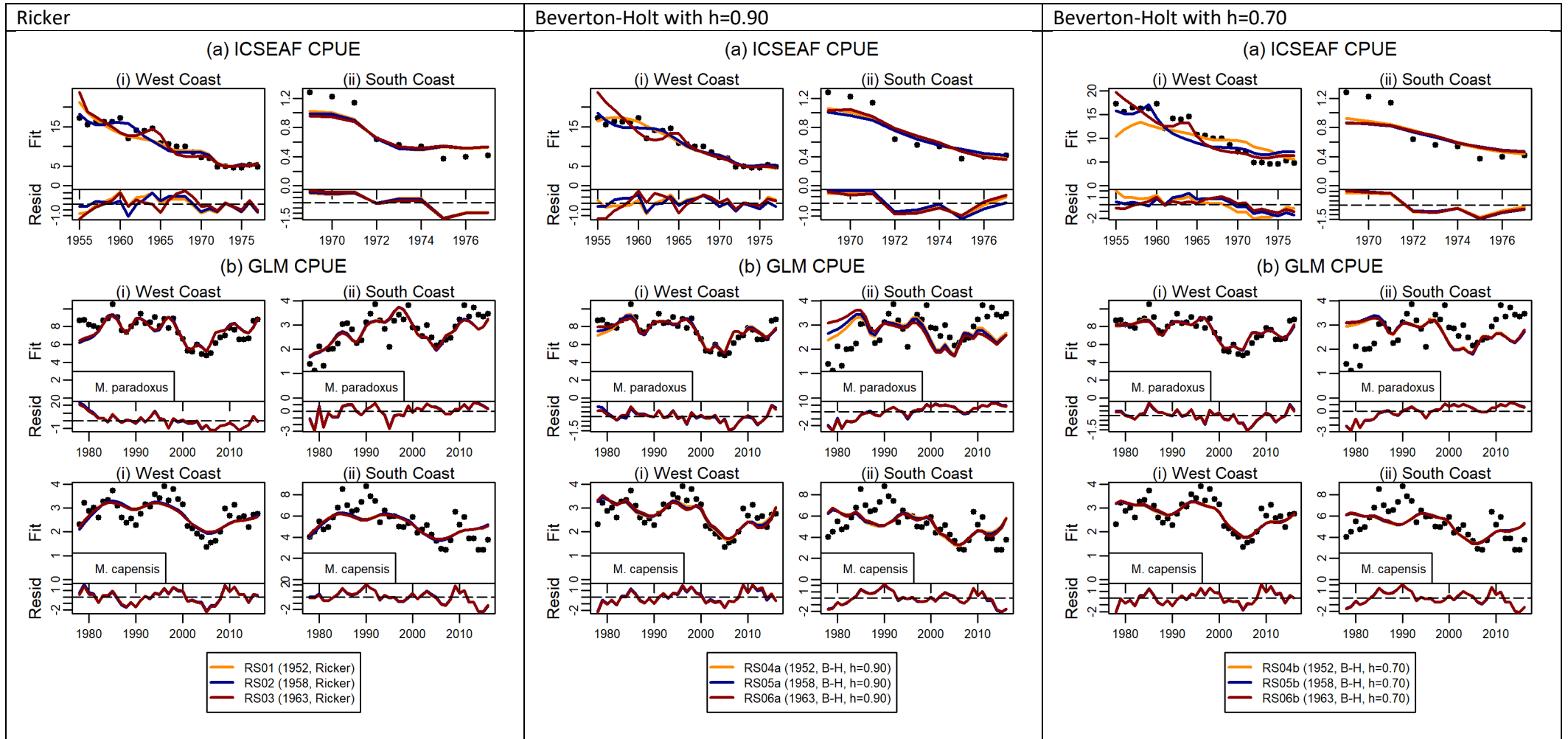


Figure C. 3: Fits to historical ICSEAF CPUE data are shown in the top panel and fits to recent commercial CPUE data are shown in the next two panel. Plots of the residuals have been included.

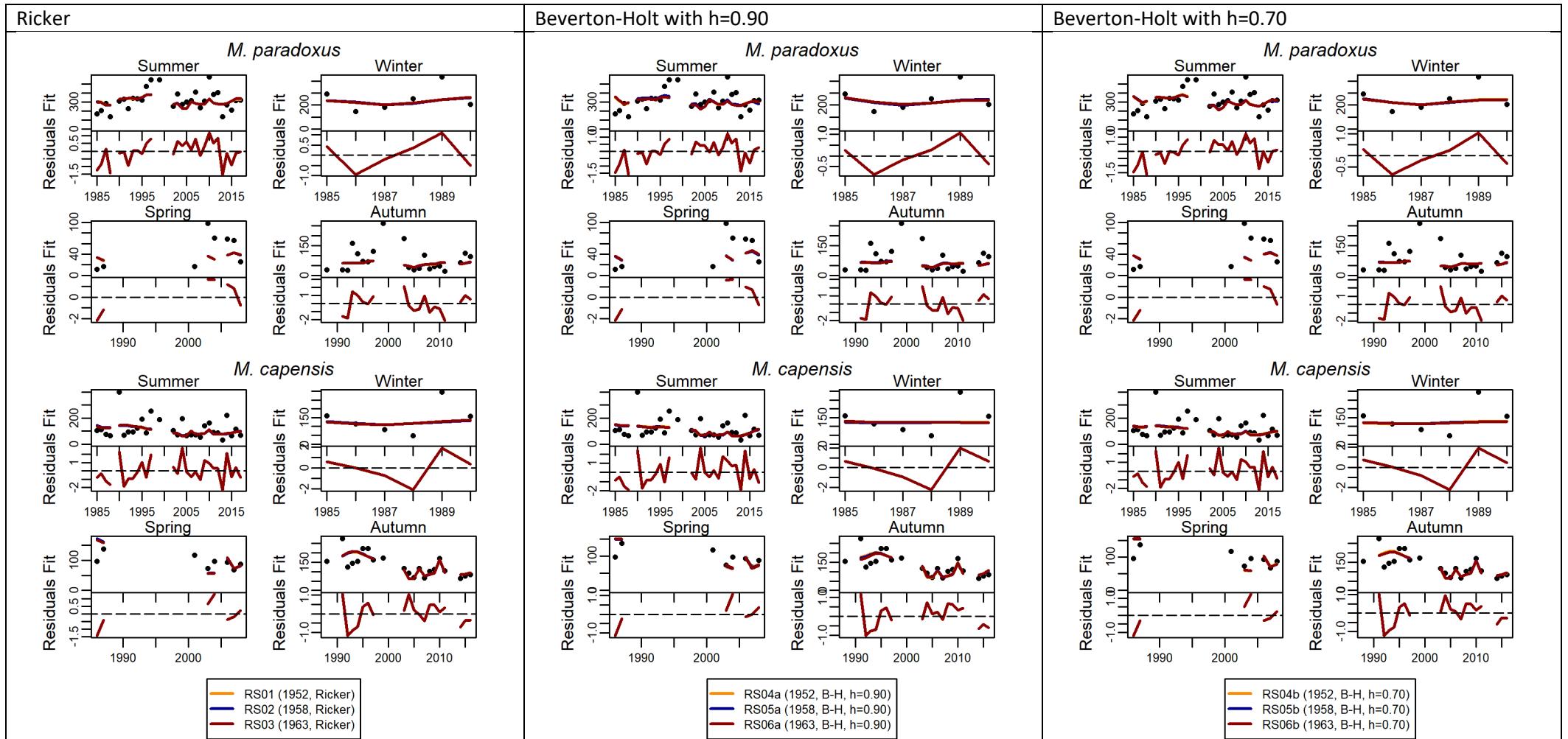


Figure C. 4: Fits to survey relative abundance indices are shown.

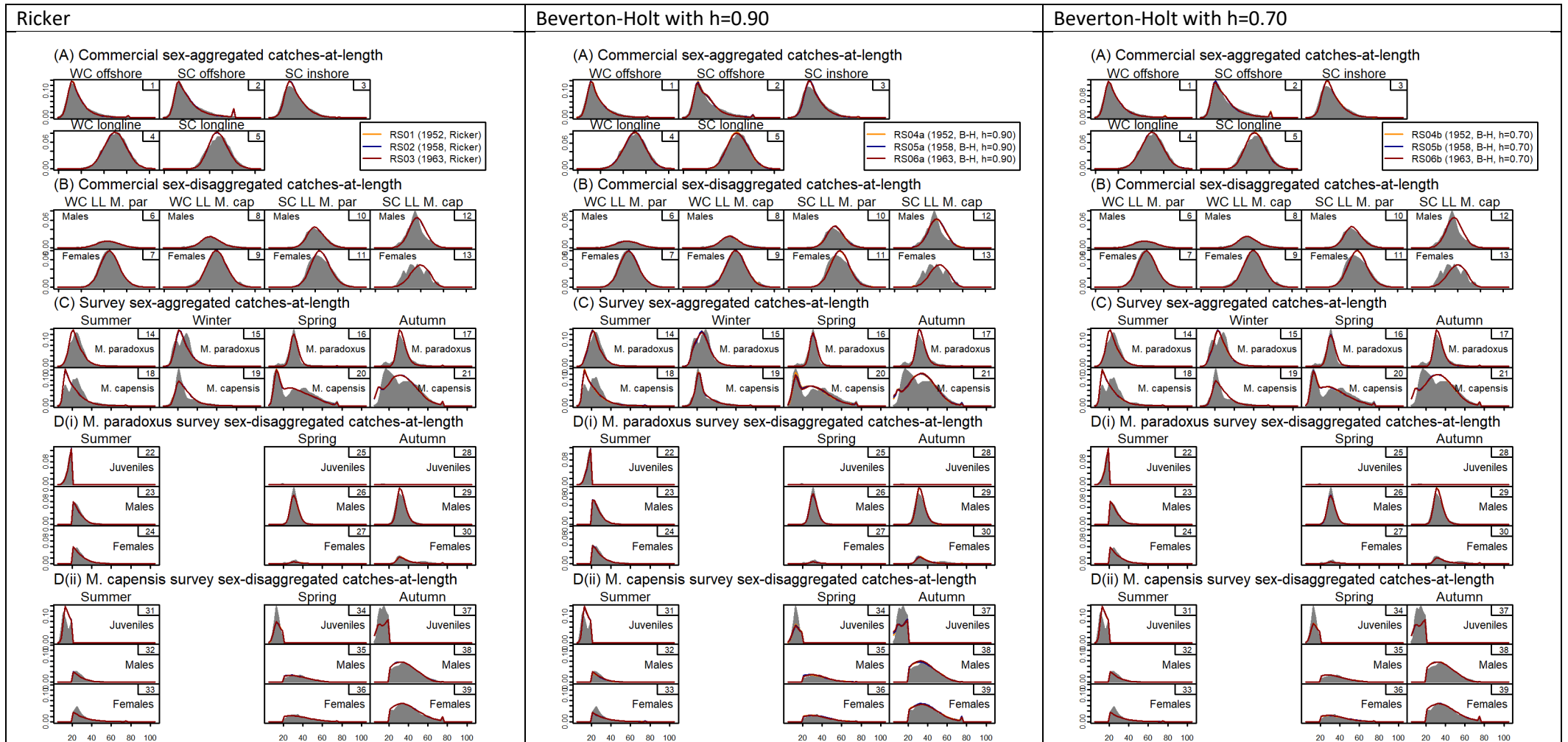


Figure C. 5: Fits to commercial and survey commercial catch-at-length data are shown.

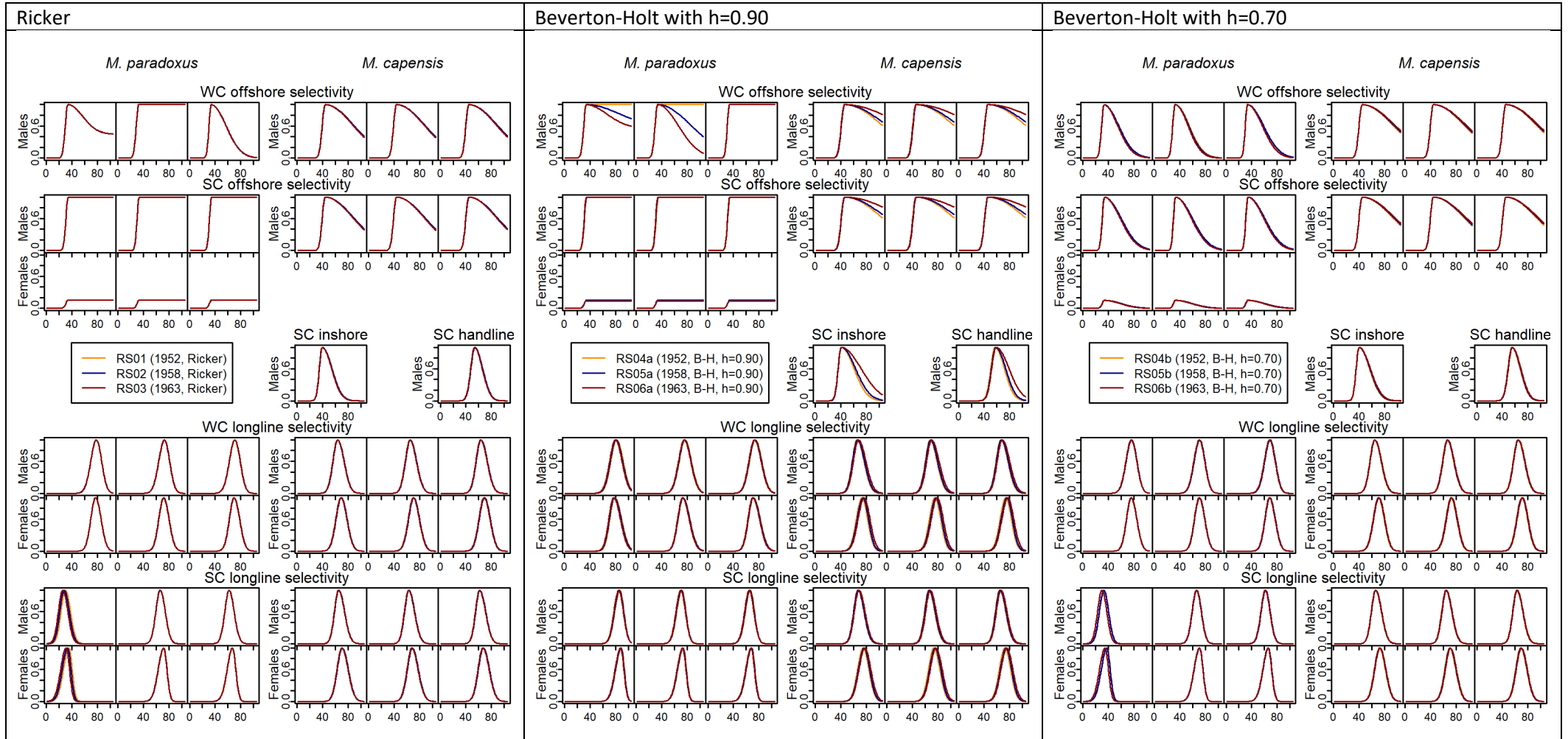


Figure C. 6a: The estimated commercial selectivity-at-length functions are shown in this Figure.

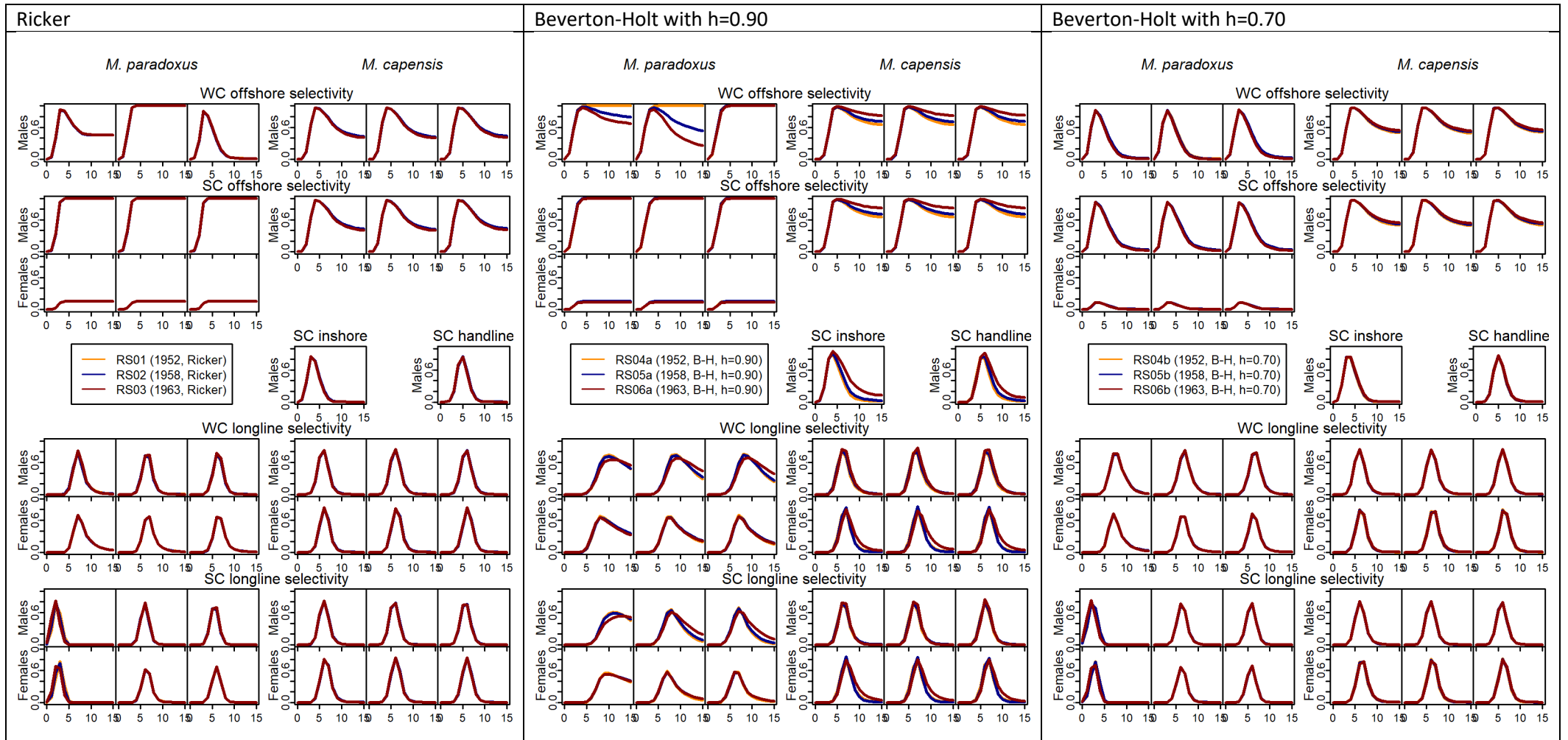


Figure C. 7b: The estimated commercial selectivity-at-age functions are shown in this Figure.

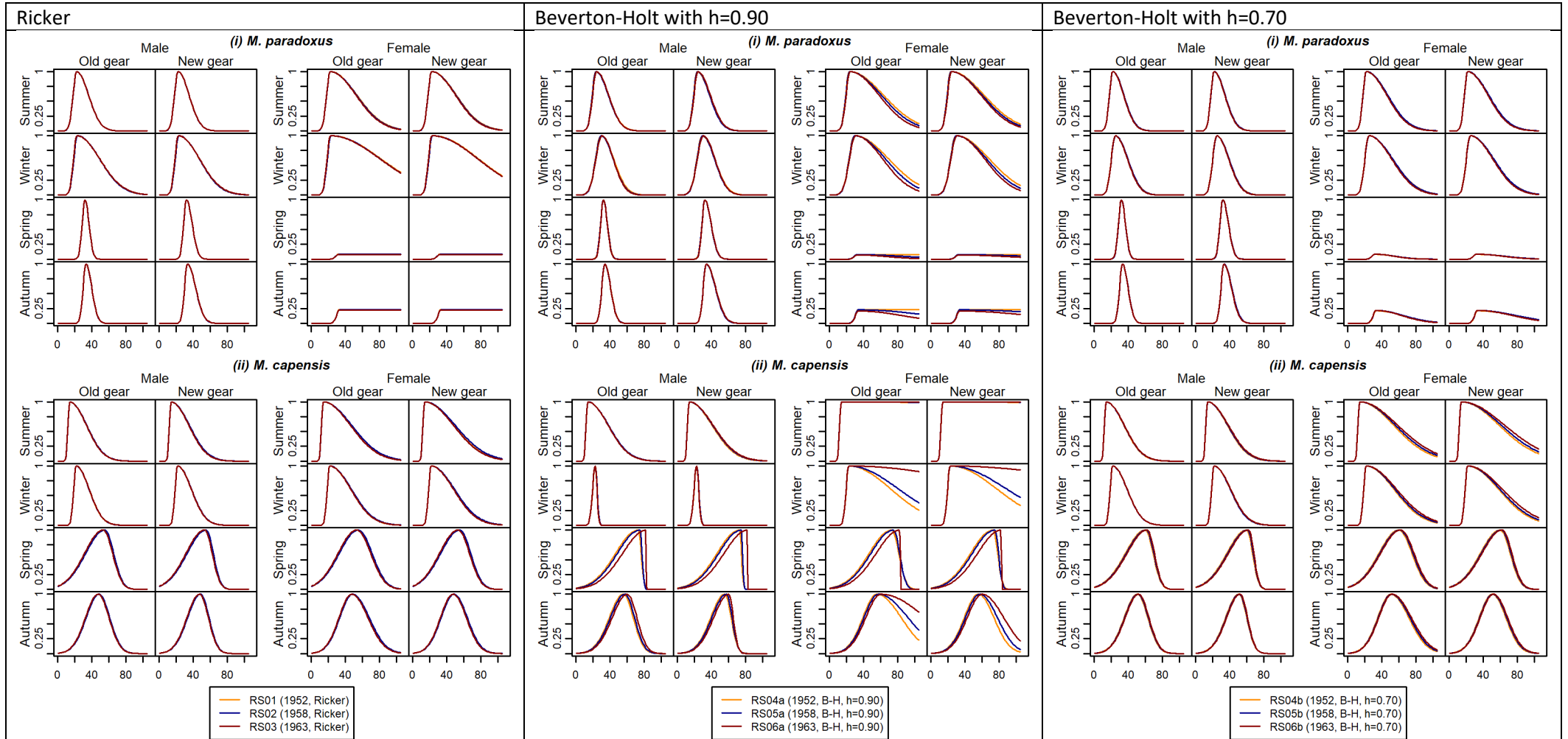


Figure C. 8a: Estimated survey selectivity-at-length functions are shown in this Figure.

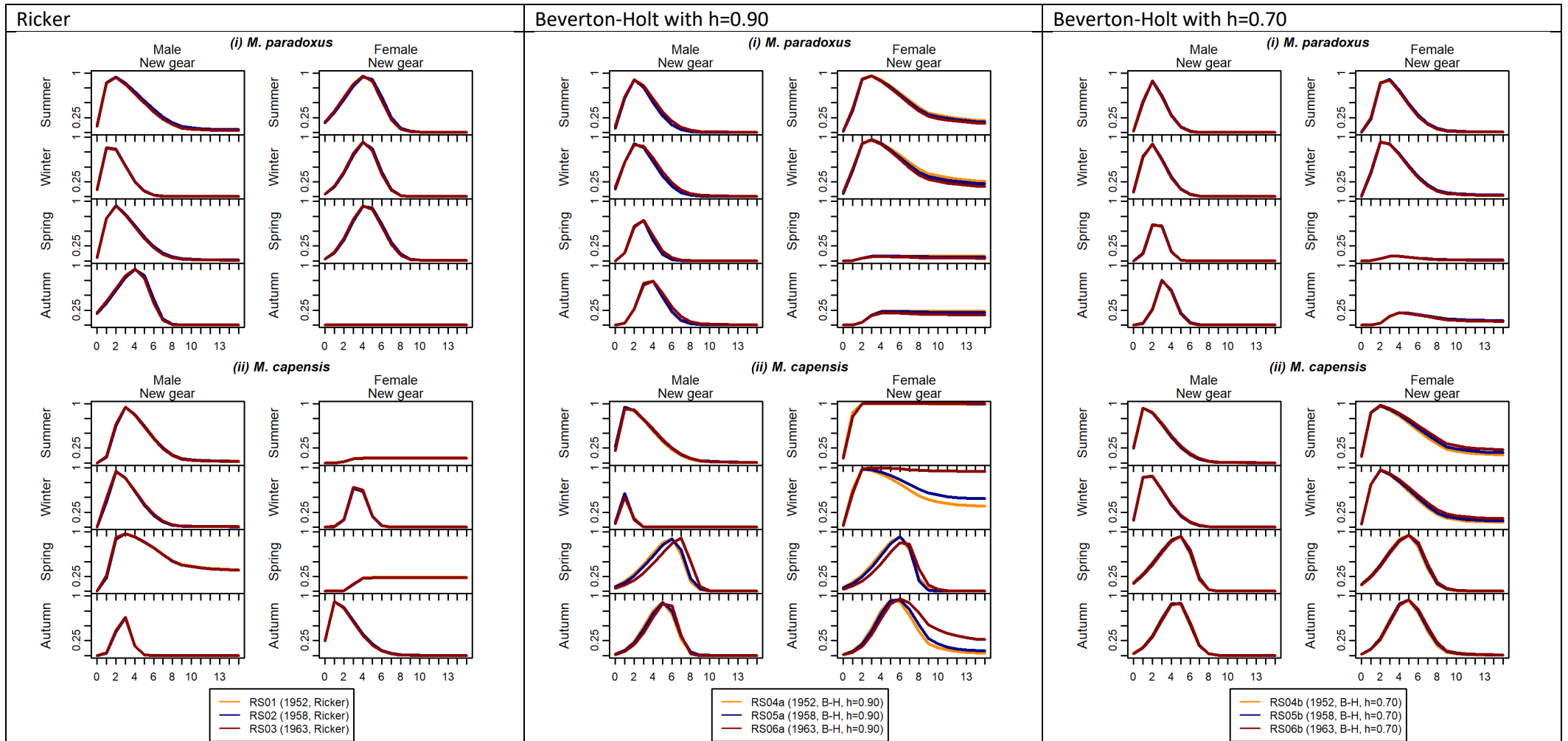


Figure C. 9b: Estimated survey selectivity-at-age functions are shown in this Figure. Selectivities are shown for the new gear only, as the old gear selectivity-at-age functions have not been coded into the standard assessment output at this point in time.

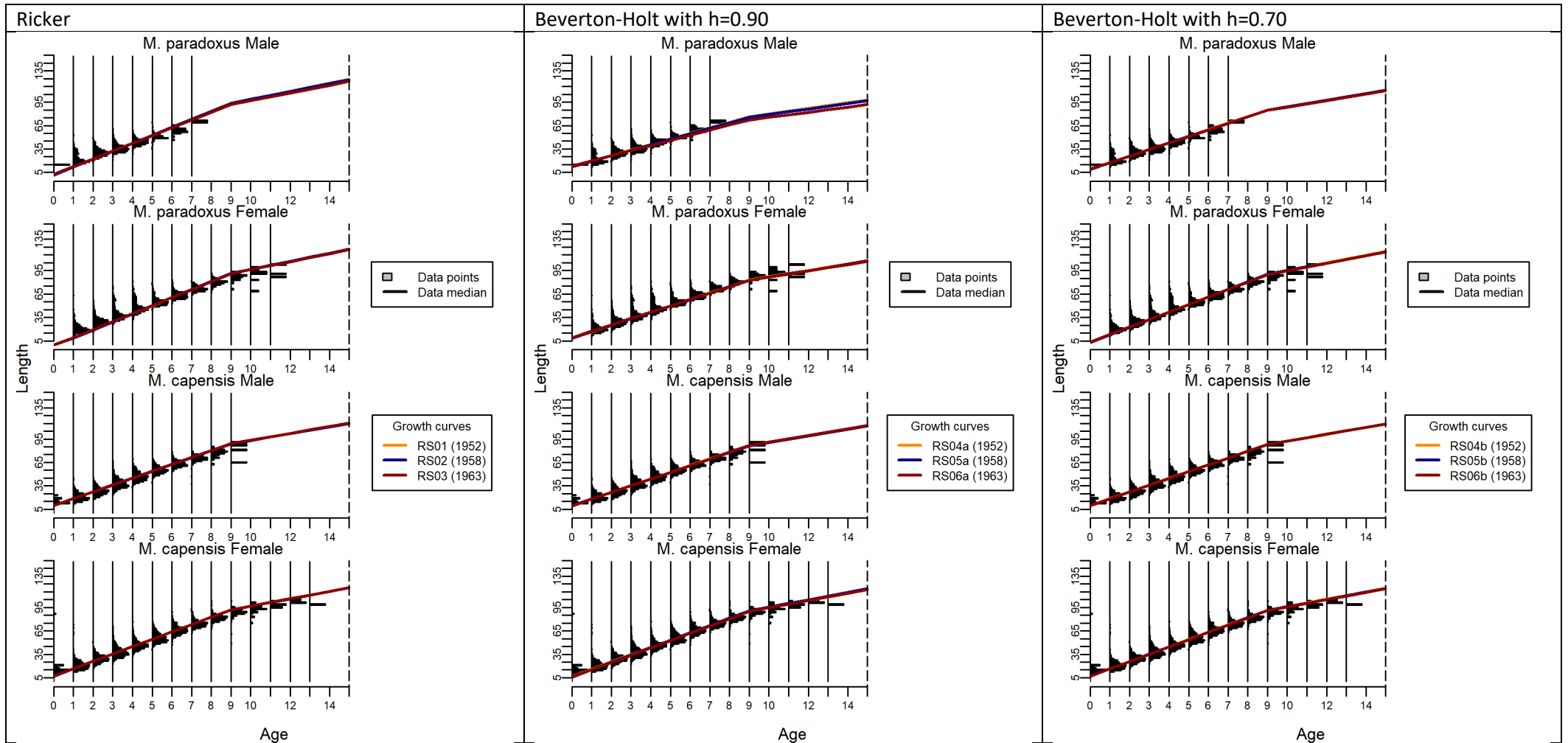


Figure C. 10: The estimated growth curves are superimposed on the length-at-age distributions derived from the age-length-key data.

Appendix D: Restricting the survey q values for the central year OMs

Some of the updated RS OMs, particularly the Beverton-Holt models which estimate a very depleted *M. capensis* population, estimate survey catchability coefficients q that are hardly realistic (for example the 1958 Beverton-Holt run with $h=0.90$ estimates that the autumn survey *M. capensis* biomass estimates are six times the actual exploitable biomass available to the survey – these q values are reported in Table C. 1a-c).

The three central year OMs (i.e. 1958 for Ricker, Beverton-Holt with $h=0.90$ and $h=0.70$) were reconditioned with restrictions on the survey q values: (i) a run where $0.67 < q < 1$ for the summer and autumn surveys with the old gear (as these correspond to the longest time series) and (ii) a run where $0.67 < q < 1$ for all the surveys. A value of 0.67 was chosen as it seems reasonable to assume that a survey should capture at least two thirds of the total biomass. These runs were then projected forward under OMP2018 to ascertain whether the OMP still performs adequately with these changed assumptions.

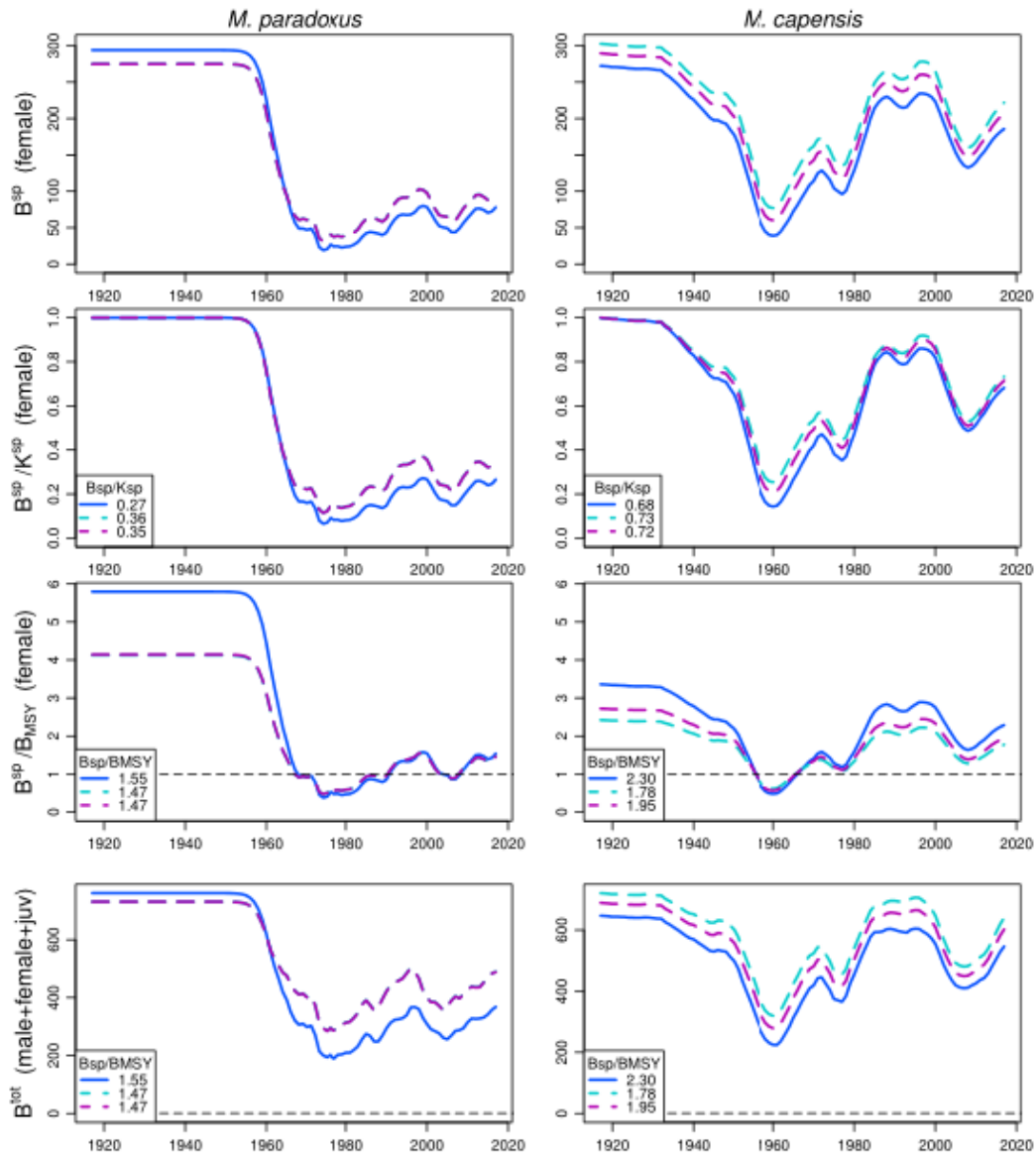
Figure D. 1 to Figure D. 3 show the spawning biomass trajectories and negative log-likelihood tables for the three central year OMs and the two variants for each. As would be expected, in all cases the negative log-likelihoods are worse when bounds are placed on the q values.

For the Ricker OMs (Figure D. 1), the increase in estimated abundance for later years (to which survey data are fit and to which the q values apply) is not as great as one would have expected given the reduction in q . The reason for this is that the model ameliorates the impact of the restriction by adjusting the selectivity functions (in particular the summer survey selectivities) in a direction that relatively more older fish are exploited by the surveys, i.e. an increase in exploitable biomass and a decrease in cryptic biomass.

For the Beverton-Holt ($h=0.90$) OMs (Figure D. 2), the results switch to “high *M. capensis*” solutions when restrictions are placed on the survey q 's. While it is possible and perhaps even likely that there are alternative “low *M. capensis*” solutions with a similar or slightly better likelihood, these were not found despite extensive jittering.

For the Beverton-Holt ($h=0.70$) OMs (Figure D. 3), a similar situation occurred to that for the Ricker models where the q values were reduced without notable change to the absolute biomass, again through adjustment of the selectivity functions. Note that in Figure D. 3, results for an additional run have been included for an alternative to variant (i) (i.e. $0.67 < q < 1$ for the summer and autumn surveys) where the current status of the *M. capensis* is estimated to be much higher, but the difference in negative log-likelihood points is only just under 6. While this is still a notable difference in negative log-likelihood, it illustrates the multi-modal surface of the likelihood – for most of the Beverton-Holt models there appear to be at least two modes, one with an appreciably depleted *M. capensis* population and one where it is estimated to be less depleted (and well above B_{MSY}). While the mode corresponding to the more depleted status generally has a somewhat better negative log-likelihood, instances have occurred during various stages of the RS conditioning where the likelihoods were very similar, suggesting that the *M. capensis* depletion level is not very well-defined.

Projections under OMP2018 (Figure D. 4) indicate that both species are likely to have recovered to close to or above B_{MSY} by 2042 (the end of the projection period), despite this uncertainty about the status of *M. capensis* in 2022 (the end of the lifespan of OMP2018). Again, it should be noted that the negative log-likelihoods for the three Ricker models are substantially better than for the Beverton-Holt models, so that arguably more credibility should be accorded to these models which estimate the *M. capensis* population to be well above B_{MSY} .



Run	GLM CPUE	ICSEAF CPUE	Survey abun.	Comm. CAL	Survey CAL	Recruit. resid.	ALKs	Penalties	Total (w/o pen.)
RS02 (Ricker, 1958)	-203.88	-37.74	-34.69	-1508.45	-1502.68	9.37	123.55	0.06	-3154.52
(i) Restrict sum. & autumn	5.49	3.89	3.30	2.06	-5.03	0.32	-0.69	-0.00	9.33
(ii) 0.67 < q < 1 for all surveys	5.37	3.85	3.81	1.71	-4.66	0.46	-0.76	0.01	9.78

Figure D. 1: Spawning biomass trajectories and negative log-likelihood table for the central year **Ricker** model and two variants where the survey q 's are restricted: (i) $0.67 < q < 1$ for the old gear summer and autumn surveys and (ii) $0.67 < q < 1$ for all surveys. The negative log-likelihood values for (i) and (ii) are shown relative to the RS OM values in the first row.

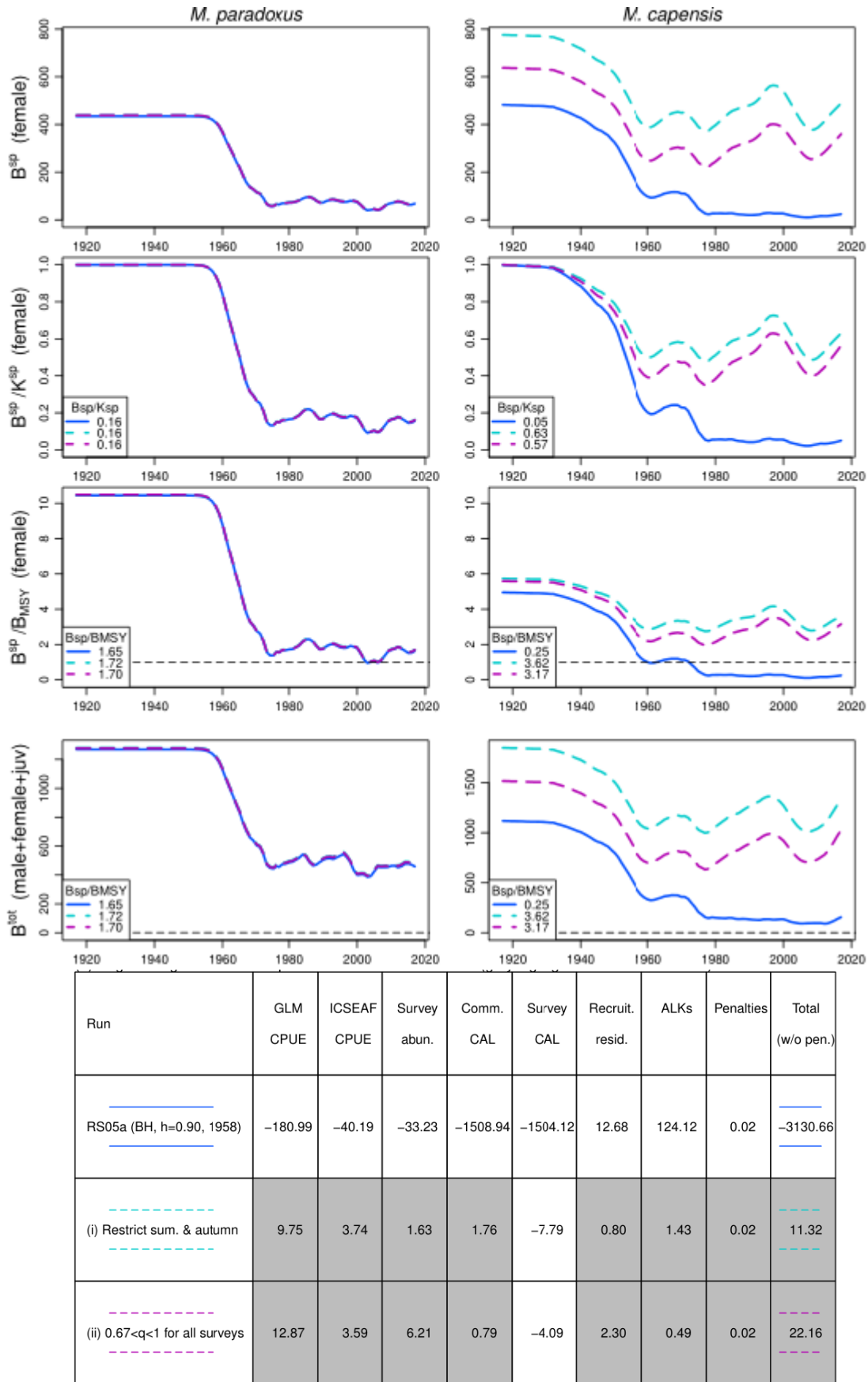


Figure D. 2: Results are shown for the central year **Beverton-Holt (with $h=0.90$)** model and the two variants restricting the survey q 's as for Figure D. 1.

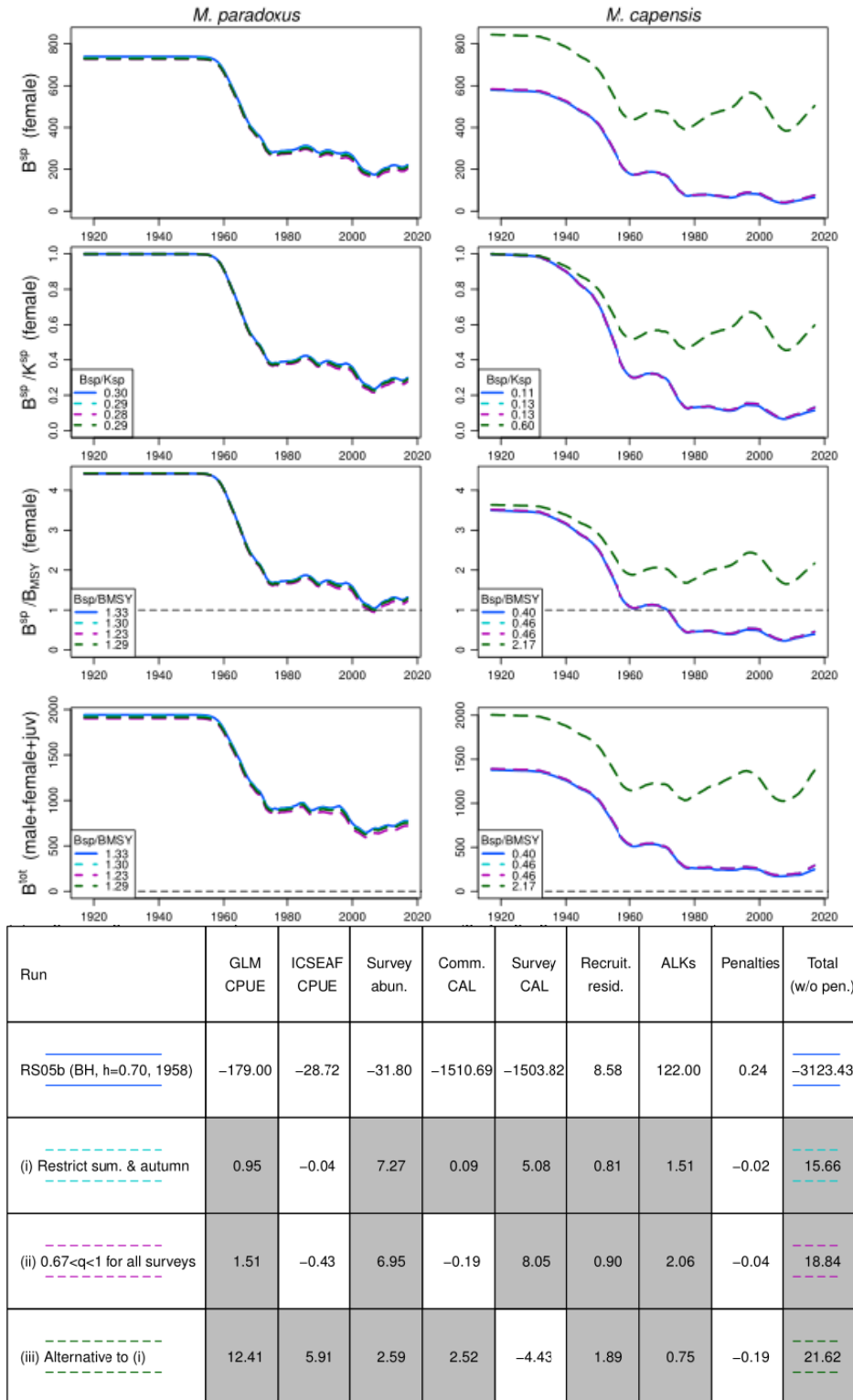


Figure D. 3: Similar results are shown for the central year **Beverton-Holt (with $h=0.70$)** model and the two variants restricting the survey q 's as for Figure D. 1. Results for an alternative to (i) where a much less depleted *M. capensis* population is estimated, but the negative log-likelihood is reasonably similar to that of run (i), are also shown.

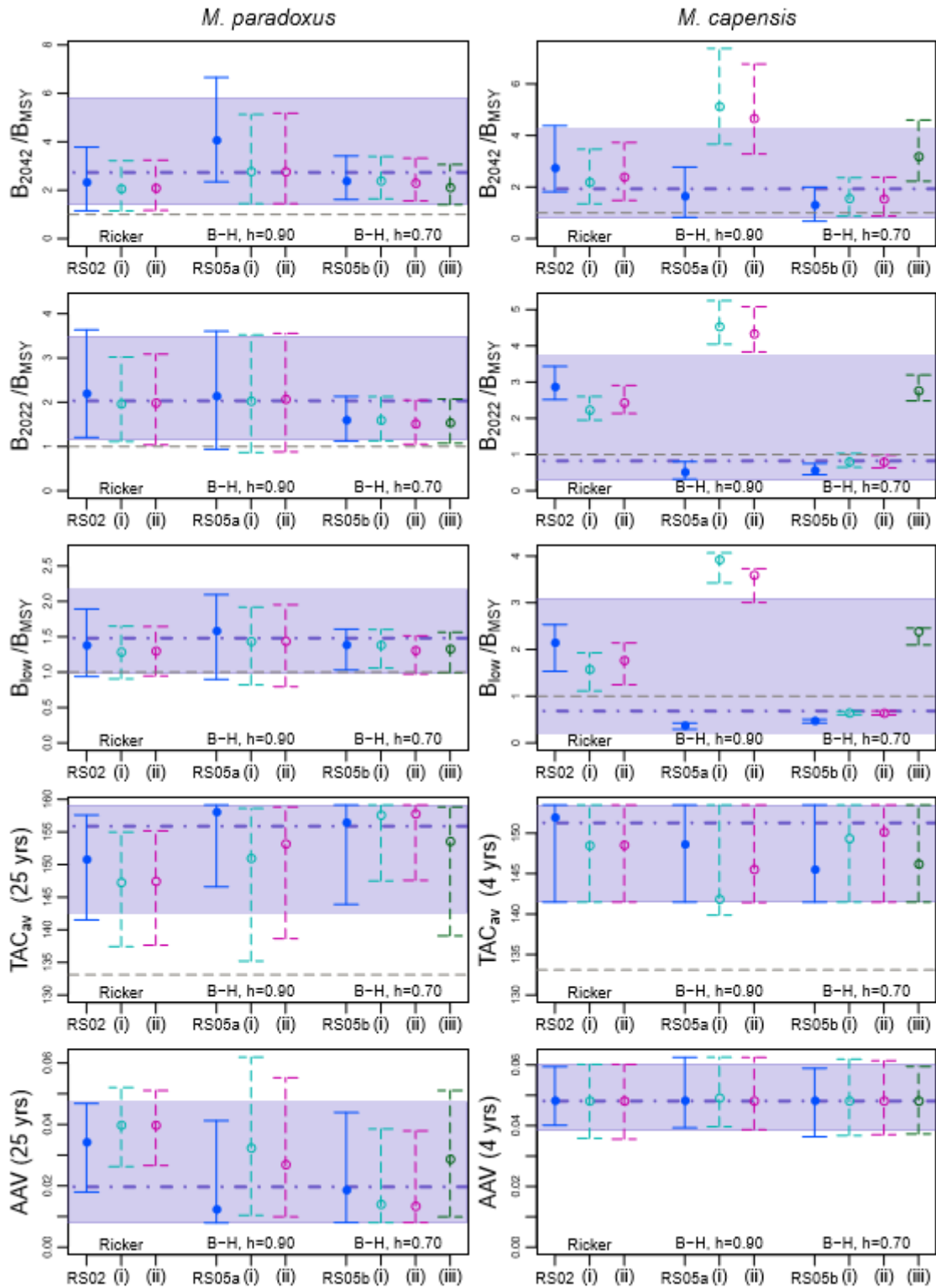


Figure D. 4: Zeh plots comparing the performance statistics of the three central year RS OMs (filled dots indicate medians and solid blue lines the 90% probability envelopes) with variants where (i) the survey q 's are confined between 0.67 and 1 for the old gear summer and autumn surveys (light blue dashed lines) and (ii) where the survey q 's are restricted between 0.67 and 1 for all the surveys (purple dashed lines). The third run for RS05b is an alternative to RS05b(i) with a less depleted *M. capensis* population but similar negative log-likelihood.

Appendix E: Convergence statistics for the RC OM

This Appendix reports on convergence statistics for the updated Reference Case OM (i.e. the Ricker OM with central year 1958). For each of the estimable parameters (note that h for *M. capensis* was fixed in order to obtain a positive definite Hessian), the tables in this Appendix report the following.

“Est (std)” - the parameter estimate with the standard deviation in parenthesis.

“|Grad|” - the modulus of the gradient – the colour scale in the tables indicates the magnitude of the gradients, with white for the smallest gradients and black for the largest.

“LB” and “UB” - the lower and upper bounds enforced.

“Pos” - the position of the estimate within the bounds: if x is the parameter estimate and the bounds are $[a,b]$, then the position within the bounds is calculated as $(x-a)/(b-a)$, i.e. a value of 0 indicates the parameter estimate is at the lower bound and a value of 1 that the estimate is at the upper bound. Cases within 0.05 of 0 and 1 are highlighted in red.

“Phase” – the phase in which the parameter in question was estimated.

Parameter	Est (Std)	Grad	LB	UB	Pos	Phase
1. par_B0[1]	5.684 (0.084)	6.55e-04	3.5	10.0	0.34	1
2. par_B0[2]	5.608 (0.051)	3.56e-03	3.5	10.0	0.32	1
3. h[1]	1.639 (0.116)	3.11e-04	0.5	2.0	0.76	1
4. SRgamma[1]	0.435 (0.106)	3.68e-04	0.0	2.0	0.22	1
5. SRgamma[2]	0.883 (0.158)	2.95e-04	0.0	2.0	0.44	1
6. Addvar[1]	0.178 (0.046)	3.71e-05	0.0	0.5	0.36	1
7. Addvar[2]	0.144 (0.032)	1.80e-05	0.0	0.5	0.29	1
8. Inqold(1)	0.670 (0.145)	4.75e-04	-5.0	2.0	0.81	1
9. Inqold(2)	0.258 (0.337)	3.45e-04	-5.0	2.0	0.75	1
10. Inqold(3)	0.064 (0.269)	1.23e-04	-5.0	2.0	0.72	1
11. Inqold(4)	0.174 (0.211)	2.33e-04	-5.0	2.0	0.74	1
12. Inqold(5)	0.058 (0.206)	8.61e-05	-5.0	2.0	0.72	1
13. Inqold(6)	0.129 (0.344)	4.63e-05	-5.0	2.0	0.73	1
14. Inqold(7)	-0.075 (0.182)	1.85e-04	-5.0	2.0	0.70	1
15. Inqold(8)	0.181 (0.115)	6.81e-05	-5.0	2.0	0.74	1
16. Inqnew(1)	0.550 (0.147)	1.12e-04	-2.0	2.0	0.64	1
17. Inqnew(2)	-0.020 (0.270)	1.84e-04	-2.0	2.0	0.50	1
18. Inqnew(3)	0.016 (0.213)	6.55e-05	-2.0	2.0	0.50	1
19. Inqnew(4)	-0.346 (0.209)	8.46e-05	-2.0	2.0	0.41	1
20. Inqnew(5)	-0.476 (0.181)	2.21e-04	-2.0	2.0	0.38	1
21. Inqnew(6)	-0.238 (0.116)	1.47e-04	-2.0	2.0	0.44	1
22. RecPar1(1985)	-0.420 (0.210)	1.12e-04	-5.0	5.0	0.46	2
23. RecPar1(1986)	-0.126 (0.214)	5.59e-05	-5.0	5.0	0.49	2
24. RecPar1(1987)	0.273 (0.172)	1.60e-04	-5.0	5.0	0.53	2
25. RecPar1(1988)	0.006 (0.205)	1.10e-05	-5.0	5.0	0.50	2
26. RecPar1(1989)	0.084 (0.192)	5.97e-05	-5.0	5.0	0.51	2
27. RecPar1(1990)	0.085 (0.205)	3.62e-05	-5.0	5.0	0.51	2
28. RecPar1(1991)	0.064 (0.205)	2.37e-05	-5.0	5.0	0.51	2
29. RecPar1(1992)	-0.152 (0.246)	5.91e-04	-5.0	5.0	0.48	2
30. RecPar1(1993)	0.270 (0.202)	7.03e-05	-5.0	5.0	0.53	2
31. RecPar1(1994)	0.174 (0.246)	2.02e-04	-5.0	5.0	0.52	2
32. RecPar1(1995)	0.260 (0.212)	6.00e-04	-5.0	5.0	0.53	2
33. RecPar1(1996)	-0.192 (0.256)	2.82e-04	-5.0	5.0	0.48	2
34. RecPar1(1997)	-0.098 (0.234)	7.41e-04	-5.0	5.0	0.49	2
35. RecPar1(1998)	-0.252 (0.268)	3.62e-04	-5.0	5.0	0.47	2
36. RecPar1(1999)	-0.298 (0.277)	1.89e-04	-5.0	5.0	0.47	2
37. RecPar1(2000)	0.081 (0.224)	2.98e-04	-5.0	5.0	0.51	2
38. RecPar1(2001)	0.090 (0.210)	4.21e-04	-5.0	5.0	0.51	2
39. RecPar1(2002)	-0.374 (0.249)	2.36e-04	-5.0	5.0	0.46	2
40. RecPar1(2003)	-0.102 (0.192)	7.98e-06	-5.0	5.0	0.49	2
41. RecPar1(2004)	0.288 (0.151)	1.17e-04	-5.0	5.0	0.53	2
42. RecPar1(2005)	0.162 (0.175)	3.02e-05	-5.0	5.0	0.52	2
43. RecPar1(2006)	-0.145 (0.232)	4.24e-04	-5.0	5.0	0.49	2
44. RecPar1(2007)	0.060 (0.235)	7.40e-05	-5.0	5.0	0.51	2
45. RecPar1(2008)	0.094 (0.241)	8.86e-05	-5.0	5.0	0.51	2
46. RecPar1(2009)	-0.129 (0.260)	1.98e-04	-5.0	5.0	0.49	2
47. RecPar1(2010)	-0.017 (0.231)	7.12e-05	-5.0	5.0	0.50	2
48. RecPar1(2011)	-0.195 (0.269)	3.97e-04	-5.0	5.0	0.48	2
49. RecPar1(2012)	0.144 (0.233)	1.91e-04	-5.0	5.0	0.51	2
50. RecPar1(2013)	0.143 (0.257)	3.84e-05	-5.0	5.0	0.51	2
51. RecPar1(2014)	0.263 (0.260)	4.65e-04	-5.0	5.0	0.53	2

Parameter	Est (Std)	Grad	LB	UB	Pos	Phase
52. RecPar1(2015)	0.004 (0.260)	2.45e-04	-5.0	5.0	0.50	2
53. RecPar1(2016)	-0.029 (0.185)	1.40e-04	-5.0	5.0	0.50	2
54. RecPar1(2017)	-0.016 (0.100)	4.43e-04	-5.0	5.0	0.50	2
55. RecPar2(1985)	-0.054 (0.243)	5.98e-04	-5.0	5.0	0.49	2
56. RecPar2(1986)	0.185 (0.233)	5.83e-04	-5.0	5.0	0.52	2
57. RecPar2(1987)	0.522 (0.212)	2.70e-04	-5.0	5.0	0.55	2
58. RecPar2(1988)	0.572 (0.214)	5.71e-05	-5.0	5.0	0.56	2
59. RecPar2(1989)	0.539 (0.193)	3.21e-04	-5.0	5.0	0.55	2
60. RecPar2(1990)	0.379 (0.186)	5.02e-04	-5.0	5.0	0.54	2
61. RecPar2(1991)	0.179 (0.195)	1.22e-04	-5.0	5.0	0.52	2
62. RecPar2(1992)	0.037 (0.218)	2.33e-04	-5.0	5.0	0.50	2
63. RecPar2(1993)	0.279 (0.202)	9.42e-06	-5.0	5.0	0.53	2
64. RecPar2(1994)	0.201 (0.209)	6.51e-05	-5.0	5.0	0.52	2
65. RecPar2(1995)	-0.029 (0.227)	1.77e-04	-5.0	5.0	0.50	2
66. RecPar2(1996)	0.143 (0.207)	8.35e-05	-5.0	5.0	0.51	2
67. RecPar2(1997)	0.121 (0.199)	1.17e-04	-5.0	5.0	0.51	2
68. RecPar2(1998)	-0.099 (0.213)	3.57e-04	-5.0	5.0	0.49	2
69. RecPar2(1999)	-0.121 (0.210)	1.65e-04	-5.0	5.0	0.49	2
70. RecPar2(2000)	0.041 (0.183)	7.44e-05	-5.0	5.0	0.50	2
71. RecPar2(2001)	-0.180 (0.181)	1.45e-04	-5.0	5.0	0.48	2
72. RecPar2(2002)	-0.367 (0.182)	3.01e-05	-5.0	5.0	0.46	2
73. RecPar2(2003)	-0.156 (0.161)	2.08e-05	-5.0	5.0	0.48	2
74. RecPar2(2004)	-0.028 (0.153)	1.10e-04	-5.0	5.0	0.50	2
75. RecPar2(2005)	-0.049 (0.165)	5.35e-05	-5.0	5.0	0.50	2
76. RecPar2(2006)	-0.204 (0.195)	1.94e-04	-5.0	5.0	0.48	2
77. RecPar2(2007)	-0.215 (0.204)	3.51e-04	-5.0	5.0	0.48	2
78. RecPar2(2008)	-0.243 (0.209)	1.79e-04	-5.0	5.0	0.48	2
79. RecPar2(2009)	-0.613 (0.250)	6.94e-05	-5.0	5.0	0.44	2
80. RecPar2(2010)	-0.473 (0.243)	1.58e-04	-5.0	5.0	0.45	2
81. RecPar2(2011)	-0.357 (0.245)	1.50e-04	-5.0	5.0	0.46	2
82. RecPar2(2012)	-0.361 (0.283)	1.51e-04	-5.0	5.0	0.46	2
83. RecPar2(2013)	0.102 (0.273)	8.79e-06	-5.0	5.0	0.51	2
84. RecPar2(2014)	0.049 (0.294)	1.50e-04	-5.0	5.0	0.50	2
85. RecPar2(2015)	0.191 (0.261)	2.57e-04	-5.0	5.0	0.52	2
86. RecPar2(2016)	0.013 (0.185)	2.18e-05	-5.0	5.0	0.50	2
87. RecPar2(2017)	-0.003 (0.100)	3.41e-05	-5.0	5.0	0.50	2
88. survpar(1)	3.116 (0.042)	1.01e-03	-10.0	10.0	0.66	3
89. survpar(2)	1.447 (0.097)	8.82e-05	-10.0	10.0	0.57	3
90. survpar(3)	2.629 (0.144)	4.99e-04	-10.0	10.0	0.63	3
91. survpar(4)	3.152 (0.181)	1.04e-04	-10.0	10.0	0.66	3
92. survpar(5)	1.444 (0.354)	2.74e-04	-10.0	10.0	0.57	3
93. survpar(6)	3.266 (0.926)	2.96e-04	-10.0	10.0	0.66	3
94. survpar(7)	3.475 (0.038)	8.32e-04	-10.0	10.0	0.67	3
95. survpar(8)	1.192 (0.214)	2.33e-05	-10.0	10.0	0.56	3
96. survpar(9)	1.539 (0.308)	2.28e-04	-10.0	10.0	0.58	3
97. survpar(10)	3.511 (0.038)	2.40e-04	-10.0	10.0	0.68	3
98. survpar(11)	1.223 (0.172)	3.87e-05	-10.0	10.0	0.56	3
99. survpar(12)	1.892 (0.219)	1.52e-04	-10.0	10.0	0.59	3
100. survpar(13)	2.661 (0.113)	1.27e-04	-10.0	10.0	0.63	3
101. survpar(14)	0.675 (0.375)	2.08e-04	-10.0	10.0	0.53	3
102. survpar(15)	2.991 (0.152)	6.63e-04	-10.0	10.0	0.65	3

Parameter	Est (Std)	Grad	LB	UB	Pos	Phase
103. survpar(16)	3.083 (0.091)	3.31e-05	-10.0	10.0	0.65	3
104. survpar(17)	1.053 (0.336)	3.27e-04	-10.0	10.0	0.55	3
105. survpar(18)	2.727 (0.304)	1.50e-05	-10.0	10.0	0.64	3
106. survpar(19)	4.017 (0.105)	1.75e-05	-10.0	10.0	0.70	3
107. survpar(20)	3.112 (0.162)	8.48e-05	-10.0	10.0	0.66	3
108. survpar(21)	2.339 (0.368)	8.00e-05	-10.0	10.0	0.62	3
109. survpar(22)	3.887 (0.047)	2.03e-03	-10.0	10.0	0.69	3
110. survpar(23)	2.710 (0.088)	6.68e-04	-10.0	10.0	0.64	3
111. survpar(24)	2.527 (0.155)	5.88e-04	-10.0	10.0	0.63	3
112. gearpar(1)	-0.078 (0.150)	2.92e-04	-4.0	4.0	0.49	3
113. gearpar(2)	0.356 (0.237)	5.46e-05	-4.0	4.0	0.54	3
114. gearpar(3)	0.072 (0.117)	1.46e-04	-4.0	4.0	0.51	3
115. gearpar(4)	-0.225 (0.124)	1.25e-04	-4.0	4.0	0.47	3
116. sexpar(1)	0.798 (0.192)	4.62e-04	-10.0	20.0	0.36	3
117. sexpar(2)	11.231 (8779)	8.44e-08	-10.0	20.0	0.71	3
118. sexpar(3)	0.518 (0.210)	8.14e-04	-10.0	20.0	0.35	3
119. sexpar(4)	0.439 (0.140)	4.61e-04	-10.0	20.0	0.35	3
120. SelScaling[3]	0.081 (0.037)	7.53e-05	0.0	1.0	0.03	3
121. SelScaling[4]	0.228 (0.068)	4.94e-05	0.0	1.0	0.19	3
122. WCOffpara2(1)	3.482 (0.029)	1.82e-02	-20.0	20.0	0.59	4
123. WCOffpara2(2)	1.359 (0.115)	1.97e-03	-20.0	20.0	0.53	4
124. WCOffpara2(3)	14.579 (10959)	3.33e-09	-20.0	20.0	0.86	4
125. WCOffpara3(1)	3.517 (0.021)	9.72e-03	-20.0	20.0	0.59	4
126. WCOffpara3(2)	1.215 (0.090)	8.05e-04	-20.0	20.0	0.53	4
127. WCOffpara3(3)	3.144 (0.113)	1.16e-03	-20.0	20.0	0.58	4
128. SCOffpara3(1)	3.536 (0.028)	3.48e-03	-20.0	20.0	0.59	4
129. SCOffpara3(2)	1.177 (0.119)	1.19e-04	-20.0	20.0	0.53	4
130. SCOffpara3(3)	15.860 (27932)	9.88e-08	-20.0	20.0	0.90	4
131. WCLLpara_M(1)	4.362 (0.024)	1.92e-02	-20.0	20.0	0.61	4
132. WCLLpara_M(2)	2.170 (0.059)	4.99e-03	-20.0	20.0	0.55	4
133. WCLLpara_M(3)	2.095 (0.116)	5.41e-04	-20.0	20.0	0.55	4
134. WCLLpara_F(1)	4.346 (0.017)	3.16e-02	-20.0	20.0	0.61	4
135. WCLLpara_F(2)	2.004 (0.047)	6.53e-03	-20.0	20.0	0.55	4
136. WCLLpara_F(3)	2.139 (0.069)	3.36e-04	-20.0	20.0	0.55	4
137. SCLLpara_M(1)	3.329 (1.483)	1.42e-02	-20.0	20.0	0.58	4
138. SCLLpara_M(2)	1.901 (0.264)	9.83e-03	-20.0	20.0	0.55	4
139. SCLLpara_M(3)	2.066 (0.415)	1.45e-03	-20.0	20.0	0.55	4
140. SCLLpara_F(1)	3.510 (1.236)	1.26e-03	-20.0	20.0	0.59	4
141. SCLLpara_F(2)	2.131 (0.238)	3.57e-04	-20.0	20.0	0.55	4
142. SCLLpara_F(3)	1.634 (0.614)	4.18e-04	-20.0	20.0	0.54	4
143. WCLLpara_shift(1)	5.624 (1.203)	2.35e-04	-20.0	20.0	0.64	4
144. WCLLpara_shift(2)	7.387 (1.259)	1.50e-04	-20.0	20.0	0.68	4
145. SCLLpara_shift(1)	-38.186 (41.210)	1.77e-04	-50.0	20.0	0.17	4
146. SCLLpara_shift(2)	-33.878 (41.185)	6.11e-04	-50.0	20.0	0.23	4
147. SCInshcap(1)	3.676 (0.020)	5.30e-03	-20.0	20.0	0.59	4
148. SCInshcap(2)	1.499 (0.074)	4.04e-05	-20.0	20.0	0.54	4
149. SCInshcap(3)	2.719 (0.053)	4.64e-03	-20.0	20.0	0.57	4
150. WCLLcap_M(1)	4.155 (0.028)	1.95e-03	-20.0	20.0	0.60	4
151. WCLLcap_M(2)	2.000 (0.096)	4.35e-04	-20.0	20.0	0.55	4
152. WCLLcap_M(3)	2.293 (0.105)	2.09e-04	-20.0	20.0	0.56	4
153. WCLLcap_F(1)	4.239 (0.021)	1.15e-02	-20.0	20.0	0.61	4

Parameter	Est (Std)	Grad	LB	UB	Pos	Phase
154. WLLcap_F(2)	2.092 (0.061)	1.07e-03	-20.0	20.0	0.55	4
155. WLLcap_F(3)	2.200 (0.075)	2.63e-03	-20.0	20.0	0.56	4
156. SLLcap_M(1)	4.178 (0.026)	1.02e-03	-20.0	20.0	0.60	4
157. SLLcap_M(2)	1.863 (0.103)	1.45e-04	-20.0	20.0	0.55	4
158. SLLcap_M(3)	2.207 (0.107)	5.09e-04	-20.0	20.0	0.56	4
159. SLLcap_F(1)	4.260 (0.021)	9.05e-03	-20.0	20.0	0.61	4
160. SLLcap_F(2)	2.040 (0.072)	6.50e-04	-20.0	20.0	0.55	4
161. SLLcap_F(3)	2.245 (0.081)	2.20e-03	-20.0	20.0	0.56	4
162. WLLcap_shift(1)	-1.312 (1.039)	1.05e-05	-20.0	20.0	0.47	4
163. WLLcap_shift(2)	0.162 (1.073)	6.73e-05	-20.0	20.0	0.50	4
164. SLLcap_shift(1)	2.434 (0.889)	1.37e-04	-20.0	20.0	0.56	4
165. SLLcap_shift(2)	3.424 (0.922)	1.89e-04	-20.0	20.0	0.59	4
166. cpue_sig[4]	0.164 (0.026)	1.02e-05	0.1	1.0	0.02	1
167. cpue_sig[5]	0.158 (0.022)	9.31e-05	0.1	1.0	0.01	1
168. cpue_sig[6]	0.222 (0.027)	3.88e-05	0.1	1.0	0.08	1
169. gamma	0.004 (0.067)	3.13e-03	0.0	1.0	0.00	1
170. qC1_1	0.118 (0.022)	2.15e-04	0.0	10.0	0.01	1
171. qC2_1	9.810 (166)	2.60e-05	0.0	10.0	0.98	1
172. qP_1	0.038 (0.004)	3.54e-03	0.0	10.0	0.00	1
173. CR	0.073 (0.010)	3.92e-05	0.0	10.0	0.01	1
174. Bi0_mcapm	2.360 (0.616)	1.33e-04	0.0	20.0	0.12	1
175. Bi0_mcapf	2.778 (0.597)	2.75e-04	0.0	20.0	0.14	1
176. Bipar1(1,1)	4.684 (0.489)	1.93e-04	0.0	20.0	0.23	1
177. Bipar1(1,2)	4.232 (0.388)	1.53e-04	0.0	20.0	0.21	1
178. Bipar1(2,1)	4.533 (0.810)	5.50e-05	0.0	20.0	0.23	1
179. Bipar1(2,2)	5.087 (0.686)	2.09e-04	0.0	20.0	0.25	1
180. Bipar14(1,1)	8.595 (4.798)	4.73e-05	0.0	20.0	0.43	1
181. Bipar14(1,2)	12.550 (2.785)	3.66e-05	0.0	20.0	0.63	1
182. Bipar14(2,1)	6.771 (3.434)	1.69e-05	0.0	20.0	0.34	1
183. Bipar14(2,2)	6.330 (2.170)	1.62e-04	0.0	20.0	0.32	1
184. L2(1,1)	22.036 (1.491)	8.12e-04	5.0	50.0	0.38	1
185. L2(1,2)	18.945 (1.323)	9.61e-04	5.0	50.0	0.31	1
186. L2(2,1)	27.359 (0.711)	3.94e-04	5.0	50.0	0.50	1
187. L2(2,2)	25.935 (0.694)	8.22e-04	5.0	50.0	0.47	1
188. L4(1,1)	42.407 (1.323)	1.96e-05	20.0	70.0	0.45	1
189. L4(1,2)	39.643 (1.031)	1.70e-03	20.0	70.0	0.39	1
190. L4(2,1)	44.892 (0.742)	9.84e-04	20.0	70.0	0.50	1
191. L4(2,2)	44.768 (0.579)	1.14e-03	20.0	70.0	0.50	1