Constant catch projections for the RS for the 2018 hake OMP review

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Summary

The RS Operating Models are projected forward under a range of constant future annual TACs from 130 000t to 160 000t to provide an initial scale on what TACs may maintain the *M. paradoxus* resource above B_{MSY}. A basis for projecting the future ratio of the two hake species in catches is put forward. A constant catch of 140 000t would maintain the *M. paradoxus* resource above B_{MSY} at the 5% probability level. A number of questions are listed for response to aid in the further development of the OMP.

Introduction

The hake Reference Set (RS) Operating Models (OMs) are projected 25 years into the future assuming a range of values for a constant Total Allowable Catch (TAC). There are nine RS models that cover two axes of uncertainty (three options for the central year in which catch shifted from primarily *M. capensis* to *M. paradoxus* crossed with three stock-recruitment relationship options (Modified Ricker and Beverton-Holt with *h* fixed at 0.90 and 0.70)). The full set of results of the conditioning of these RS models is reported in FISHERIES/2018/JUL/SWG-DEM/28; however plots of the spawning biomass trajectories have been included in Figure 1a and b to aid consideration of subsequent results reported in this document.

The methodology for projecting into the future is mostly consistent with the descriptions in Appendix 10.I of Rademeyer (2012), with one notable adjustment concerning the manner in which future fishing mortality rates are generated. The first version of the new method was discussed at a small working group meeting and details of an updated version (that uses a restricted beta function) which has been used for the projections reported in this document can be found in Appendix A. Appendix B provides the equations for deriving the future fishing mortality rates.

Another adjustment that has been made to the projection methodology is that the future TAC is split into fleets using the legal allocations, rather than the ratios derived from recent catches as has been the case in the past. The legal allocations provide a split between offshore trawl, inshore trawl, longline and handline catches, with the trawl catches being further split by coast using the ratios of recent catches. For the results reported in this document, the proportional split between the fleets was thus:

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WC offshore	0.62269
SC offshore	0.21658
SC inshore	0.06179
WC longline	0.05979
SC longline	0.00572
SC handline	0.03343

Note is made here of the fact that catches resulting from surveys have not been included in the projections, as these catches have historically also not been included in the OMs. These catches are not substantial and unlikely to make any difference of note, though should ideally be included for the final set of results. Hake by-catch from the midwater trawl has similarly not been included at the projections at this stage, as some further discussion for clarification is first required.

A revised detailed description of the projection methodology will be provided in due course.

Results

Table 1 summarises the TAC not caught in the simulations when the projected catch-at-age for one or more of the age cohorts exceeds 90% of that cohort (note that these proportions will reduce under an OMP which will set lower catches in years of lower abundance).

Figure 2a-Figure 2c show the median female spawning biomass trajectories projected forward under various levels of constant future catch for the nine RS models. Figure 3a and Figure 3b show the median female spawning biomass trajectories for future constant TACs of 140 000t and 150 000t, along with the 90% probability envelopes (p.e.'s). Figure 4 shows the projected trajectories for the species-combined exploitable biomass with the 90% p.e.'s, while Figure 5a - Figure 5c show projections for commercial trawl CPUE.

Figure 6 provides the equally-weighted averages of the spawning biomass relative to B_{MSY}, the exploitable biomass, a measure of effort and CPUE trajectories across the nine RS models. These values are derived by combining the results of the 100 simulations from all nine RS models, and calculating the median, 5th and 95th percentiles from the resulting 900 values for each year. 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:

$$J_y = \left(1.0 J_y^{WC,para} + .075 J_y^{SC,para}\right)/1.75 \quad (1)$$

with

$$J_y^{WC/SC,para} = \sum_{y'=y-3}^{y-1} I_{y'}^{WC/SC,para} / \sum_{y'=2010}^{2012} I_{y'}^{WC/SC,para} \quad (2)$$

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.

Discussion

Details of the OMP-2014 rules used to set the annual TAC can be found in FISHERIES/2017/OCT/SWG-DEM/41. Some discussion points to aid the development of OMP-2018 are listed below. Figure 6 probably provides an appropriate starting point for their consideration.

1. Given the choice, would 140 000t or 150 000t be preferable as a constant TAC?

   Simulations suggest that a TAC of up to 140 000t would allow for the *M. paradoxus* population to remain above B_{MSY}, with even the lower bound for the 90% p.e. remaining close to or above B_{MSY} (see Figure 3a). At 150 000t the median trajectory remains above B_{MSY}, but for a few scenarios the envelopes do go below this level. The *M. capensis* trajectories remains well above B_{MSY} in all cases except for three of the Beverton-Holt models (plots 4, 7 and 9 of Figure 3b), which are the three models where biomass has little impact on recruitment, though biomass does still show some increase except for the 160 000t TAC.

   There is of course a trade-off between catch levels and catch rates: estimates of exploitable biomass and CPUE are generally constant or increasing under 140 000t, while at 150 000t the median catch rates and the lower bound for the 90% p.e. start to decline.

2. Should the 150 000t cap on TAC in the current OMP remain in place (recall that one reason for this cap was not to have to invest to be able to process catches above this level if they were to occur only infrequently), or should it be increased somewhat?

3. What is more important for industry – keeping CPUE above a certain level, or taking higher catches when possible?

4. What CPUE is desirable compared to that at present?

5. What fleet expansion/contraction policy should the industry pursue?

   Note that Figure 6 (C) indicates near stability: a slight decrease for 140 000t, but a very slight increase for 150 000t.

6. Should the current bounds on inter-annual TAC variation be maintained?

   Under OMP-2014, the maximum allowable annual increase in TAC is 10% and the maximum allowable decrease is 5% (unless the *M. paradoxus* biomass index falls too low).

7. What can be anticipated regarding vessels to be used for future surveys? (This information will also be pertinent to the design of robustness tests.)

Table 1: Summary of future TAC (in thousand tons) not caught in the simulations when the catch-at-age is greater than 90% of the cohort size. Note that the "average TAC not caught per year" is averaged over the years where the whole TAC is not caught.

Model	TAC	Proportion of the 100 simulations for which not all TAC is caught	Average number of years per simulation for which TAC is not caught	Maximum no. of years in any one simulation for which TAC is not caught	Average TAC not caught per year	Maximum TAC not caught in any one year of any one simulation
RS01 (Ricker, CY=1952)	140	0.02	1.5	2	6.01	10.8
RS01 (Ricker, CY=1952)	150	0.12	1.9	6	4.74	5.4
RS02 (Ricker, CY=1958)	140	0.04	1.5	3	5.54	11.5
RS02 (Ricker, CY=1958)	150	0.12	1.9	5	6.18	12.0
RS03 (Ricker, CY=1963)	140	0.06	1.3	2	7.02	11.1
RS03 (Ricker, CY=1963)	150	0.13	2.7	7	5.50	12.9
RS04a (B-H, h=0.90, CY=1952)	140	0.09	1.9	9	9.16	16.3
RS04a (B-H, h=0.90, CY=1952)	150	0.34	2.5	18	10.29	22.1
RS05a (B-H, h=0.90, CY=1958)	140	0.53	2.7	13	6.40	12.2
RS05a (B-H, h=0.90, CY=1958)	150	0.77	4.7	19	7.63	12.8
RS06a (B-H, h=0.90, CY=1963)	140	0.54	2.2	8	6.01	9.7
RS06a (B-H, h=0.90, CY=1963)	150	0.7	3.9	16	6.94	12.3
RS04b (B-H, h=0.70, CY=1952)	140	0.01	8.0	8	7.99	14.0
RS04b (B-H, h=0.70, CY=1952)	150	0.09	3.7	16	14.49	65.8
RS05b (B-H, h=0.70, CY=1958)	140	0.06	1.3	3	8.95	10.9
RS05b (B-H, h=0.70, CY=1958)	150	0.14	2.4	12	9.31	13.3
RS06b (B-H, h=0.70, CY=1963)	140	0.14	2.4	12	9.31	13.3
RS06b (B-H, h=0.70, CY=1963)	150	0.01	2.0	2	18.10	20.1

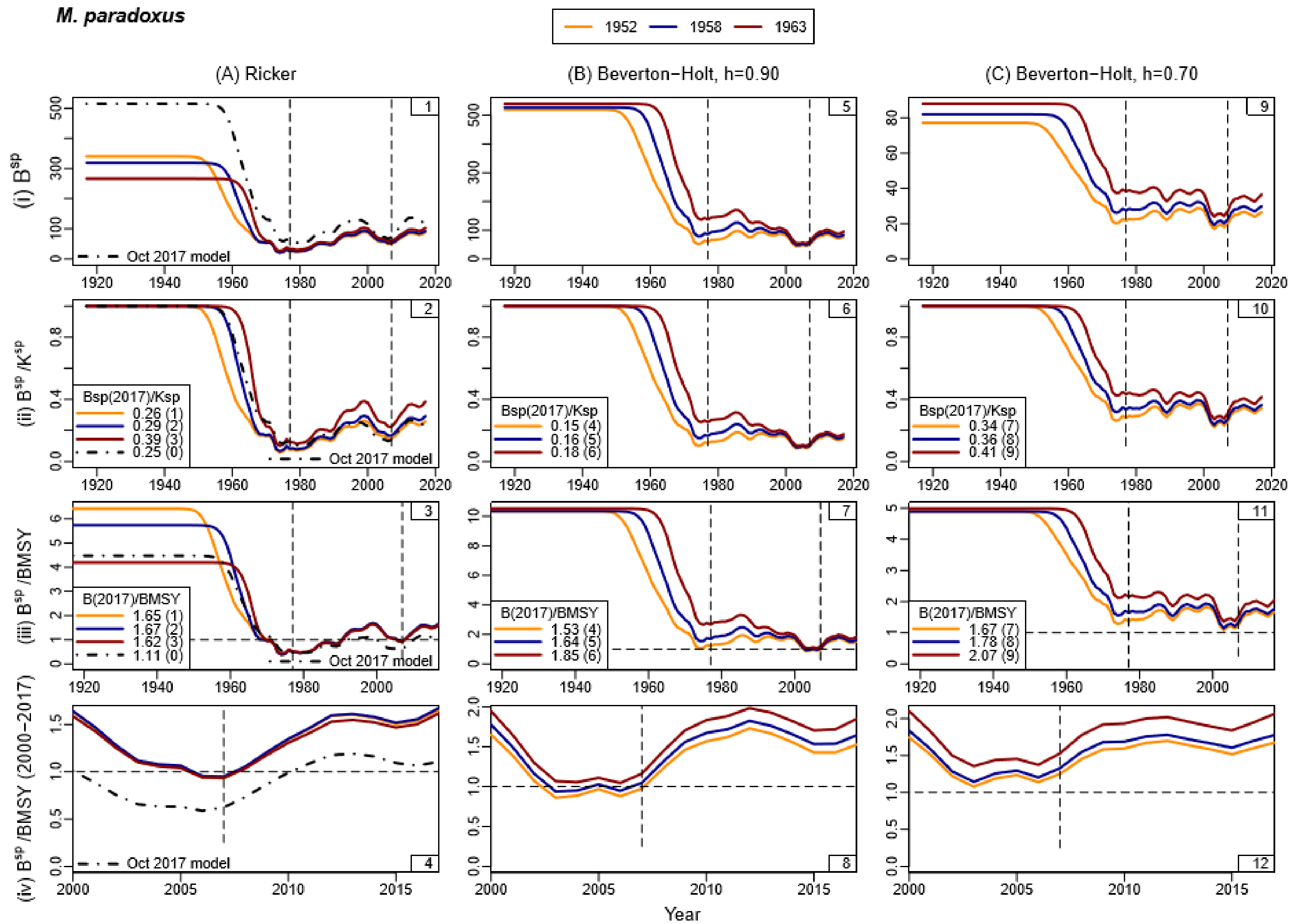

Figure 1a: Female spawning biomass trajectories are shown for ***M. paradoxus*** for smaller groupings of models. In the plots, yellow lines have been used for the models with the central year of shift occurring in 1952, blue lines for the 1958 models and red lines for the 1963 models. The Oct 2017 model has been included in the first column with the RS Ricker models (black dash-dot lines). This Figure has been reproduced from FISHERIES/2018/JUL/SWG-DEM/28.

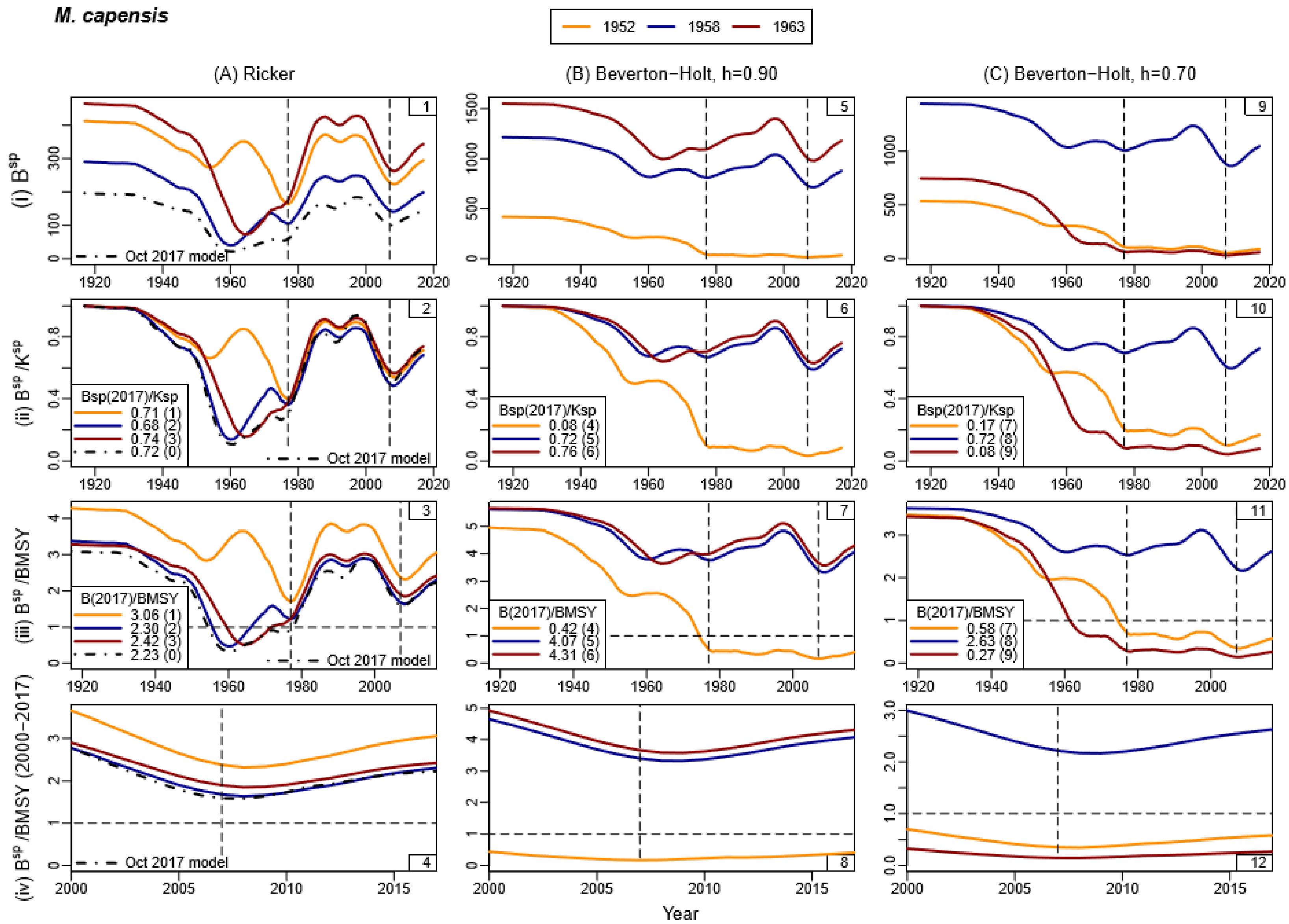

Figure 1b: Female spawning biomass trajectories are shown for ***M. capensis*** for the smaller groupings of models (as in Figure 1a).

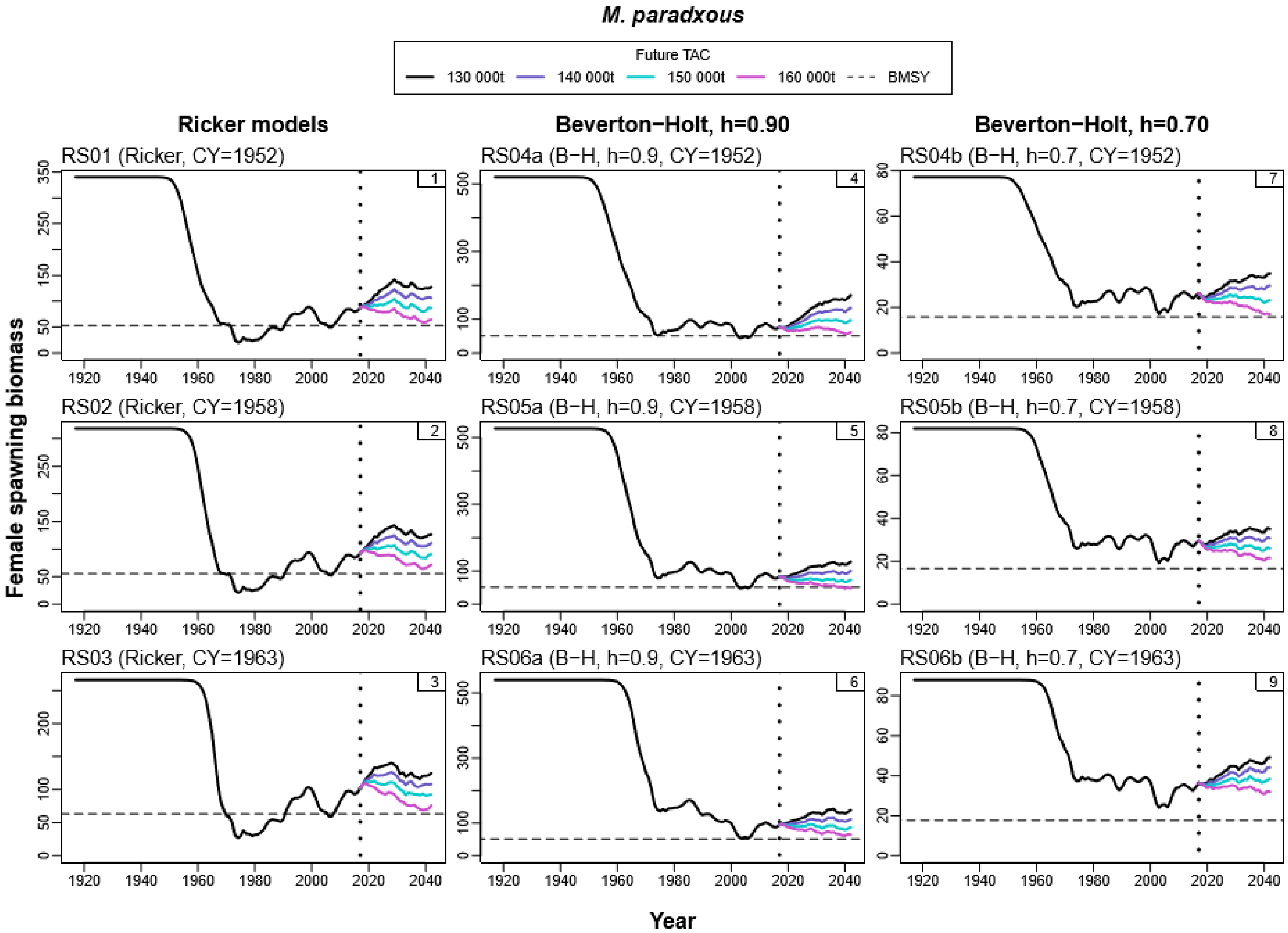

Figure 2a: Median projected female spawning biomass trajectories for ***M. paradoxus*** for a selection of possible future TACs ranging from 130 000t to 160 000t. The horizontal dashed line indicates the $\mathbf{B_{MSY}}$ estimate for each RS model, and the vertical dashed line marks the year 2017, the last year of the RS models after which projections start.

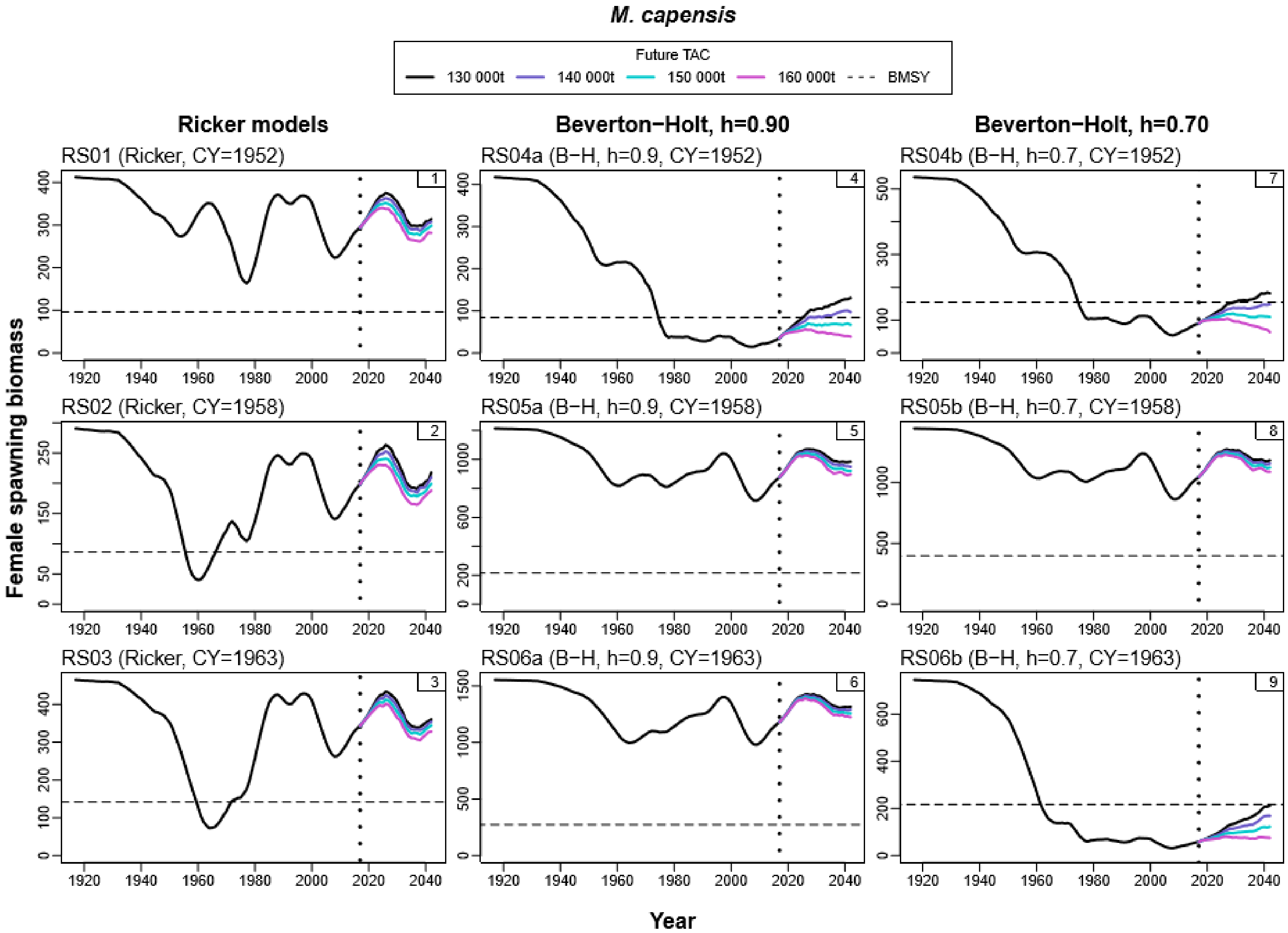

Figure 2b: Median projected female spawning biomass trajectories for ***M. capensis*** for a selection of possible future TACs.

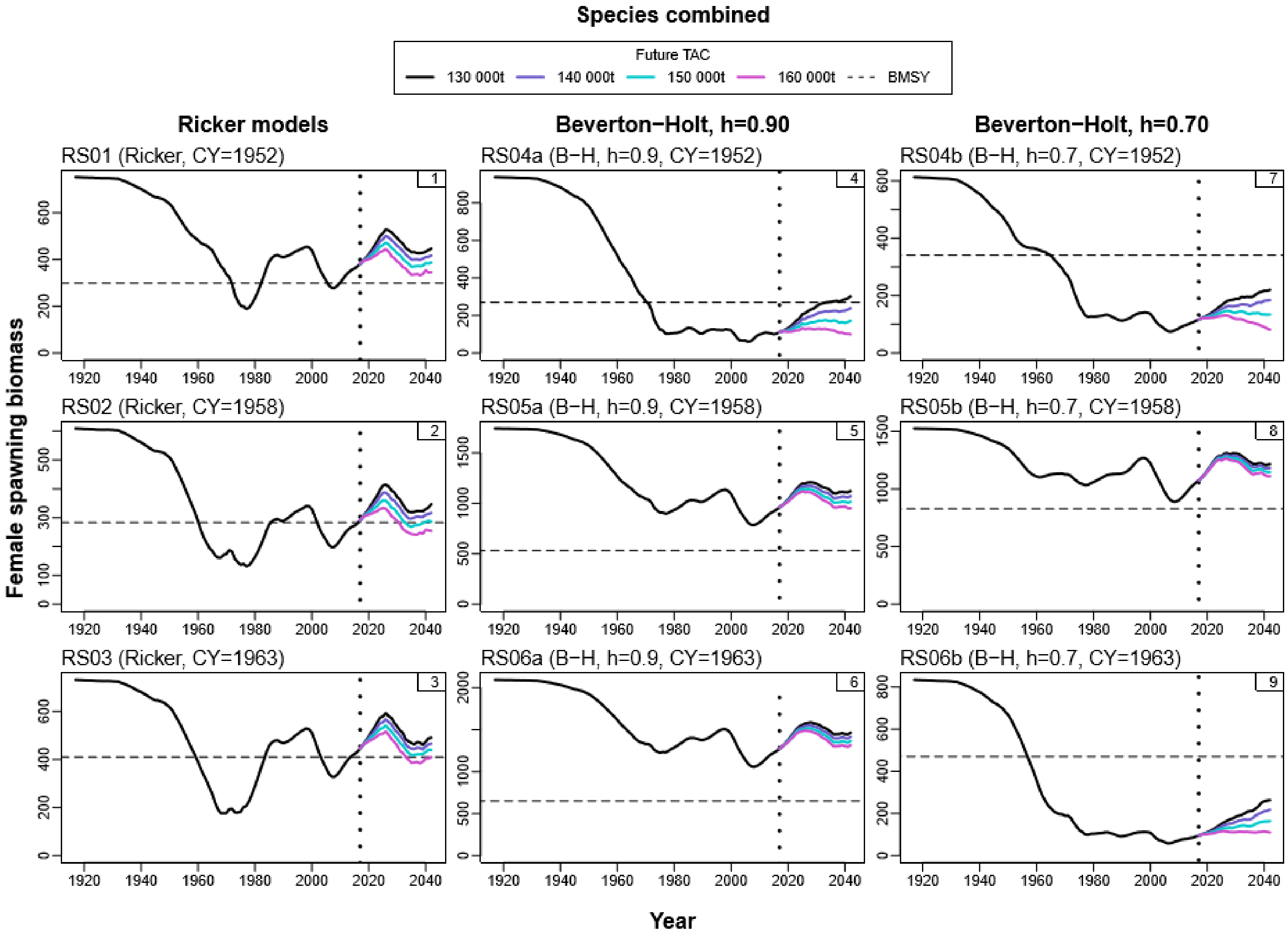

Figure 2c: Median projected female spawning biomass trajectories for ***both species combined*** for a selection of possible future TACs. The dashed horizontal line is the sum of the $\mathbf{B_{MSY}}$ estimates for the two species for the RS model in question.

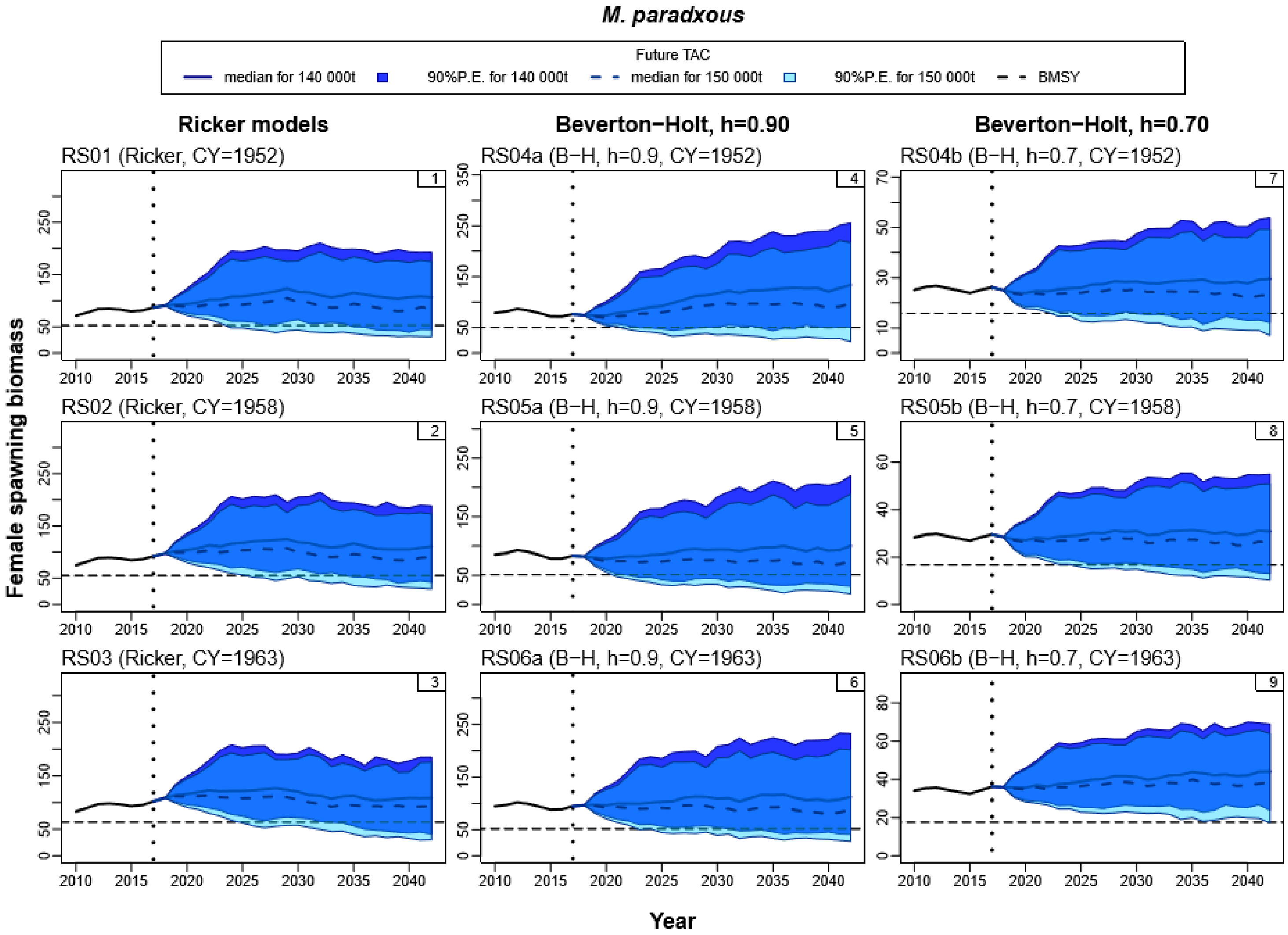

Figure 3a: Projected trajectories for ***M. paradoxus*** for 140 000t and 150 000t, showing the 90% probability envelopes (p.e.) from the 100 simulations conducted. The median trajectory for 140 000t TAC is shown by the solid blue line and the corresponding 90% p.e. in dark blue shading. The median trajectory for 150 000t TAC is shown by the dashed blue line, with the 90% p.e. in light blue. The intermediate blue area is the area of overlap between the two p.e.'s. As before, the horizontal dashed line marks the B_{MSY} estimate for each RS model and the vertical dotted line marks the year 2017.

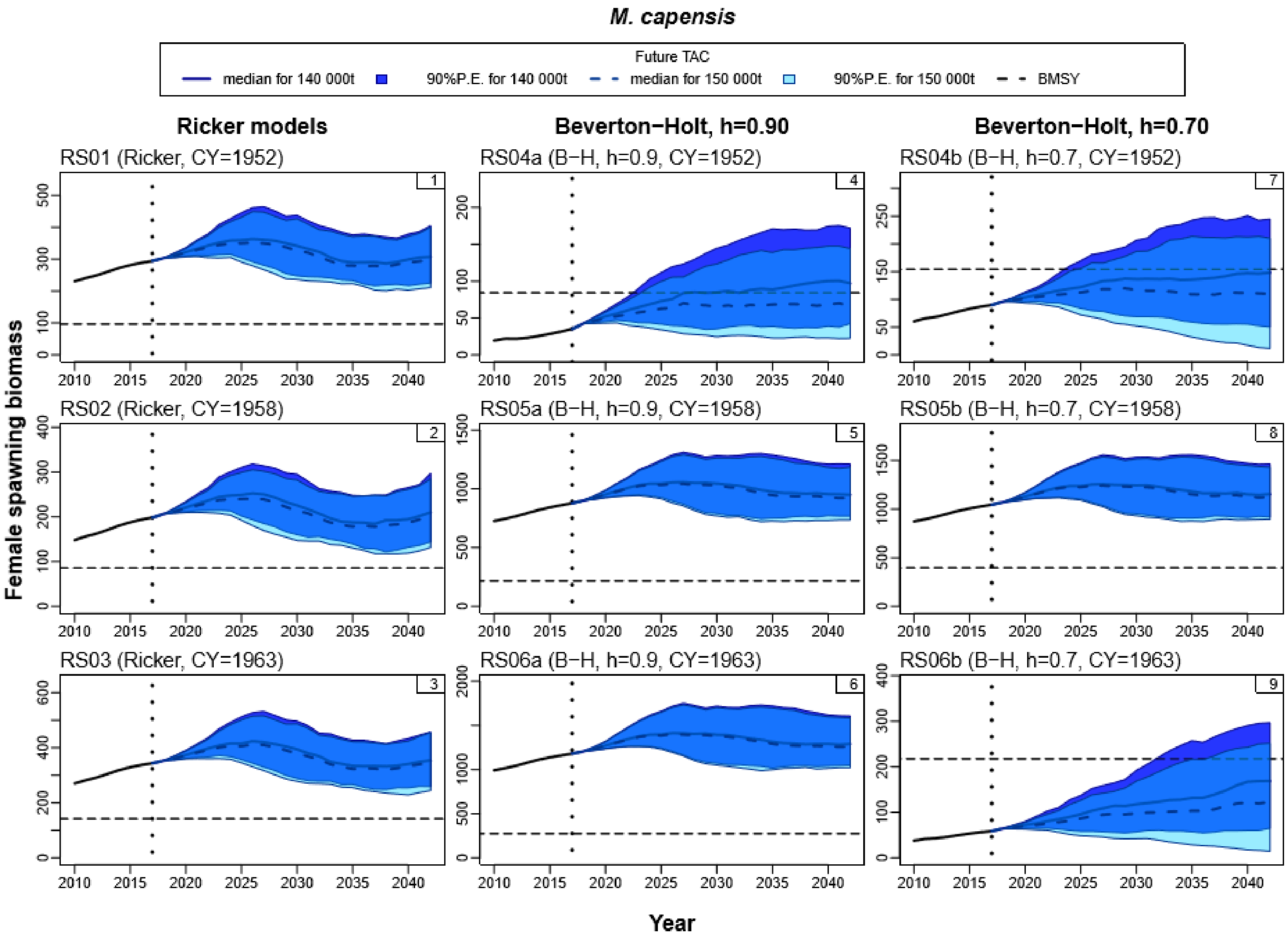

Figure 3b: Projected trajectories for ***M. capensis*** for 140 000t and 150 000t, showing the 90% probability envelopes.

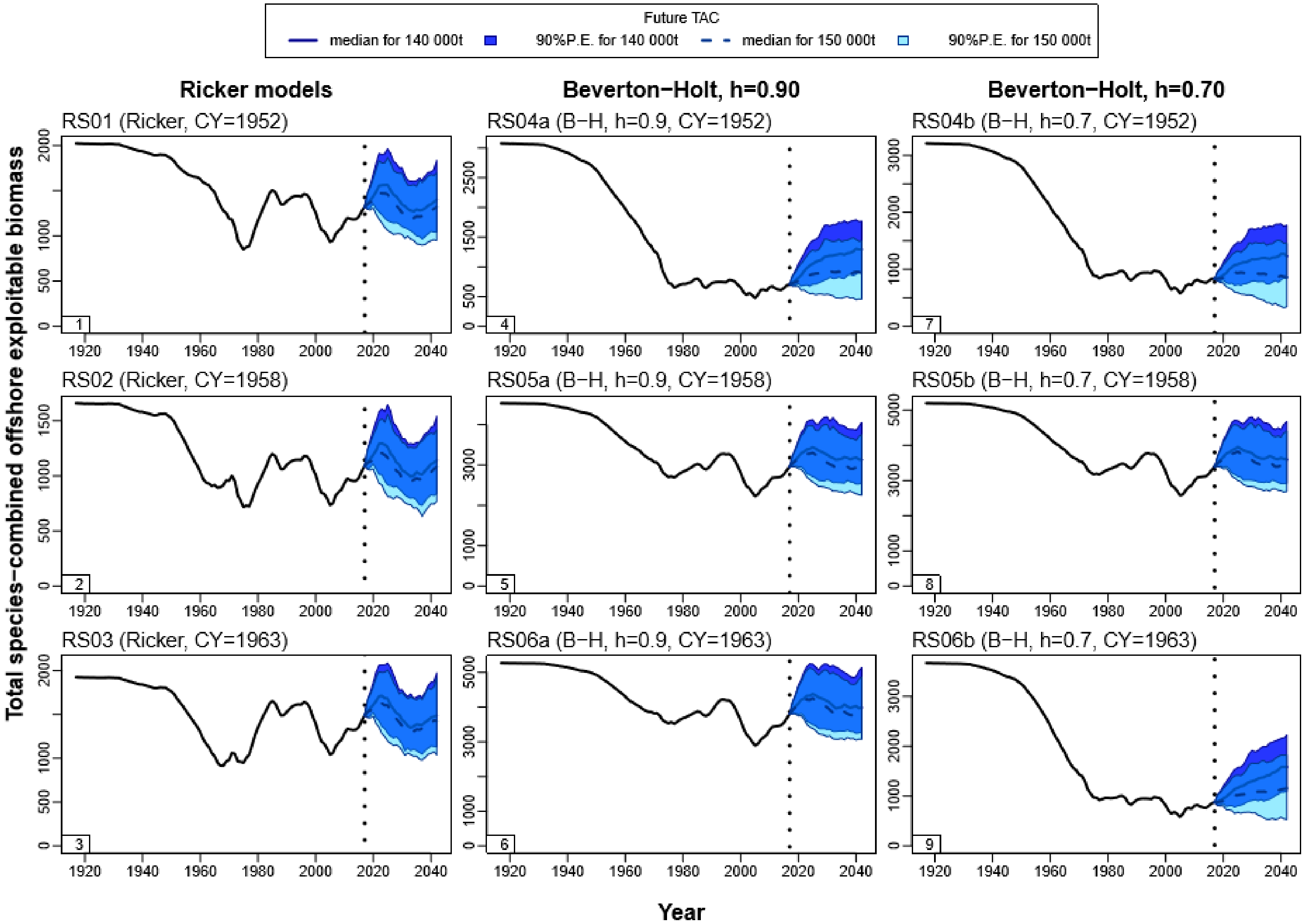

Figure 4: Projected trajectories for the **species-combined exploitable biomass** (in thousand tons) for 140 000t and 150 000t future TAC, showing the 90% probability envelopes.

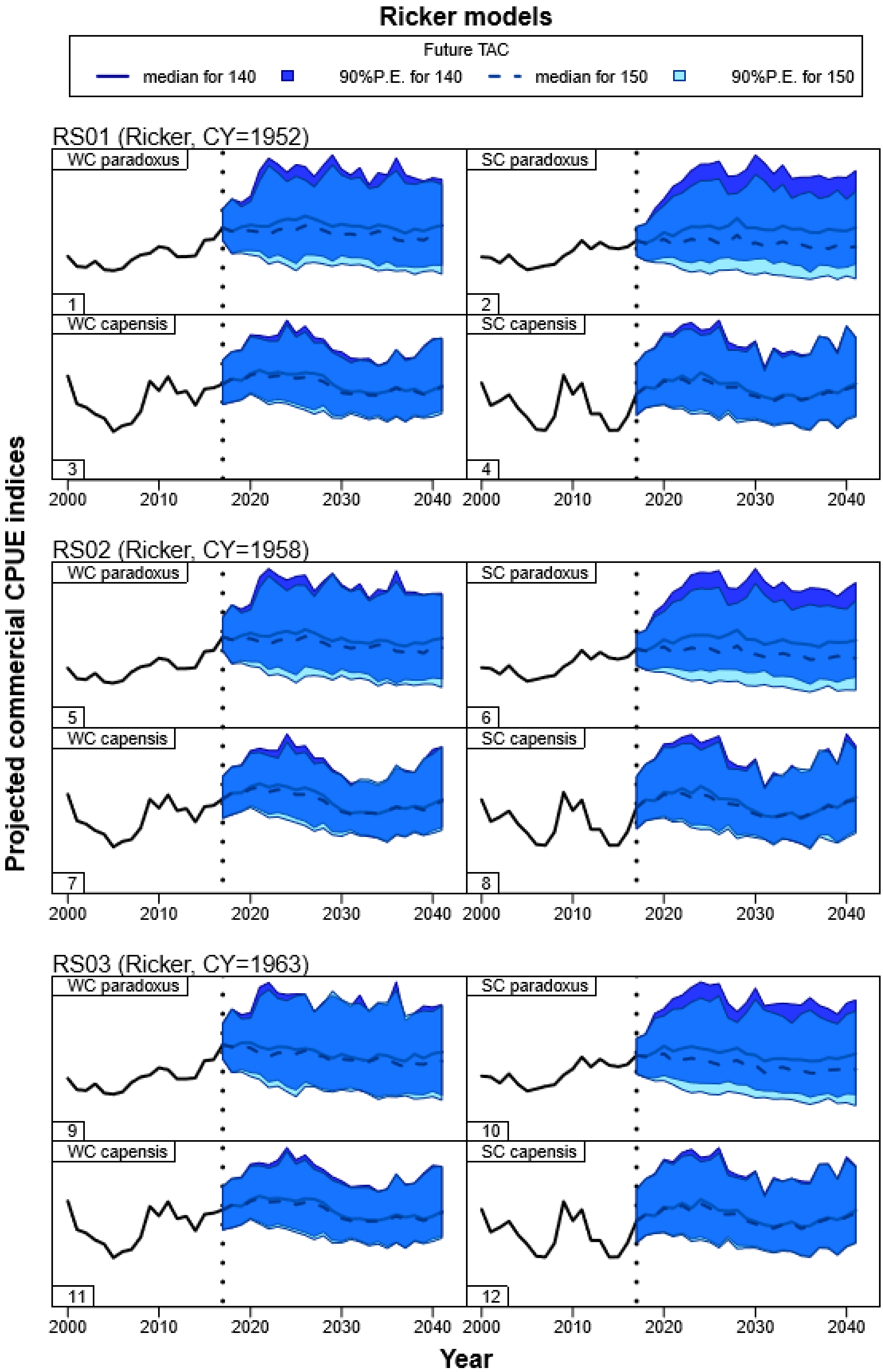

Figure 5a: Projected commercial CPUE trajectories for the **first three RS models** for 140 000t and 150 000t future TAC, showing median trajectories and the 90% probability envelopes.

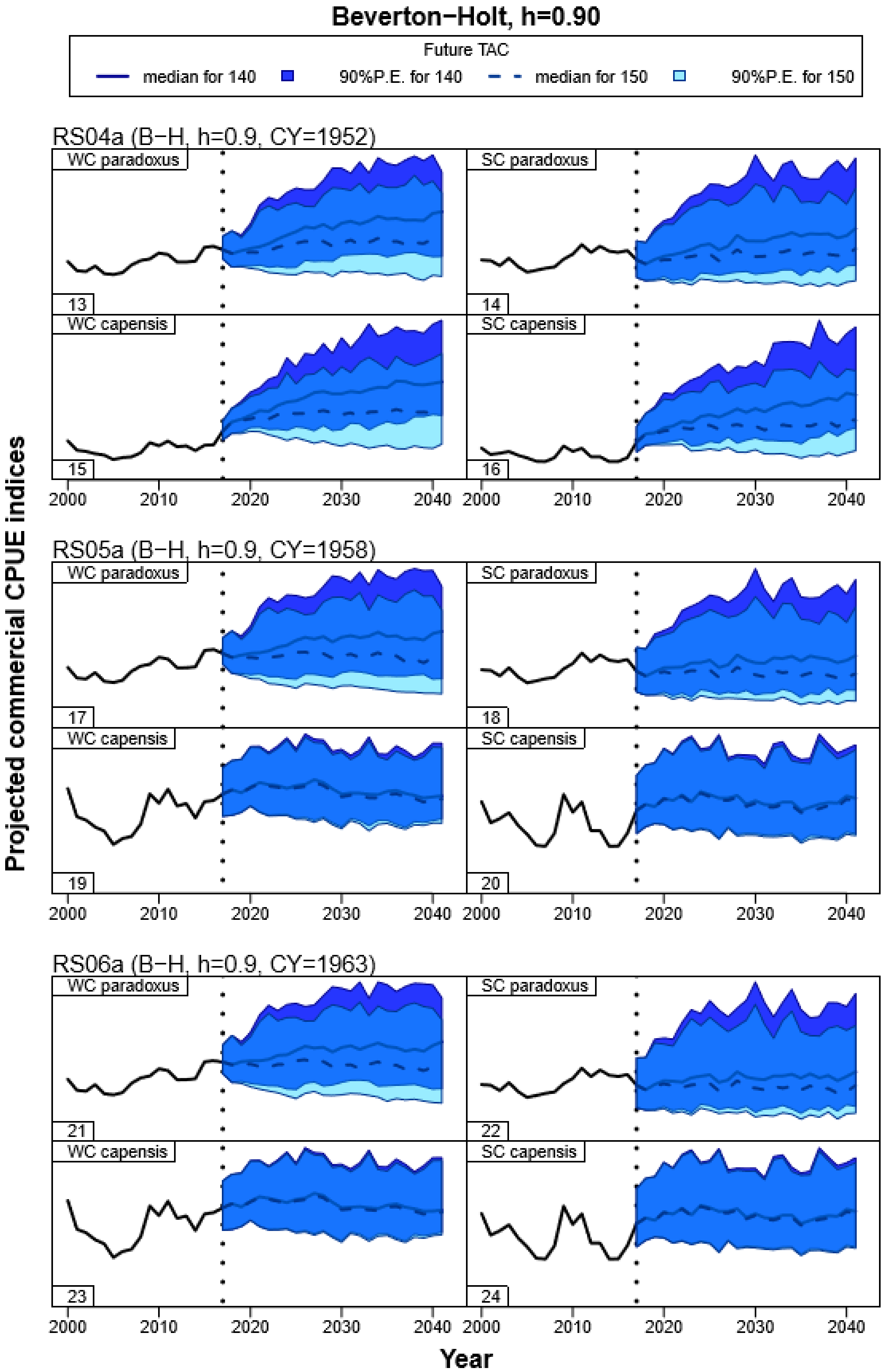

Figure 5b: Projected commercial CPUE trajectories for the **middle three RS models**.

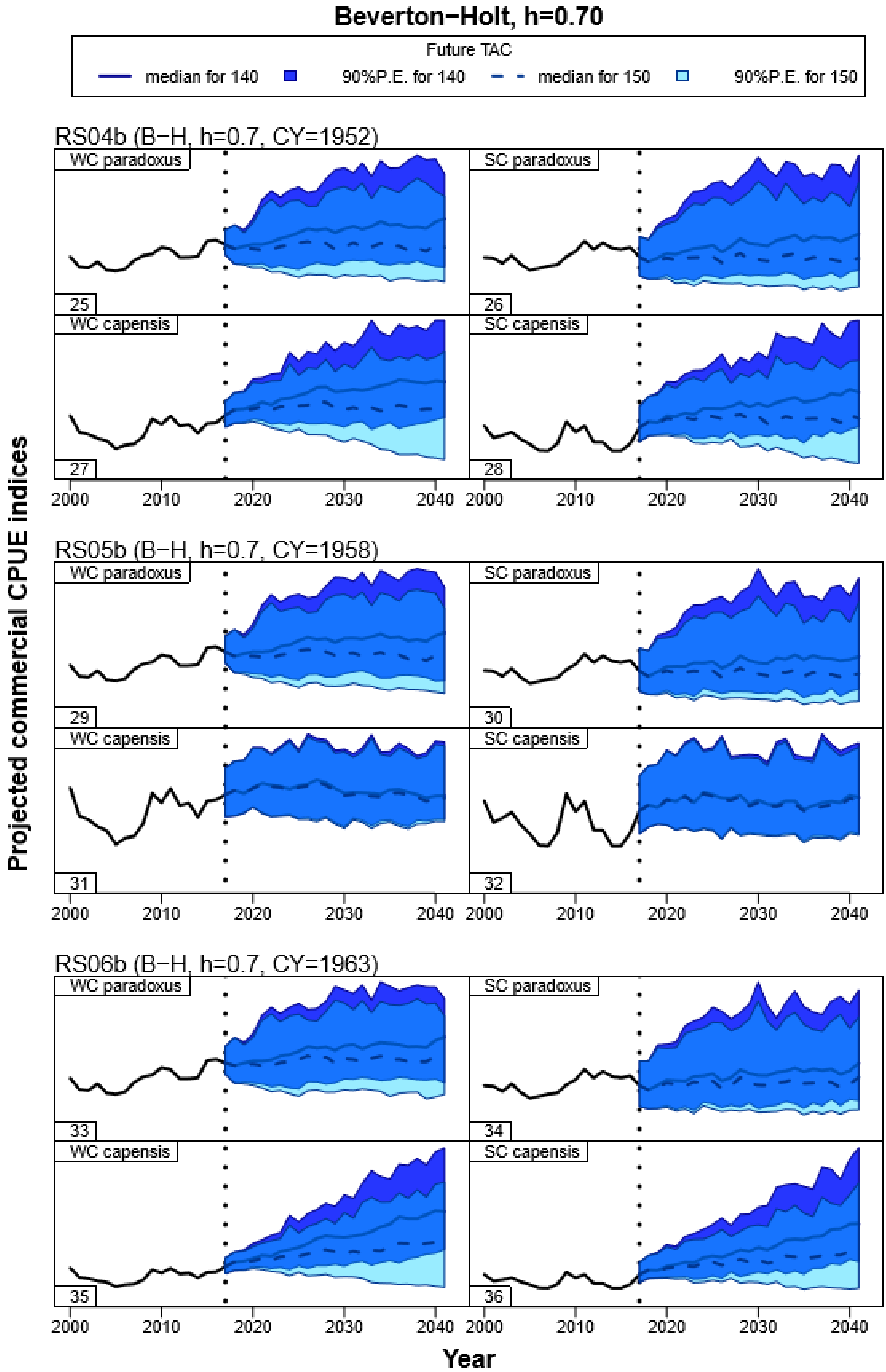

Figure 5c: Projected commercial CPUE trajectories for the **last three RS models.**

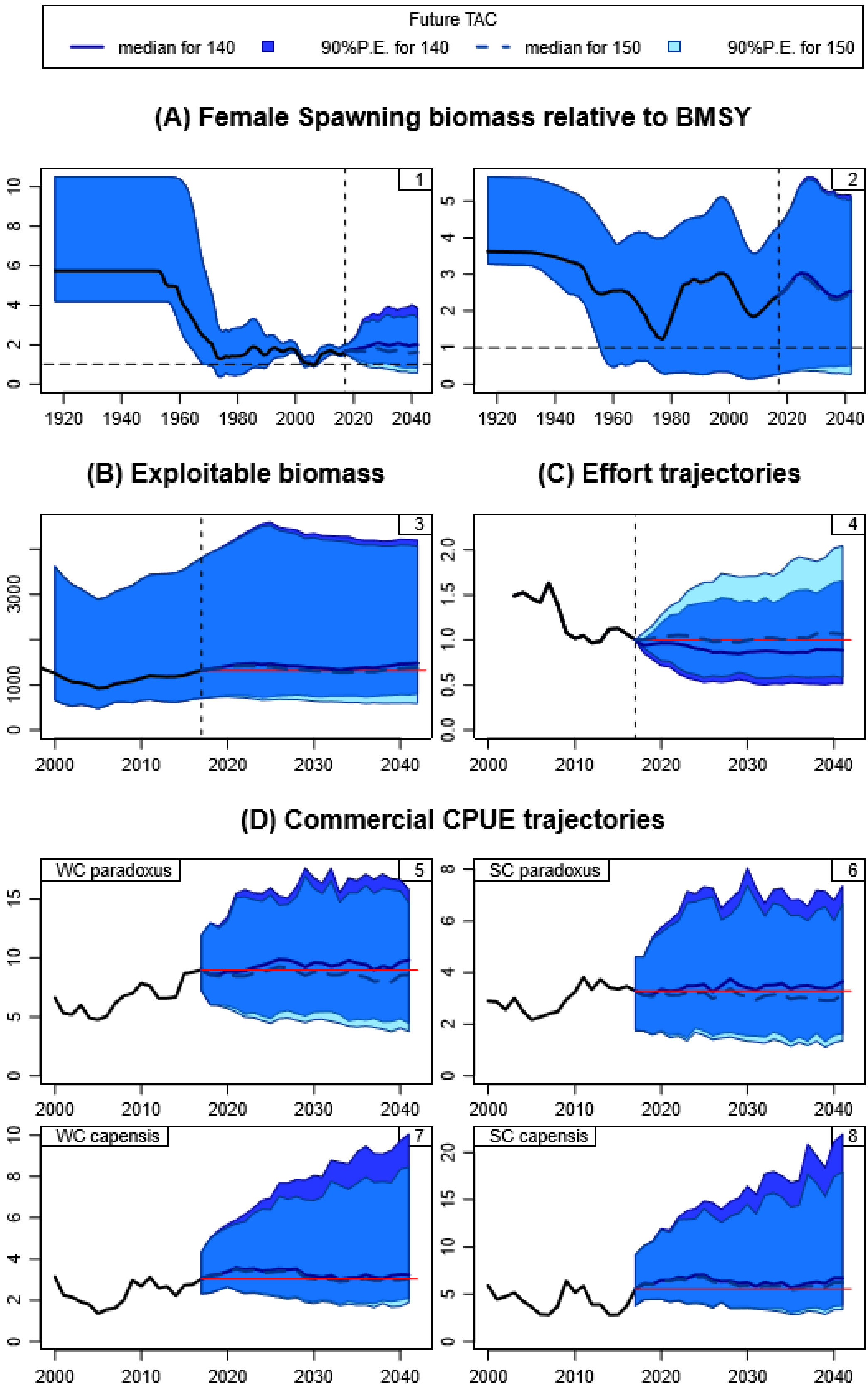

Figure 6: This figure shows the equally weighted averages across the nine RS models for (A) the female spawning biomass divided by B_{MSY}, (B) the species-combined exploitable biomass, (C) a measure of effort, and (D) the CPUE trajectories. Median and 90% p.e.'s are shown for 140 000t and 150 000t future TAC. Note that the p.e.'s now show the uncertainty arising from the different RS models as well as the future simulation variation. Dotted horizontal lines in plots B-D indicate the current (2017) value.

Appendix A

Method for projecting fishing mortality rates into the future

The method used previously to generate future fishing mortality rate (*F*) values for projecting the hake populations forward involved calculating the mean $\bar{R}_f$ and standard deviation σ_f of the ratios of fishing mortalities (F_{par}/F_{cap}) for each fleet from the last five years of the assessment model and generating future ratios assuming these were normally distributed with mean $\bar{R}_f$ and standard deviation σ_f.

Upon further consideration, a more robust approach is now put forward which is to calculate the average proportion of *M. paradoxus P* (i.e. $F_{par}/(F_{par}+F_{cap})$) as this produces a value between zero and one, in contrast to the *R* values which at times can be very large or very small.

This F proportion for fleet *f* is calculated as the proportion of averages:

$$\bar{P}_f = \frac{\bar{F}_{par,f}}{\bar{F}_{par,f} + \bar{F}_{cap,f}} \tag{1}$$

where $\bar{F}_{s,f} = \frac{1}{5}\sum_{y=ny-4}^{ny} F_{s,f,y}$ with $F_{s,f,y}$ being the fishing mortality rate for species *s* and fleet *f* in year *y* of the assessment model.

A measure of the variance for the mean proportion is calculated as:

$$\sigma_{pf}^2 = \frac{\sum_{y=ny-4}^{ny}(P_{y,f} - \bar{P}_f)^2}{5-1} \tag{2}$$

where $P_{y,f} = \frac{F_{par,y,f}}{F_{par,y,f}+F_{cap,y,f}}$.

In order to generate future values, a beta distribution is assumed where the *α* and *β* parameters can be obtained from:

$$\text{Mean} = \bar{P}_f = \alpha/(\alpha+\beta) \tag{3}$$
$$\text{Variance} = \sigma_{pf}^2 = \alpha\beta/[(\alpha+\beta)^2(\alpha+\beta+1)] \tag{4}$$

The beta distribution was restricted to [Min-0.05; Max+0.05] where Min and Max are the minimum and maximum F proportions estimated in the OM.

Results and discussion

Figures 1(a)-(c) show examples of random future proportions *P* generated using this method, for the three fleets which target both hake species (SC inshore and SC handline are assumed to be *M. capensis* only, so there is no need to split the P values for future catch) and for the 9 models in the Reference Set (RS). In most cases using the last five years of assessment model output was appropriate, but for the South Coast longline the resulting beta function was often bi-modal, thus the last 15 years of the model estimated proportions were used instead.

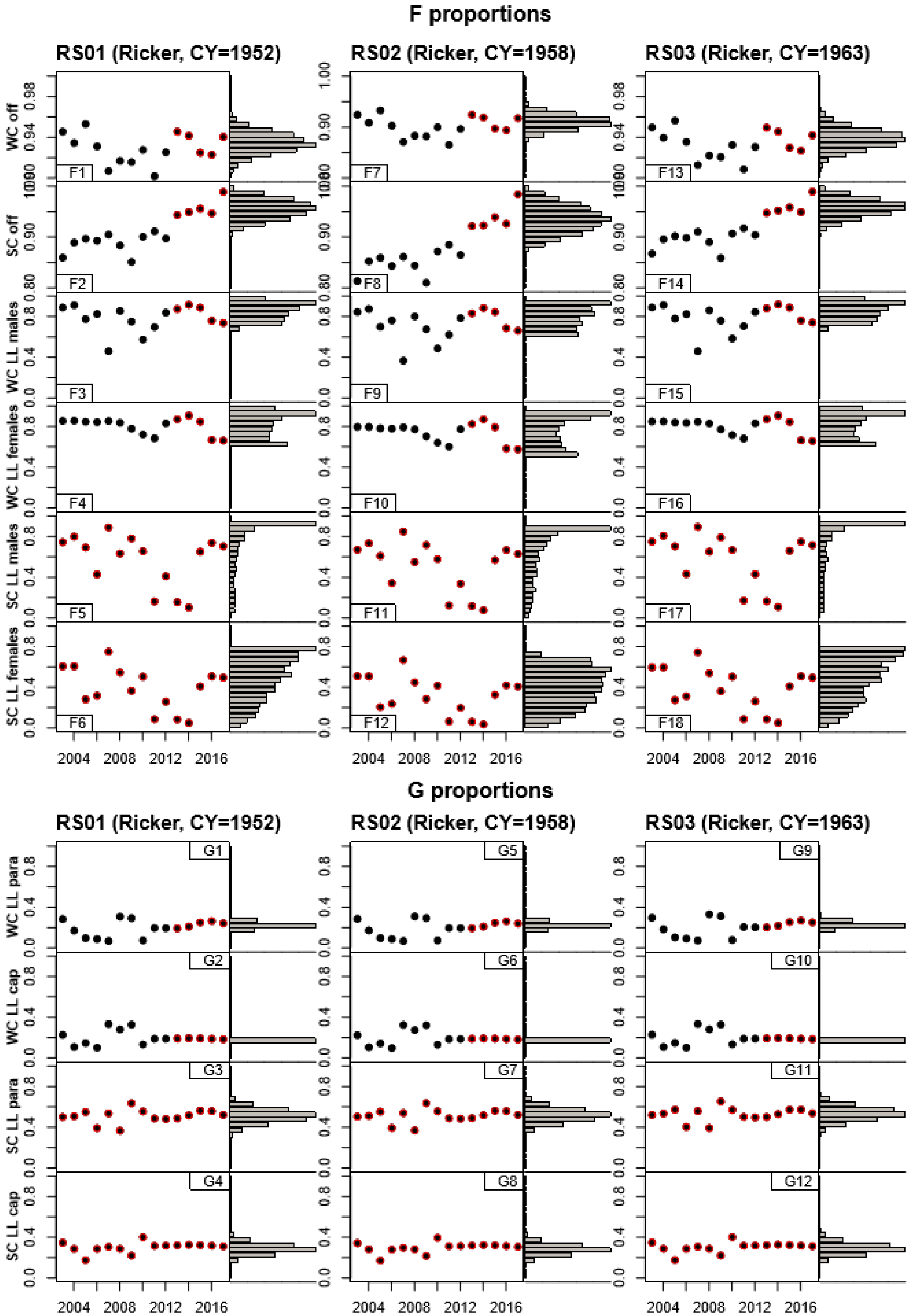

Figure A1a: Proportion of fishing mortality attributed to *M. paradoxus* for the three **Ricker** models in the RS. Filled dots on the left are the proportions estimated in the assessment model (pre-2017). The points have been circled in red to indicate whether the last five or 15 years of model output have been used in calculating the beta function. The histograms to the right show the distribution of future generated F proportions (2500 values). Note that the vertical axes are not all to the same scale across the fleets; however for any one fleet the scale is consistent across the RS models.

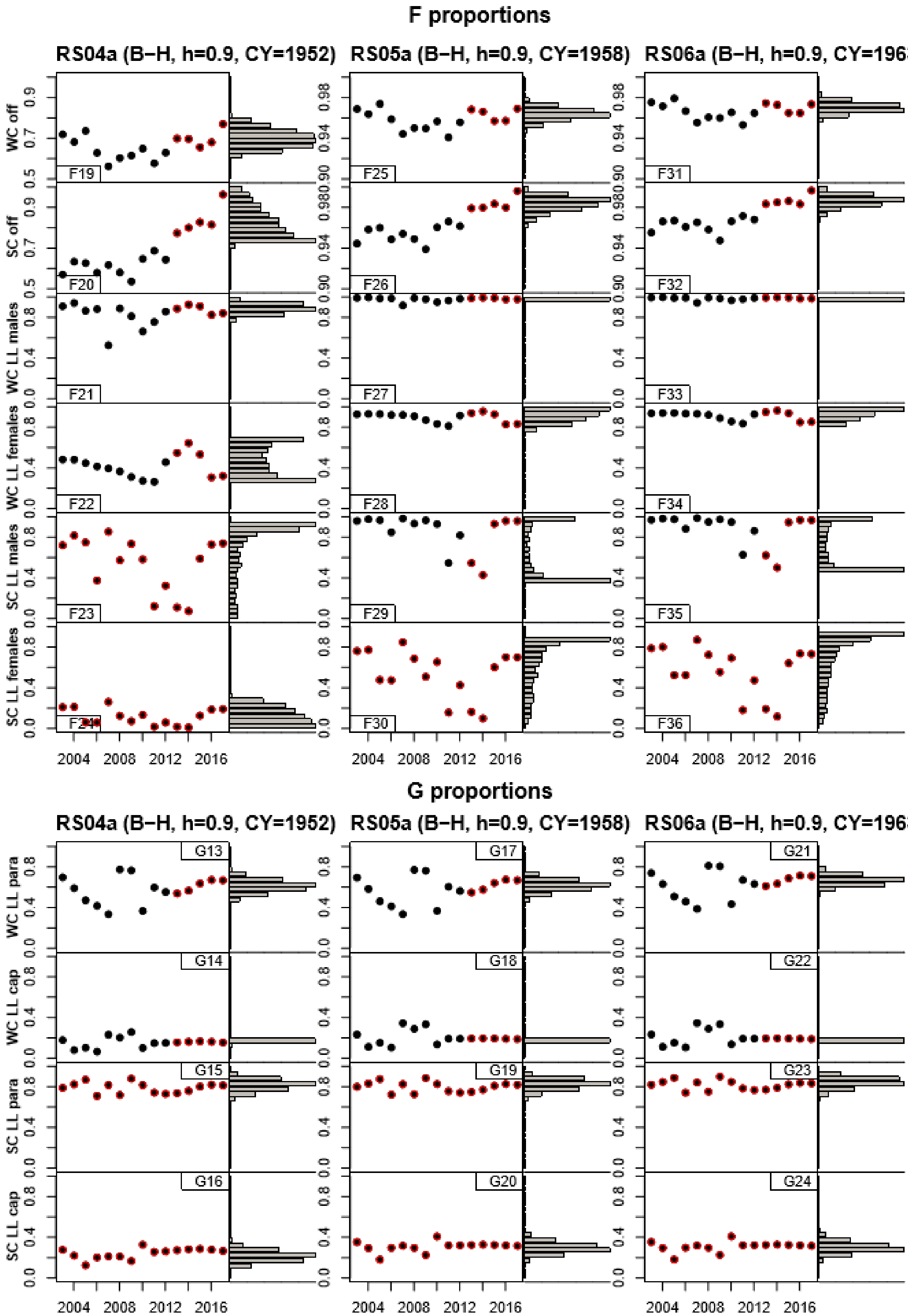

Figure A1b: Repeat of Figure 1a but for the three **Beverton-Holt** models with ***h* fixed at 0.90**.

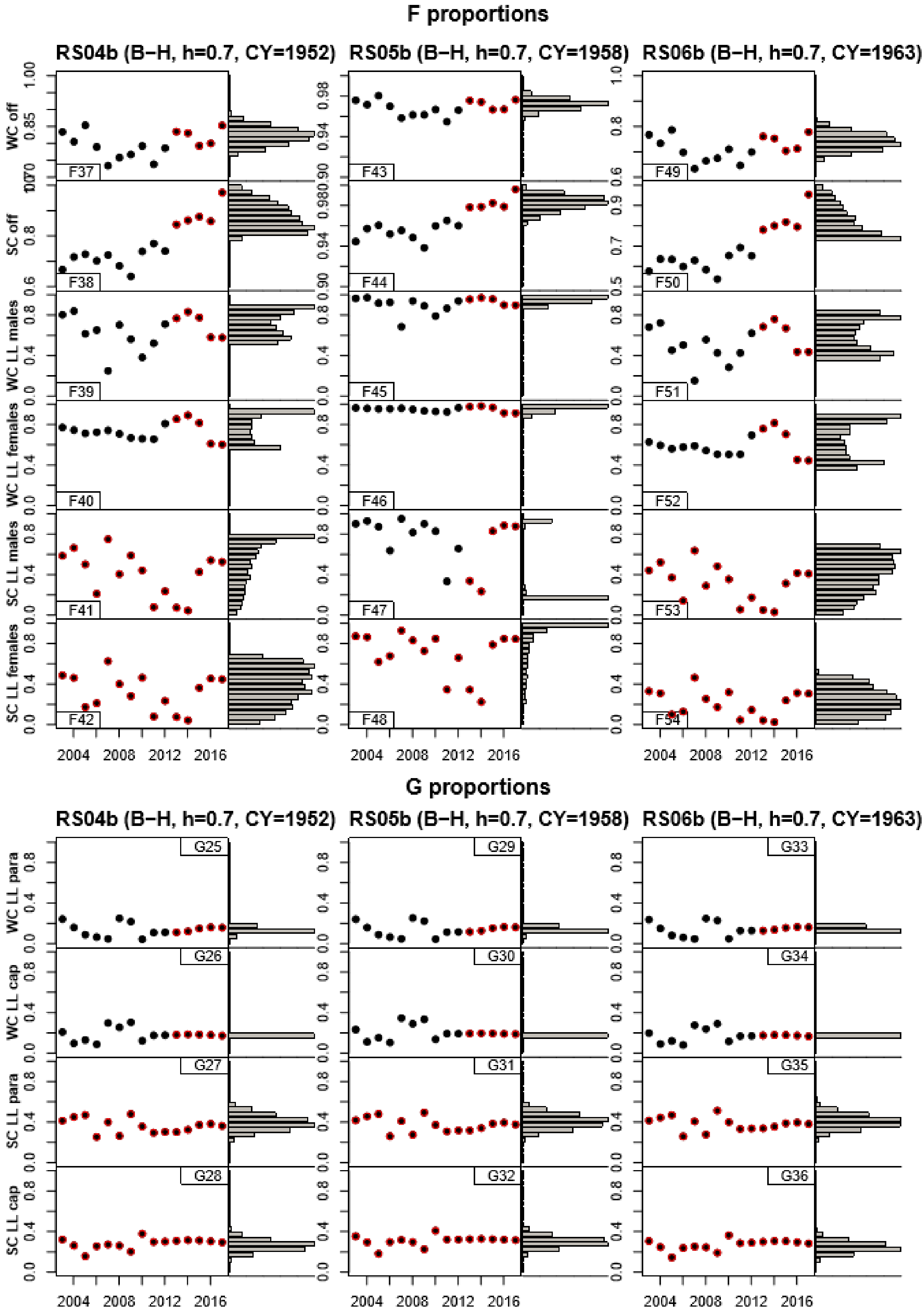

Figure A1c: Repeat of Figure 1a but for the three **Beverton-Holt** models with ***h* fixed at 0.70**.

Appendix B

Deriving the future fishing mortality rates from the generated F proportions

Gender aggregated fleets

Let $\bar{F}_{s,f}$ be the average fishing mortality rate for species *s* and fleet *f* from the last five years of the assessment model, i.e.

$$\bar{F}_{s,f} = \frac{1}{5}\sum_{ny-4}^{ny} F_{s,f,y} \tag{B1}$$

Where *ny* is the last year considered in the model (2017) and $F_{s,f,y}$ is the fishing mortality rate exerted by fleet *f* on species *s* in year *y.*

Define the average proportion which the *M. paradoxus* fishing mortality rate comprises of the sum of the rates on both species together as

$$\bar{P}_f = \frac{\bar{F}_{par,f}}{\bar{F}_{par,f} + \bar{F}_{cap,f}} \tag{B2}$$

It follows from equation (B2) that

$$\bar{F}_{par,f} = \left(\frac{\bar{P}_f}{1-\bar{P}_f}\right)\bar{F}_{cap,f} \tag{B3}$$

Let $F^*_{s,f,y}$ be the fishing mortality rate exerted by fleet *f* on species *s* in year *y* of the projection. Then the total catch for fleet *f* in year *y* is given by

$$C_{f,y} = F^*_{par,f,y}B^{exp}_{par,f,y} + F^*_{cap,f,y}B^{exp}_{cap,f,y} \tag{B4}$$

where

$$B^{exp}_{sfy} = \sum_a \widetilde{w}_{sfya}\, S_{sfya}F_{sfy}N_{sya}\; e^{-M_{sa}/2} \tag{B5}$$

If $TAC_{f,y}$ is the TAC allocated to fishing fleet *f* in year *y* of the projection*,* we wish to find a λ such that

$$TAC_{f,y} = \lambda\bar{F}_{par,f,y}B^{exp}_{par,f,y} + \lambda\bar{F}_{cap,f,y}B^{exp}_{cap,f,y} = F^*_{par,f,y}B^{exp}_{par,f,y} + F^*_{cap,f,y}B^{exp}_{cap,f,y} \tag{B6}$$

Substituting Equation (B3) into (B6):

$$TAC_{f,y} = \lambda\left(\frac{\bar{P}_f}{1-\bar{P}_f}\right)\bar{F}_{cap,f}B^{exp}_{par,f,y} + \lambda\bar{F}_{cap,f,y}B^{exp}_{cap,f,y} \tag{B7}$$

$$= \lambda^*\left(\frac{\bar{P}_f}{1-\bar{P}_f}\right)B^{exp}_{par,f,y} + \lambda^* B^{exp}_{cap,f,y} \tag{B8}$$

Thus

$$\lambda^* = TAC_{f,y}\Big/\left(\left(\frac{\bar{P}_f}{1-\bar{P}_f}\right)B^{exp}_{par,f,y} + B^{exp}_{cap,f,y}\right) \tag{B9}$$

and

$$F^*_{cap,f,y} = \lambda^* = \frac{TAC_{f,y}}{\left(\frac{\bar{P}_f}{1-\bar{P}_f}\right) B^{exp}_{par,f,y} + B^{exp}_{cap,f,y}} \quad \text{(B10)}$$

$$F^*_{par,f,y} = \lambda^* \left(\frac{\bar{P}_f}{1-\bar{P}_f}\right) = \frac{\left(\frac{\bar{P}_f}{1-\bar{P}_f}\right) TAC_{f,y}}{\left(\frac{\bar{P}_f}{1-\bar{P}_f}\right) B^{exp}_{par,f,y} + B^{exp}_{cap,f,y}} \quad \text{(B11)}$$

Gender disaggregated fleets (West Coast and South Coast longline)

Let $\bar{F}_{s,g,f}$ be the average fishing mortality rate for species *s*, gender *g* and fleet *f* from the last five years of the assessment model, i.e.

$$\bar{F}_{s,g,f} = \frac{1}{5}\sum_{ny-4}^{ny} F_{s,g,f,y} \quad \text{(B12)}$$

Where *ny* is the last year considered in the model (2017) and $F_{s,g,f,y}$ is the fishing mortality rate exerted by fleet *f* on gender *g* of species *s* in year *y.*

Define the average proportion which the *M. paradoxus* fishing mortality rate comprises of the sum of the rates on both species together **for gender *g*** as

$$\bar{P}_{g,f} = \frac{\bar{F}_{par,g,f}}{\bar{F}_{par,g,f} + \bar{F}_{cap,g,f}} \quad \text{(B13)}$$

Further, define the average proportion which the male fishing mortality rate comprises the sum of the rates on both genders for species *s* as

$$\bar{G}_{s,f} = \frac{\bar{F}_{s,male,f}}{\bar{F}_{s,male,f} + \bar{F}_{s,female,f}} \quad \text{(B14)}$$

It follows from equations (B13) and (B14) that

$$\bar{F}_{cap,male,f} = \left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) \bar{F}_{cap,female,f} \quad \text{(B15)}$$

$$\bar{F}_{par,male,f} = \left(\frac{\bar{P}_{male,f}}{1-\bar{P}_{male,f}}\right) \bar{F}_{cap,male,f} = \left(\frac{\bar{P}_{male,f}}{1-\bar{P}_{male,f}}\right)\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) \bar{F}_{cap,female,f} \quad \text{(B16)}$$

$$\bar{F}_{par,female,f} = \frac{\bar{P}_{female,f}}{1-\bar{P}_{female,f}} \bar{F}_{cap,f} \quad \text{(B17)}$$

Let $F^*_{s,g,f,y}$ be the fishing mortality rate exerted by fleet *f* on species *s* in year *y* of the projection. Then the total catch for fleet *f* in year *y* is given by

$$\begin{aligned} C_{f,y} = {} & F^*_{par,malef,y} B^{exp}_{par,malef,y} + F^*_{par,femalef,y} B^{exp}_{par,femalef,y} \\ & + F^*_{cap,male,f,y} B^{exp}_{cap,malef,y} + F^*_{cap,female,f,y} B^{exp}_{cap,femalef,y} \end{aligned} \quad \text{(B18)}$$

If $TAC_{f,y}$ is the TAC allocated to fishing fleet *f* in year *y,* we wish to find a λ such that

$$TAC_{f,y} = \sum_s \sum_g \lambda \bar{F}_{s,g,f,y} B^{exp}_{s,g,f,y} = \sum_s \sum_g \; F^*_{s,g,f,y} B^{exp}_{s,g,f,y} \tag{B19}$$

But

$$\begin{aligned} TAC_{f,y} &= \lambda \left(\frac{\bar{P}_{male,f}}{1-\bar{P}_{male,f}}\right)\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right)\bar{F}_{cap,female,f} B^{exp}_{par,male,f,y} \\ &+\lambda\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right)\bar{F}_{cap,female,f,y} B^{exp}_{cap,male,f,y} \\ &+\lambda\left(\frac{\bar{P}_{female,f}}{1-\bar{P}_{female,f}}\right)\bar{F}_{cap,female,f} B^{exp}_{par,female,f,y} \\ &+\lambda\,\bar{F}_{cap,female,f} B^{exp}_{cap,female,f,y} \end{aligned} \tag{B20}$$

i.e.

$$\begin{aligned} TAC_{f,y} &= \lambda^* \left(\frac{\bar{P}_{male,f}}{1-\bar{P}_{male,f}}\right)\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) B^{exp}_{par,male,f,y} + \lambda^*\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) B^{exp}_{cap,male,f,y} \\ &+\lambda^*\left(\frac{\bar{P}_{female,f}}{1-\bar{P}_{female,f}}\right) B^{exp}_{par,female,f,y} + \lambda^* B^{exp}_{cap,female,f,y} \end{aligned} \tag{B21}$$

Thus

$$\begin{aligned} \lambda^* = TAC_{f,y} / \Bigg(&\left(\frac{\bar{P}_{male,f}}{1-\bar{P}_{male,f}}\right)\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) B^{exp}_{par,male,f,y} + \left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) B^{exp}_{cap,male,f,y} \\ &+\left(\frac{\bar{P}_{female,f}}{1-\bar{P}_{female,f}}\right) B^{exp}_{par,female,f,y} + B^{exp}_{cap,female,f,y} \Bigg) \end{aligned} \tag{B22}$$

and

$$F^*_{cap,female,f,y} = \lambda^* \tag{B23}$$

$$F^*_{par,female,f,y} = \lambda^* \left(\frac{\bar{P}_{female,f}}{1-\bar{P}_{female,f}}\right) \tag{B24}$$

$$F^*_{cap,male,f,y} = \lambda^* \left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) \tag{B25}$$

$$F^*_{par,male,f,y} = \lambda^* \left(\frac{\bar{P}_{male,f}}{1-\bar{P}_{male,f}}\right)\left(\frac{\bar{G}_{cap,f}}{1-\bar{G}_{cap,f}}\right) \tag{B26}$$