Sardine projections based on constant catch scenarios

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Short term projections of the sardine resource are considered under alternative constant catch scenarios. Baseline results suggest that 2019 catch and bycatch scenarios totalling up to 23 000t would not have a substantial negative 1-year impact on the population. However, results are sensitive to model assumptions and projections are more pessimistic if greater west-south movement is assumed or if the actual population structure in November 2018 consisted of fewer recruits and more adults than was estimated by the November 2018 survey length frequency.

Introduction

In December 2018 the Small Pelagic Scientific Working Group (SWG-PEL) declared Exceptional Circumstances for the sardine resource as a result of (among other things) the very low survey estimate of sardine abundance in November 2018. Any Total Allowable Catch/Bycatches (TAC/Bs) that would have been recommended under OMP-18 were thus set aside. The SWG-PEL recommended a delay in the start of the directed sardine fishery to allow further computations to be undertaken to assess whether some non-zero directed sardine TAC could be scientifically justified for 2019.

Following some preliminary analyses by de Moor (2019b), the SWG-PEL recommended the following TAC/Bs for South African sardine (DAFF 2019):

Directed >14cm sardine TAC:	4750t with at most 70% to be taken west of Cape Agulhas
≤14cm sardine TAB for directed sardine fishing:	250t
≤14cm sardine TAB for directed anchovy fishing:	3250t
>14cm sardine TAB with directed round herring and anchovy fishing:	1000t
≤14cm sardine TAB with directed round herring fishing:	100t

However, the SWG-PEL requested further analyses to be conducted to advise whether these quotas could be further increased without substantially negatively impacting the resource. This document considers further projections of the sardine resource under alternative constant catch scenarios, based on a modified projection framework.

Methods

The model used for projections was based on the most recent updated assessment of the sardine resource (de Moor 2019a,c). Most of the population dynamics were similar to those assumed historically (Appendix A) except that catch was modelled to be taken in a single pulse during the year. Other assumptions made during these projections are detailed in Appendix A.

The assessment provided a single set of model parameters at the joint posterior mode, including numbers-at-length (age) and biomass in November 2018 from which projections were initiated. A likelihood profile of the model predicted November survey biomass in 2018 was calculated from AD Model Builder output (Figure 1). Some variability in the November 2018 starting point for projections was thus incorporated by adjusting the numbers-at-age[1] such that, for

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[1] The effective spawning biomass in 2018 was similarly adjusted for the purpose of reporting statistics only.

simulation i, $1 \leq i \leq 100$, $N_{j,2018,a}^{S,i} = p_i N_{j,2018,a}^{S}$, where $p_i = B_i^{sample} / (k_N^S B_{j,2018}^S)$, and $B_{j,2018}^S$ denotes the model predicted total biomass in November 2018 and B_i^{sample} denotes the survey biomass sampled from the likelihood profile.

Recruitment to the west component has previously been shown to be the major contribution of recruitment to the population as a whole (de Moor *et al.* 2017). Fitting a hockey stick stock recruitment relationship showed no clear dependence of recruitment on effective spawning biomass (Figure 2). Figure 3 indicates sardine recruitment may change 'regime' over time, for example depending on prevailing environmental conditions rather than on spawning stock biomass (Szuwalski *et al*. 2019). Baseline future recruitment was thus assumed to be according to the recent 'regime' (Appendix A) in line with the relatively high autocorrelation in the historical time series of recruitment, while sensitivity to this assumption by assuming future recruitment would be according to the Hockey Stick stock recruitment relationship (effectively implying recruitment is independent of time or spawning biomass) was also tested.

Variability in the projections was therefore introduced by running 100 simulations from different starting points (of the likelihood profile), with different future recruitment each year and different future average weight-at-length (see Appendix A).

The primary model (Model 0) considered by the Sardine Task Team was that of de Moor (2019c), but with $\rho_j = 0$ given indications that sardine condition at the beginning of 2019 was similar to that of other years rather than below average as observed during the 2018 November survey (van der Lingen et al. 2019).

Alternative models considered were

a) The 'revised' model of de Moor (2019c), with autocorrelation included. (Model 1)
b) The 'old' model of de Moor (2019a), with autocorrelation included. (Model 2)
c) A third alternative model which allowed for the possibility of the November 2018 survey length frequency being unrepresentative of the available population, in particular that the length frequency reflected an under sampling of larger sardine (Coetzee 2019). This alternative involved reconditioning the model to the historical data where the November 2018 survey biomass observations were increased by a factor of 1.5 and the November 2018 survey biomass length frequency was taken to be a weighted average of the survey length frequency and the length frequency of commercial catches during October-December (Coetzee pers. comm). (Model 3)

Sensitivity of results to the following alternative assumptions were tested:

i) $\mathrm{move}_{y,1} = 0.1$: The proportion of 1-year old sardine moving from the west to the south coast in November each year is 0.1 in all future years. Baseline has $\mathrm{move}_{y,1} = 0.3$
ii) $\mathrm{move}_{y,1} = 0.5$: The proportion of 1-year old sardine moving from the west to the south coast in November each year is 0.5 in all future years. Baseline has $\mathrm{move}_{y,1} = 0.3$
iii) $\sigma_{R,j} =$: Future recruitment is generated from a hockey-stick stock recruitment relationship fit to the historically estimated effective spawning biomass and recruitment time series (excluding pulse years). The value of $\sigma_{R,j}$ is 0.85 for the old model and 0.80 for the revised model (Figure 2).

iv) $w^S_{j,2019,l} = w^S_{j,2018,l}$: The stock weights-at-length in November 2019 are assumed to be the same as those in November 2018.

v) Low start: The assessment model's numbers-at-age in 2018 were decreased by 1 standard error based on the survey CVs as another means to reflect the uncertainty surrounding the recent survey estimate. This sensitivity test follows concerns of the missing May 2018 data point and the model predicting a substantially higher biomass in November 2018 than that surveyed (de Moor 2019a,c). The west component numbers-at-age are decreased to 1-0.3591=0.64 of the assessment point estimates and the south component numbers-at-age are decreased to 1-0.7828=0.22 of the assessment point estimates. The same proportions are applied to the effective spawning biomasses in 2018 in order to calculate the summary statistics in the tables below.

Results and Discussion

The impact of fishing on the sardine population was considered for the immediate (1-year) future as follows:

i) The additive change (increase or decrease) in effective spawning biomass from November 2018 to November 2019;

ii) The multiplicative change in effective spawning biomass from November 2018 to November 2019; and

iii) The west component effective spawning biomass in November 2019 compared multiplicatively to that in November 2007 (the sardine risk threshold)

Table 1 shows the results for ii) for all four models under the baseline assumptions and four alternative directed catch and bycatch scenarios. Figures 4 to 7 show the corresponding projected sardine effective spawning biomasses. Figure 8 graphically compares the statistics relating to Model 0. Tables B1a-c show the results for i)-iii) for further alternative catch and bycatch scenarios. Scenarios in which the selectivity function required modification to enable the catch to be taken (see Appendix A) and scenarios in which after such modification the full catch could still not be simulated to be taken are indicated in the tables by shading.

Naturally the depletion increases with increasing constant catch/bycatch scenarios. The ratio of the November 2019:2018 effective west component spawner biomass under catch/bycatch to no catch/bycatch scenarios was selected by the SWG-PEL as a key diagnostic on which to focus (Butterworth and Coetzee 2019). This ratio is given in the final column of the Tables. For this (very) short-term projection for a short-lived species the SWG-PEL focused on catch/bycatch scenarios that resulted in a ratio around 0.80. The short-term predictions under Model 0 were more optimistic than those from Model 1, but the task team gave a higher implicit weight to Model 0 than Model 1 (see above). The results from Model 3, however, caution that the projections under Model 0 may be over-optimistic. There is uncertainty surrounding the November 2018 survey length frequency and should the population have consisted of fewer recruits and more adults than estimated, short-term management advice for sardine should be more cautious.

Tables B2a-c show the results for the sensitivity tests against Model 0. As expected, higher/lower west to south movement resulted in higher/lower effective west component spawning biomass in 2019 and higher/lower equilibrium west component spawning biomass, and vice versa for the south component. The results were relatively insensitive in the immediate future to a change in the generation of future recruitment, although larger differences over time were observed. The results were very sensitive to assuming the weight-at-length observed during November 2018 persisted until

November 2019, however given recent observations (van der Lingen *et al*. 2019) the task team no longer considered this scenario of high probability. The results were also sensitive to a lower starting point in 2019, with lower projected biomass levels in 2019 and lower ratios compared to that under a no catch scenario.

It is important to note that the “directed” catches modelled in this analysis were taken to include all large sardine catch and bycatch, as well as small sardine bycatch with the directed sardine fishery. The “bycatches” modelled in this analysis were taken to include small sardine bycatch with anchovy and round herring. Thus if, for example, the option of 5250t directed west – 5000t directed south – 10500t bycatch was selected from the Tables below to inform quota recommendations, the 5250t would need to allow for the directed sardine TAC west of Cape Agulhas, the associated small sardine TAB and large sardine TAB with round herring and anchovy, while the 10500t would need to allow for small sardine TAB with anchovy and small sardine TAB with round herring.

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Table 1. The multiplicative increase (or decrease) in effective spawning biomass from November 2018 to November 2019, assuming $\mathrm{move}_{\mathrm{y},1} = 0.3$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

					West component				South component				20% west
Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	5%ile	20%ile	30%ile	50%ile	difference
Old	0	0	0	0	2.87	3.42	3.59	3.83	1.35	1.89	1.98	2.36	
Old	**16.775**	**4.575**	**4.2**	**8**	2.53	3.12	3.38	3.69	1.32	1.8	1.93	2.31	**0.88**
Old	20.75	5.25	5	10.5	2.49	3.05	3.34	3.65	1.32	1.83	1.92	2.30	**0.85**
Old	23	6.5	7	9.5	2.49	3.04	3.31	3.63	1.31	1.82	1.90	2.29	**0.84**
Old	**26.75**	**8.25**	**8**	**10.5**	**2.45**	**2.99**	**3.24**	**3.59**	**1.30**	**1.81**	**1.89**	**2.27**	**0.82**
Revised	0	0	0	0	1.70	2.13	2.40	2.83	0.45	0.94	0.94	1.41	
Revised	16.775	4.575	4.2	8	1.49	1.91	2.16	2.61	0.44	0.91	0.92	1.38	**0.81**
Revised	20.75	5.25	5	10.5	1.43	1.86	2.10	2.55	0.44	0.91	0.91	1.38	**0.76**
Revised	23	6.5	7	9.5	1.43	1.85	2.09	2.53	0.43	0.90	0.90	1.37	**0.75**
Revised	26.75	8.25	8	10.5	1.39	1.81	2.05	2.48	0.43	0.89	0.90	1.36	**0.72**
Revised, $\rho_j = 0$	0	0	0	0	2.20	2.67	2.95	3.40	0.45	1.05	1.05	1.55	
Revised, $\rho_j = 0$	16.775	4.575	4.2	8	1.96	2.44	2.70	3.17	0.44	1.02	1.03	1.52	**0.86**
Revised, $\rho_j = 0$	20.75	5.25	5	10.5	1.90	2.38	2.64	3.12	0.44	1.02	1.02	1.52	**0.83**
Revised, $\rho_j = 0$	23	6.5	7	9.5	1.88	2.36	2.62	3.09	0.44	1.01	1.02	1.51	**0.82**
Revised, $\rho_j = 0$	26.75	8.25	8	10.5	1.83	2.32	2.57	3.03	0.43	1.01	1.01	1.50	**0.79**
Revised, alt 2018 data, $\rho_j = 0$	0	0	0	0	1.08	1.38	1.47	1.68	0.31	0.74	0.76	1.15	
Revised, alt 2018 data, $\rho_j = 0$	16.775	4.575	4.2	8	0.94	1.24	1.33	1.55	0.30	0.72	0.75	1.13	**0.65**
Revised, alt 2018 data, $\rho_j = 0$	20.75	5.25	5	10.5	0.91	1.21	1.30	1.52	0.30	0.72	0.75	1.13	**0.57**
Revised, alt 2018 data, $\rho_j = 0$	23	6.5	7	9.5	0.89	1.20	1.29	1.50	0.30	0.71	0.74	1.12	**0.53**
Revised, alt 2018 data, $\rho_j = 0$	26.75	8.25	8	10.5	0.86	1.17	1.26	1.47	0.30	0.71	0.74	1.12	**0.44**

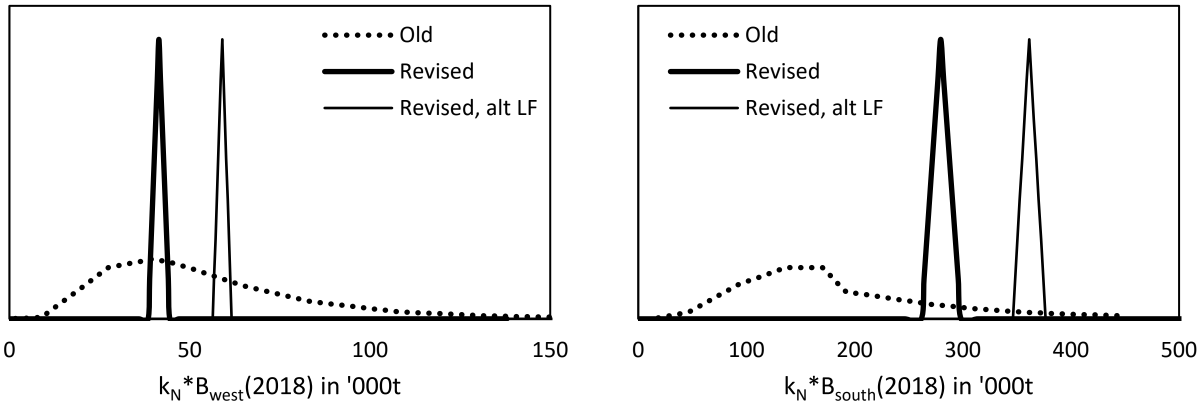

Figure 1. The likelihood profile generated by AD Model Builder for the model predicted survey biomass in November 2018 west of Cape Agulhas (left) and east of Cape Agulhas (right).

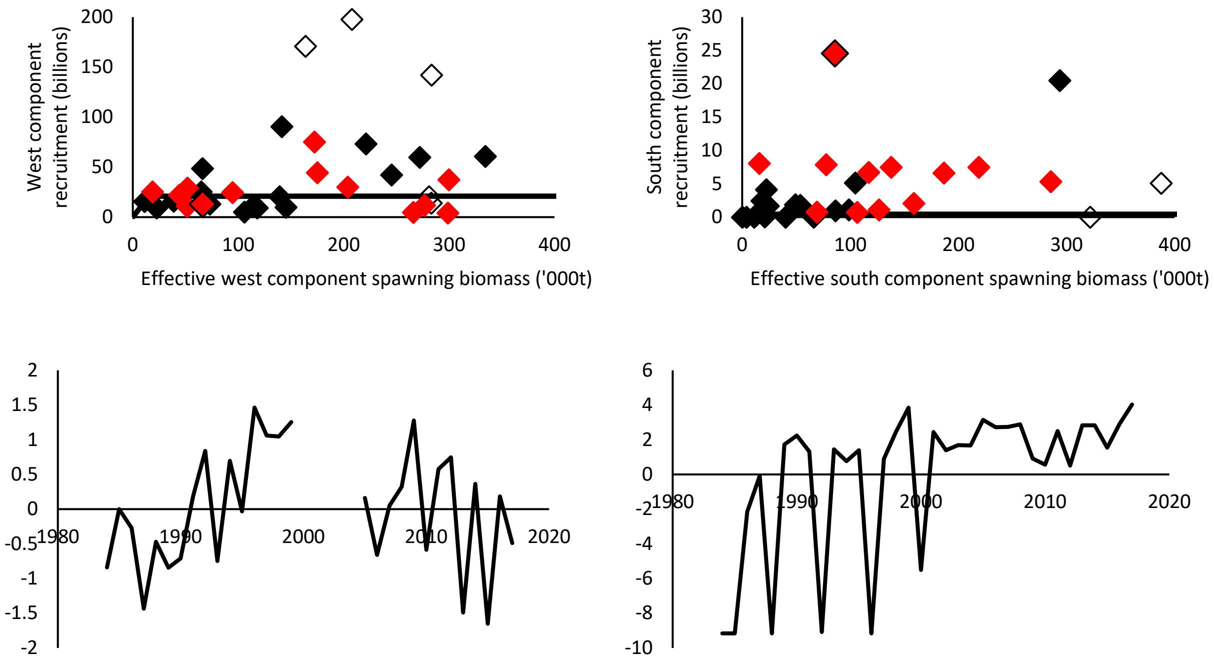

Figure 2a. The model predicted recruitment and effective spawning biomass[2] in November between 1984 and 2017 (1984-99 in black diamonds, 2000-04 unfilled diamonds, 2005-17 in red diamonds) as estimated by de Moor (2019a). Hockey stick stock recruitment curves are fitted to all years. The standardised residuals from the model fit to all years are shown in the lower plots (west – left; south – right).

[2] 8% of south component spawning biomass is assumed to contribute to west component effective spawning biomass.

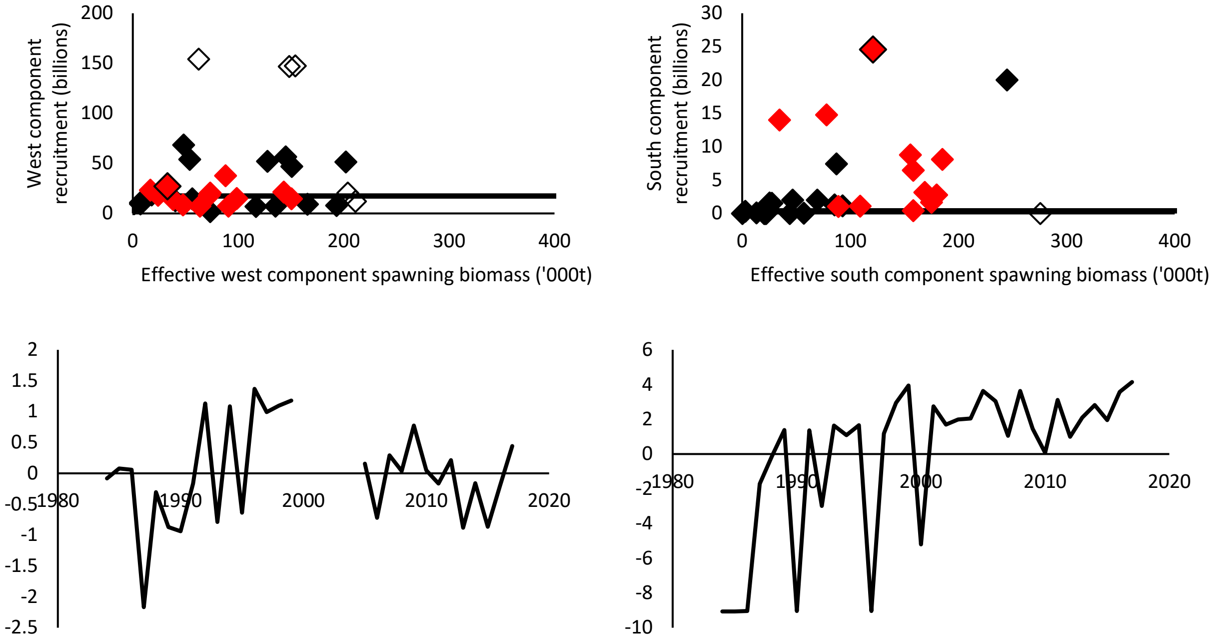

Figure 2b. As for Figure 2a, but as estimated by de Moor (2019c).

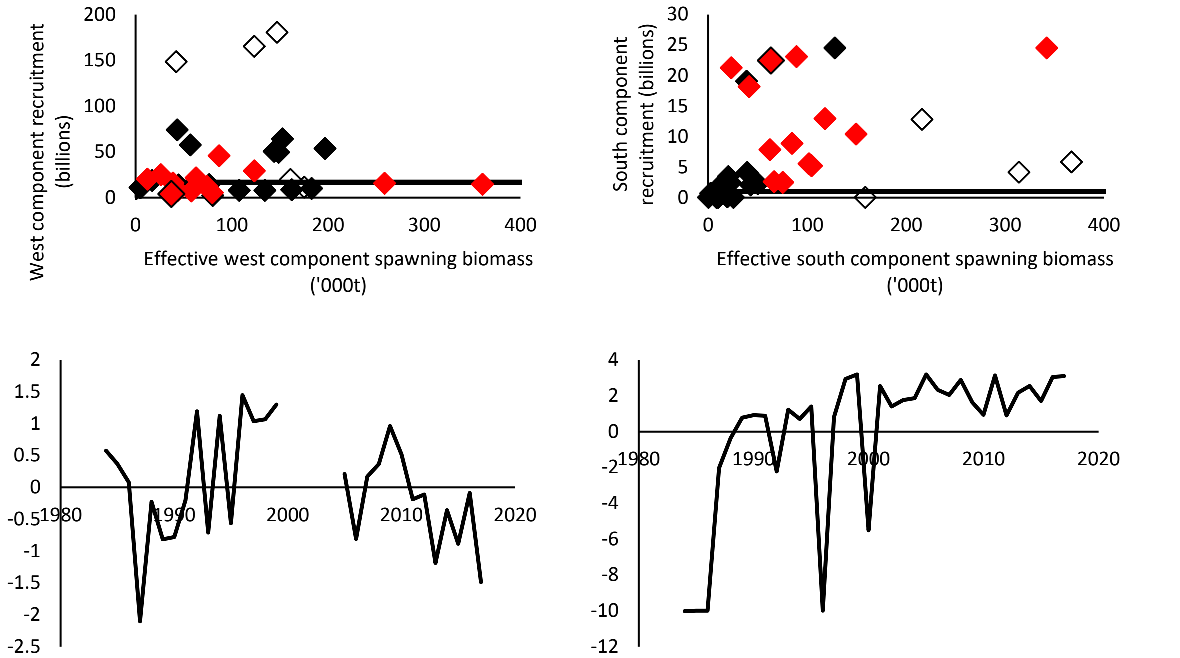

Figure 2c. As for Figure 2a, but as estimated by de Moor (2019c) and fitted to an alternative length frequency in November 2018.

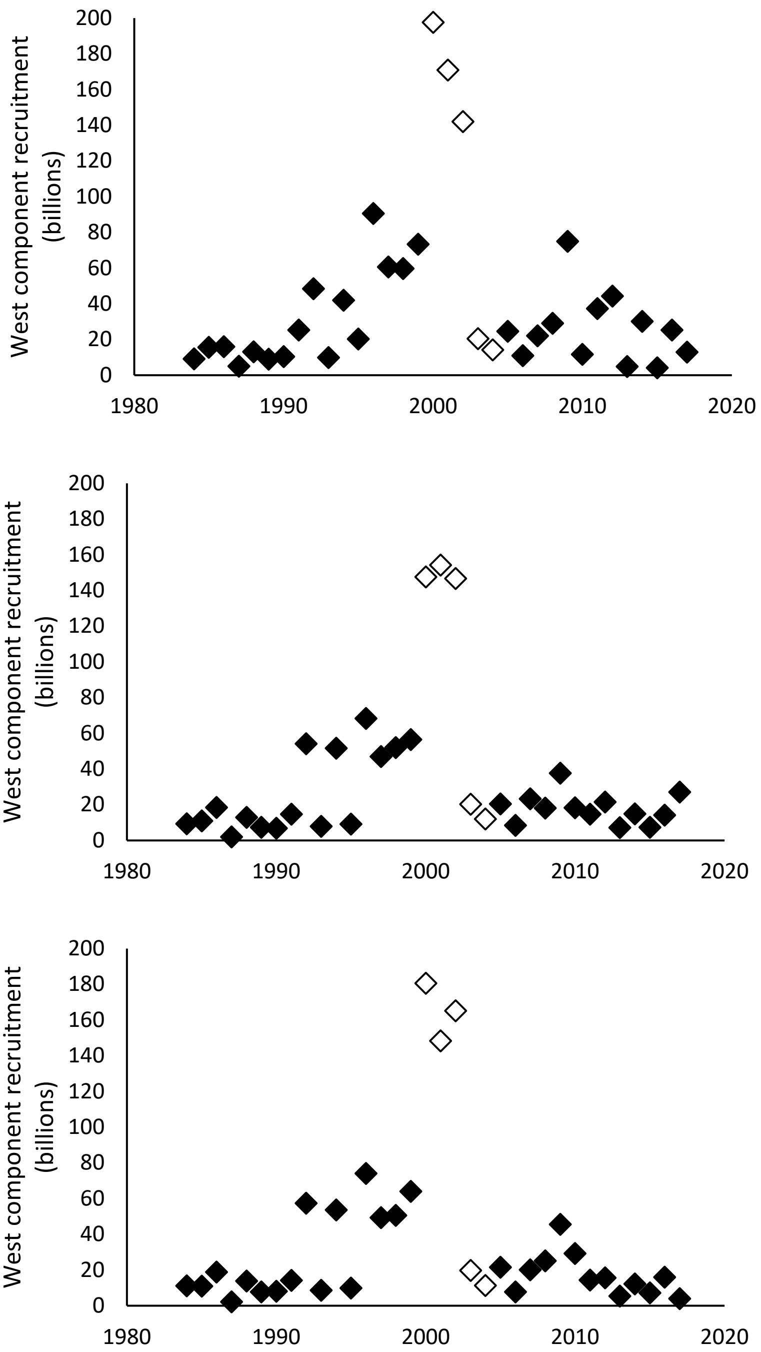

Figure 3. The model predicted west component recruitment from de Moor (2019a) (top), de Moor (2019c) (middle) and de Moor (2019c), but fitted to an alternative length frequency in November 2018 (bottom). The autocorrelation in the time series is 0.63 (top), 0.64 (middle), 0.61 (bottom).

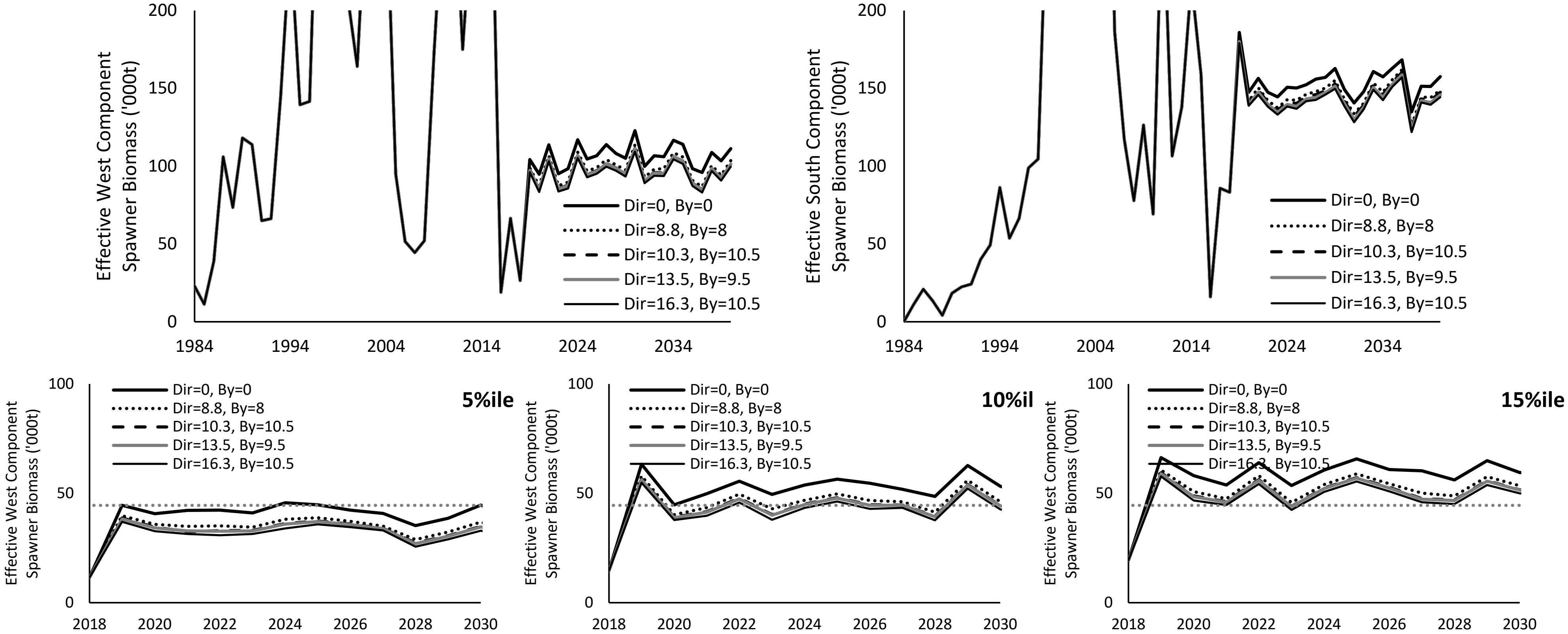

Figure 4. Effective spawning biomass for the (left) west and (right) south components for projections assuming a range of constant future [west large catch + south large catch, west small bycatch] options, using the baseline assumptions and the old model of de Moor (2019a). The upper plots show the median while the lower plots show the 5, 10 and 15%ile for the west component over a narrower range on both axes. The grey dotted line indicates the risk threshold of the 2007 effective west component spawning biomass.

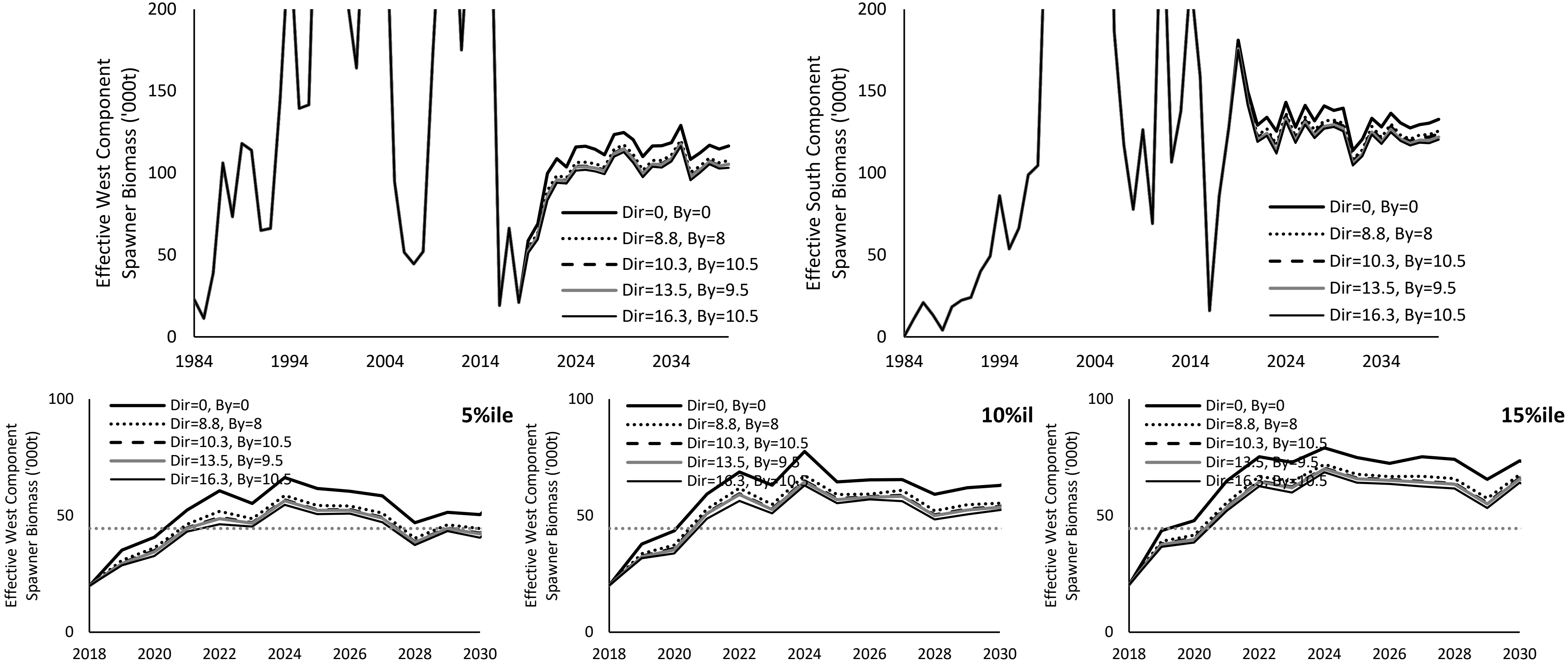

Figure 5. As for Figure 4, but using the baseline assumptions and the revised model of de Moor (2019c).

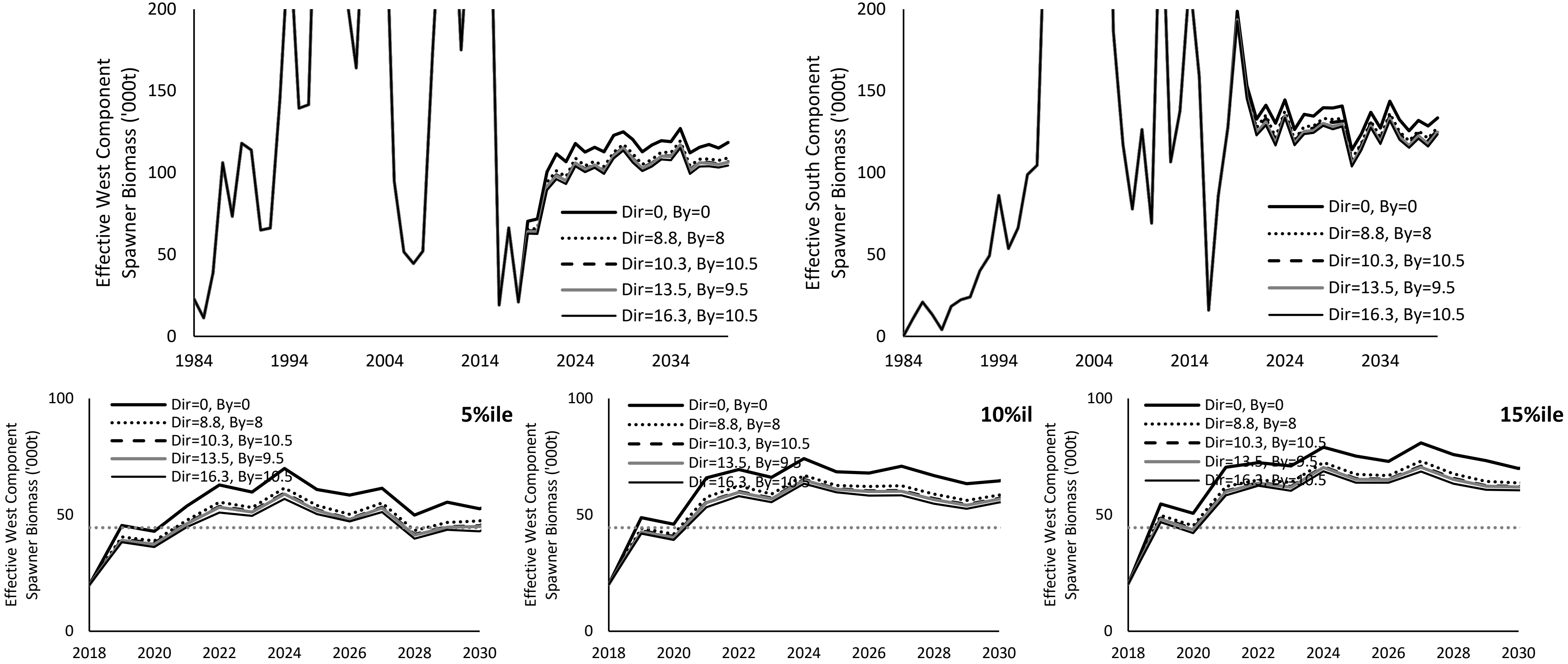

Figure 6. As for Figure 4, but using the baseline assumptions and the revised model of de Moor (2019c) with $\rho_j = 0$.

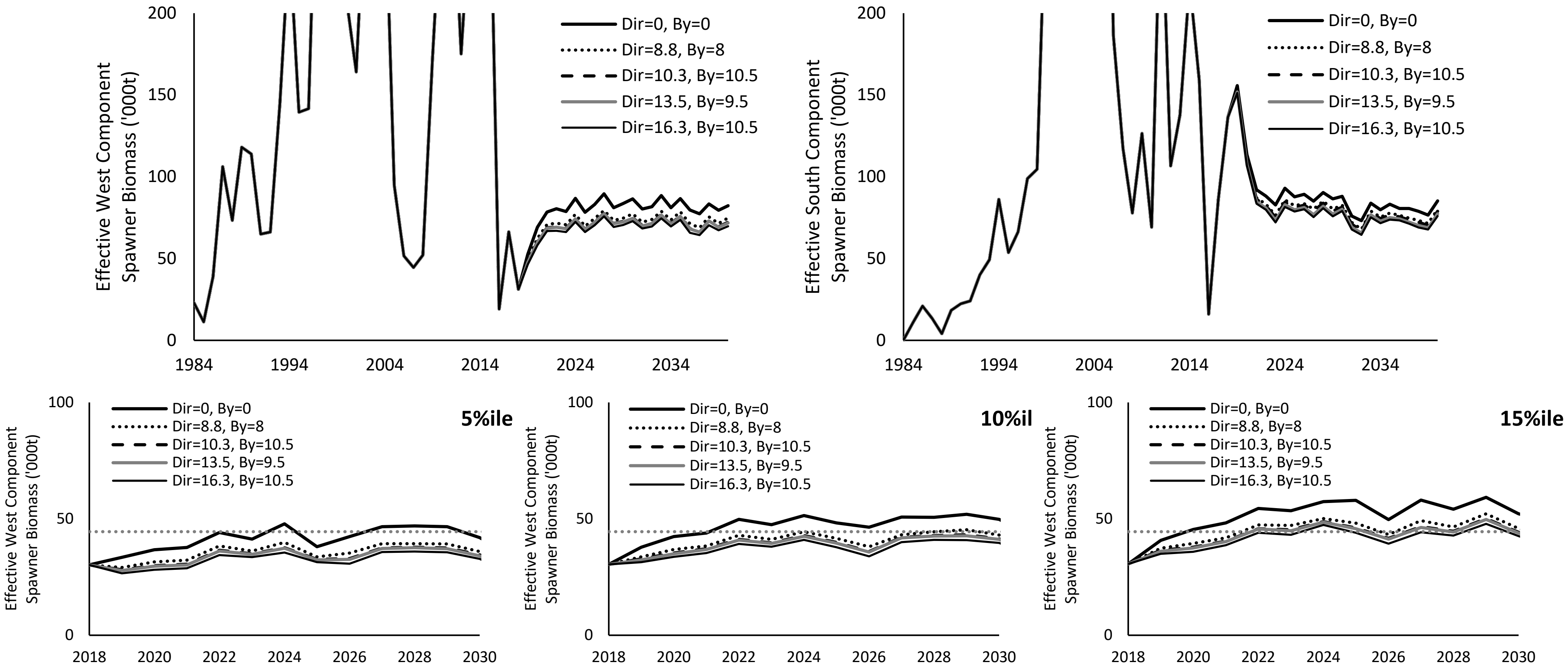

Figure 7. As for Figure 4, but using the baseline assumptions and the revised model of de Moor (2019c) with $\rho_j = 0$, but fitted to an alternative length frequency in November 2018.

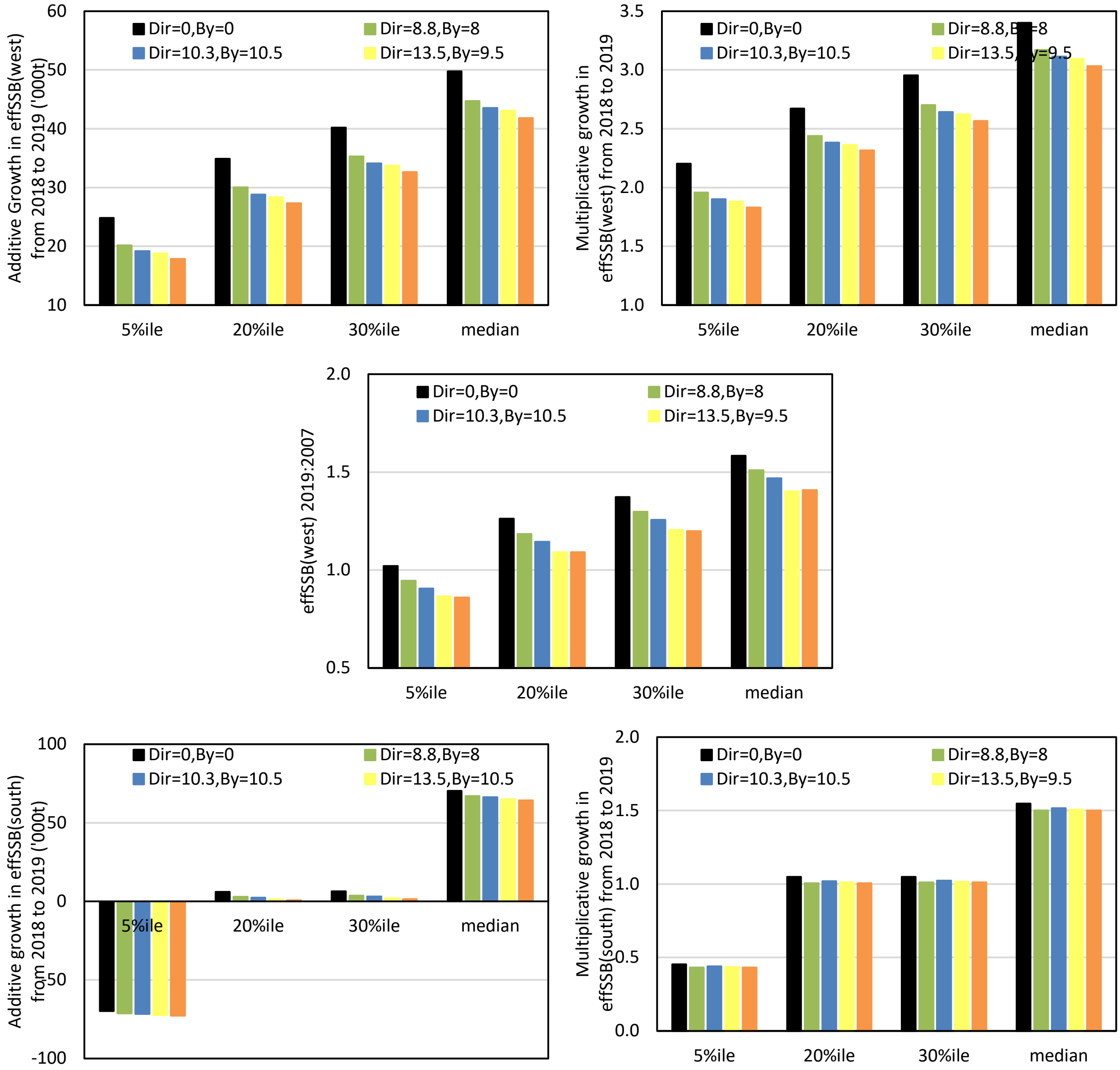

Figure 8. Histograms corresponding to Table 1, showing a) the west component effective spawning biomass in 2019-2018, b) the west component effective spawning biomass in 2019:2018, c) the west component effective spawning biomass in 2019:2007, d) the south component effective spawning biomass in 2019-2018, e) the south component effective spawning biomass in 2019:2018.

Appendix A: Baseline projections using constant catch assumptions

The projections are run from November $y_1 = 2018$ to November $y_n = 2040$. The notation from Appendix A and Tables A1 and A2 of de Moor (2019a) remain the same. The following assumptions are made:

- The numbers-at-age are calculated as follows:

$$N_{j,p,y,a}^{S*} = \left(N_{j,p,y-1,a-1}^{S} e^{-M_{y,a-1}^{S}/2} - C_{j,p,y,a-1}^{S}\right) e^{-M_{y,a-1}^{S}/2} \qquad p = I, NI, y_1 \le y \le y_n, 1 \le a \le 5^{+} \qquad (1)$$

$$N_{j,p,y,5^+}^{S*} = \left(N_{j,p,y-1,4}^{S} e^{-M_{y,4}^{S}/2} - C_{j,p,y,4}^{S}\right) e^{-M_{y,4}^{S}/2} + \left(N_{j,p,y-1,5^+}^{S} e^{-M_{y,5^+}^{S}/2} - C_{j,p,y,5^+}^{S}\right) e^{-M_{y,5^+}^{S}/2}$$
$$p = I, NI, y_1 \le y \le y_n \qquad (2)$$

and

$$\mathrm{N}_{\mathrm{W,p,y,a}}^{\mathrm{S}} = \left(1 - \mathrm{move}_{\mathrm{y,a}}\right)\mathrm{N}_{\mathrm{W,p,y,a}}^{\mathrm{S**}} \qquad p = I, NI, y_1 \le y \le y_n, 1 \le a \le 5^{+}$$

$$\mathrm{N}_{\mathrm{S,p,y,a}}^{\mathrm{S}} = \mathrm{N}_{\mathrm{S,p,y,a}}^{\mathrm{S**}} + \mathrm{move}_{\mathrm{y,a}}\mathrm{N}_{\mathrm{W,p,y,a}}^{\mathrm{S**}} \qquad p = I, NI, y_1 \le y \le y_n, 1 \le a \le 5^{+} \qquad (3)$$

- Future infection is assumed to be zero (this is inconsequential to projections).
- Future movement of 1-year olds from the west to the south component is assumed to be time-invariant and $\mathrm{move}_{\mathrm{y,1}}$ =0.3, which is roughly the average estimated for the past 5 and 10 years[3]. Additionally, if a density-dependent hypothesis were assumed (de Moor e*t al.* 2018), one would expect movement in the short-term to be relatively low.
- Future recruitment is generated from the past 5[4] years of recruitment under the assumption that future recruitment, particularly in the immediate short-term future, may be from a similar regime to that of the more recent 5 years. Autocorrelation in the historical recruitment time series is non-negligible lending further weight to this being a preferred baseline choice for these analyses.
- Natural mortality is assumed to be time-invariant: $M_{y,a=0}^{S} = \bar{M}_{ju}^{S}$ and $M_{y,a=1+}^{S} = \bar{M}_{ad}^{S}$
- No allowance is made for early/late recruitment in future years, i.e. $\varepsilon_y^t = 0$ in equation (A8) (see Figure A1).
- Growth curves at the mid-point of each quarter (equation A17) and therefore the quarterly commercial selectivity-at-age functions (equation A16) are the same[5] for all future years.
- Growth curves in November (equation A7) are thus also the same for all future years.
- Future annual selectivity-at-age is assumed to be time-invariant and averaged over all quarters of the most recent commercial selectivity-at-length estimated from 2002-2018 (note growth curves are time-invariant in future years):

$$S_{j,a}^{S} = 0.25 \sum_{q=1}^{4} \sum_{l=2.5^-}^{24^+} A_{j,2019,q,a,l}^{com} S_{j,2018,q,l} \quad 0 \le a \le 5^{+} \qquad (5)$$

- The numbers-at-length are calculated according to equations (A5) and (A6).
- The same maturity-at-length relationship, based on that corresponding to the period 1965-1975, is assumed from 2004 onwards, for all projected years.

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[3] November 2018 was excluded as there are fewer data to reliably inform the estimate. The average over the past 5 years was 0.30 for the old model and 0.36 for the revised model. The average over the past 10 years was 0.30 for the old model and 0.44 for the revised model.

[4] The most recent 5 or 10 years are frequent choices for the “recent past” in projection analyses internationally.

[5] Except in cases where the selectivity is modified to allow catch to be spread to lower ages (described below)

- The November biomass, spawning biomass and effective spawning biomass are calculated according to equations (A11) to (A13).
- Figures A2 and A3 indicate the weight-at-length in November 2018 was substantially lower than other years (except 2006) for the west component. For future years, the weight-at-length is assumed to be given by

  $w^S_{j,y,l} = a_{j,y} l^b$, where $a_{j,y} - \overline{a}_j = \rho_j(a_{j,y-1} - \overline{a}_j) + \sqrt{1-\rho_j^2}\, a^*_{j,y}$ (6)

  where $a^*_{j,y}$ is drawn randomly from the historical set of $a_{j,y} - \overline{a}_j$'s obtained by fitting $a_{j,y} l^b$ to the $w^S_{j,y,l}$ estimated by the assessment for $1984 \le y \le 2018$ for the west component and $2008 \le y \le 2018$[6] for the south component (Figures A3 and A4). The future $a_{j,y}$ generated in this manner are constrained by the minimum and maximum of the historically estimated $a_{j,y}$'s.
- Catch weight-at-age is taken to be the average of the weight-at-age in November immediately before and after the pulse fishery is assumed, i.e.

  $$w^{catch}_{j,y,a} = 0.5\left(w^S_{j,y-1,a} + w^S_{j,y,a+1}\right) \quad 0 \le a \le 4$$
  $$w^{catch}_{j,y,5^+} = 0.5\left(w^S_{j,y-1,5^+} + w^S_{j,y,5^+}\right) \quad (7)$$

  where

  $$w^S_{j,y,a} = \sum_{l=2.5^-}^{l=24^+} A^{sur}_{j,y,a,l} w^S_{j,y,l} \quad (8)$$
- Catch is assumed to be taken in a single pulse, mid-way through the year. Bycatch is calculated as:

  $$C^{bycatch}_{j,p,y,a} = \frac{Bycatch}{\sum_{a=0}^{1}\sum_{p=I,NI} N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} w^{catch}_{j,a}} \times N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} \le N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2}$$

  and directed catch (taken to include large sardine bycatch) is calculated as:

  $$C^{dir}_{j,p,y,a} = \frac{Directed+Large\ Bycatch}{\sum_{a=0}^{5^+}\sum_{p=I,NI}\left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a} w^{catch}_{j,a}} \times \left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a}$$, with

  $$\frac{Directed+Large\ Bycatch}{\sum_{a=0}^{5^+}\sum_{p=I,NI}\left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a} w^{catch}_{j,a}} \times S^S_{j,5} \le 0.95$$

  $$C^S_{j,p,y,a} = C^{bycatch}_{j,p,y,a} + C^{dir}_{j,p,y,a} \qquad p = I, NI, y > y_n,\ 1 \le q \le 4, 0 \le a \le 5^+ \quad (9)$$
- In cases where the above constraints would otherwise result in the realised catch being less than the tested scenario, the selectivity is modified as follows:

  If $\frac{Directed+Large\ Bycatch}{\sum_{a=0}^{5^+}\sum_{p=I,NI}\left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a} w^{catch}_{j,a}} \times S^S_{j,5} \le 0.95$

  Then $C^{dir}_{j,p,y,5+} = 0.95\left(N^S_{j,p,y-1,5+} e^{-M^S_{y,5+}/2} - C^{bycatch}_{j,p,y,5+}\right)$

  If $\frac{Directed+Large\ Bycatch}{\sum_{a=0}^{4}\sum_{p=I,NI}\left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a} w^{catch}_{j,a}} \times S^S_{j,4} \le 0.95$

  Then $C^{dir}_{j,p,y,4} = 0.95\left(N^S_{j,p,y-1,4} e^{-M^S_{y,4}/2} - C^{bycatch}_{j,p,y,4}\right)$

  Else $C^{dir}_{j,p,y,a<5} = \frac{Directed+Large\ Bycatch}{\sum_{a=0}^{3}\sum_{p=I,NI}\left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a} w^{catch}_{j,a}} \times \left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a}$

  If $\frac{Directed+Large\ Bycatch}{\sum_{a=0}^{3}\sum_{p=I,NI}\left(N^S_{j,p,y-1,a} e^{-M^S_{y,a}/2} - C^{bycatch}_{j,p,y,a}\right) S^S_{j,a} w^{catch}_{j,a}} \times S^S_{j,3} \le 0.95$

[6] A shorter time frame is used for the south component due to the apparently lower a's in more recent years compared to the full time series (Figure A2).

Then $C_{j,p,y,3}^{dir} = 0.95\left(N_{j,p,y-1,3}^{S}e^{-M_{y,3}^{S}/2} - C_{j,p,y,3}^{bycatch}\right)$

Else $C_{j,p,y,a<4}^{dir} = \frac{Directed+Large\ Bycatch}{\sum_{a=0}^{3}\sum_{p=I,NI}\left(N_{j,p,y-1,a}^{S}e^{-M_{y,a}^{S}/2}-C_{j,p,y,a}^{bycatch}\right)S_{j,a}^{S}w_{j,a}^{catch}} \times \left(N_{j,p,y-1,a}^{S}e^{-M_{y,a}^{S}/2} - C_{j,p,y,a}^{bycatch}\right)S_{j,a}^{S}$

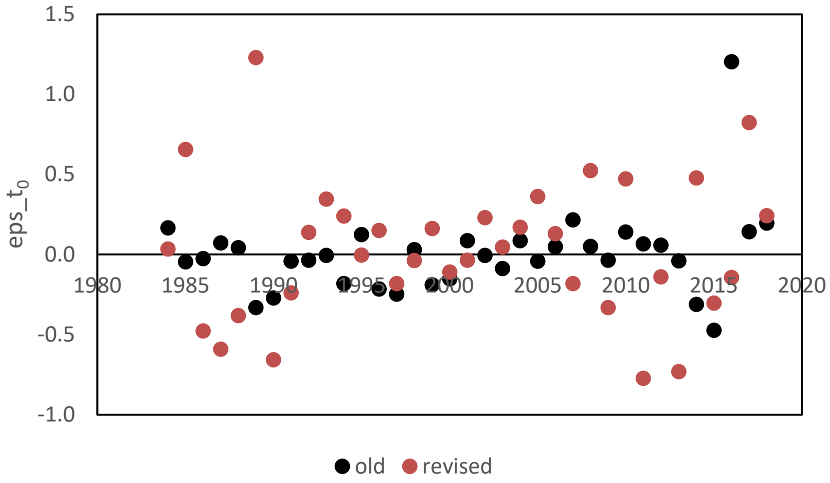
If $\frac{Directed+Large\ Bycatch}{\sum_{a=0}^{2}\sum_{p=I,NI}\left(N_{j,p,y-1,a}^{S}e^{-M_{y,a}^{S}/2}-C_{j,p,y,a}^{bycatch}\right)S_{j,a}^{S}w_{j,a}^{catch}} \times S_{j,2}^{S} \leq 0.95$

Then $C_{j,p,y,2}^{dir} = 0.95\left(N_{j,p,y-1,2}^{S}e^{-M_{y,2}^{S}/2} - C_{j,p,y,2}^{bycatch}\right)$

$C_{j,p,y,a<2}^{dir} = \frac{Directed+Large\ Bycatch}{\sum_{a=0}^{1}\sum_{p=I,NI}\left(N_{j,p,y-1,a}^{S}e^{-M_{y,a}^{S}/2}-C_{j,p,y,a}^{bycatch}\right)S_{j,a}^{S}w_{j,a}^{catch}} \times \left(N_{j,p,y-1,a}^{S}e^{-M_{y,a}^{S}/2} - C_{j,p,y,a}^{bycatch}\right)S_{j,a}^{S}$, with

$\frac{Directed+Large\ Bycatch}{\sum_{a=0}^{1}\sum_{p=I,NI}\left(N_{j,p,y-1,a}^{S}e^{-M_{y,a}^{S}/2}-C_{j,p,y,a}^{bycatch}\right)S_{j,a}^{S}w_{j,a}^{catch}} \times S_{j,5}^{S} \leq 0.95$ [7]

[7] There are still a few cases where the full catch is not realised by this equation reaching the constraint, even after the modifications to the selectivity are done.



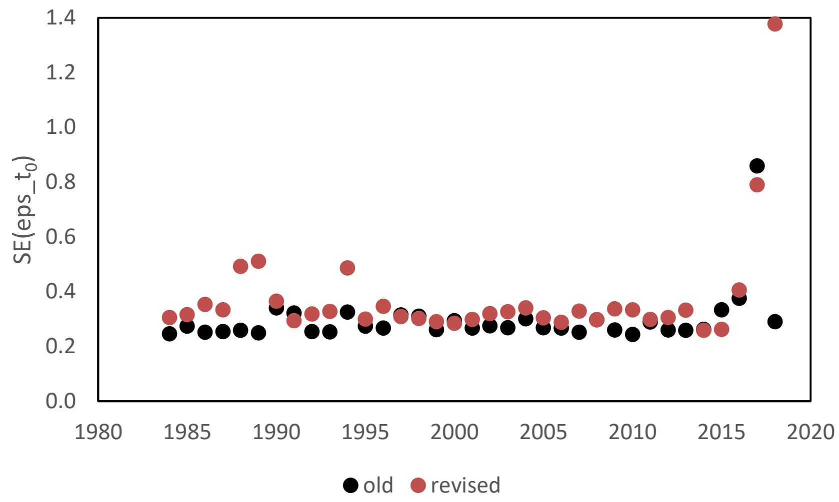


Figure A1. The model estimates of ε_y^t from 1984 to 2018 with the hessian-based SE.

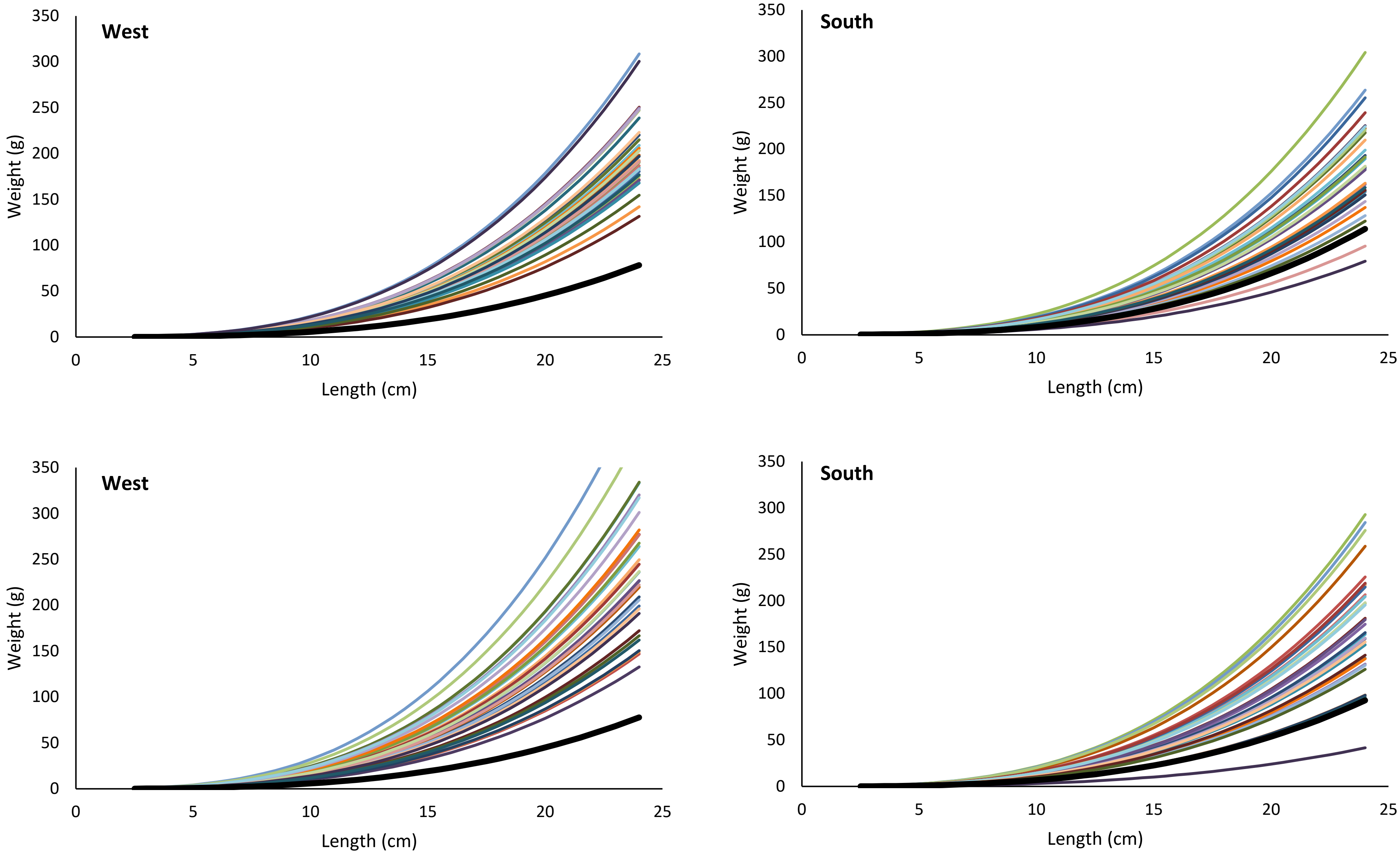


Figure A2. The annual weight-at-length estimated by de Moor (2018a) (upper plots) and de Moor (2018c) (lower plots). The dark line denotes 2018.

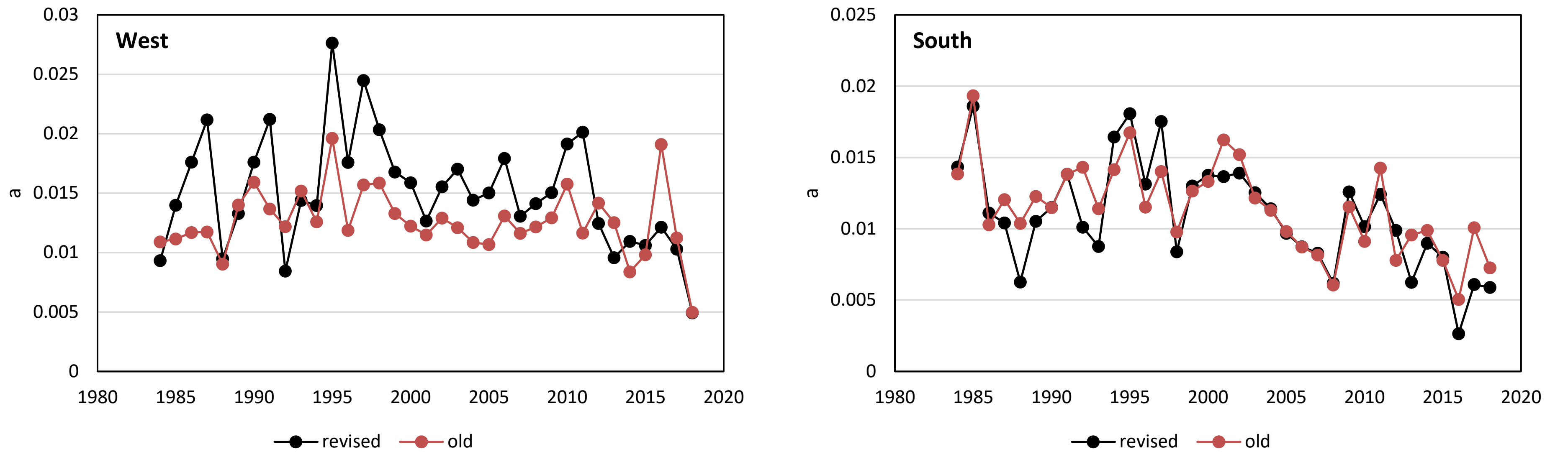


Figure A3. The $a_{j,y}$ values estimated by fixing $b = 3.031$ and fitting to the historically estimated annual weight-at-length using sum of squares. The historical averages are 0.013 and 0.151 for the west component, old and revised models, respectively and 0.009 and 0.008 for the south component, old and revised models, respectively.

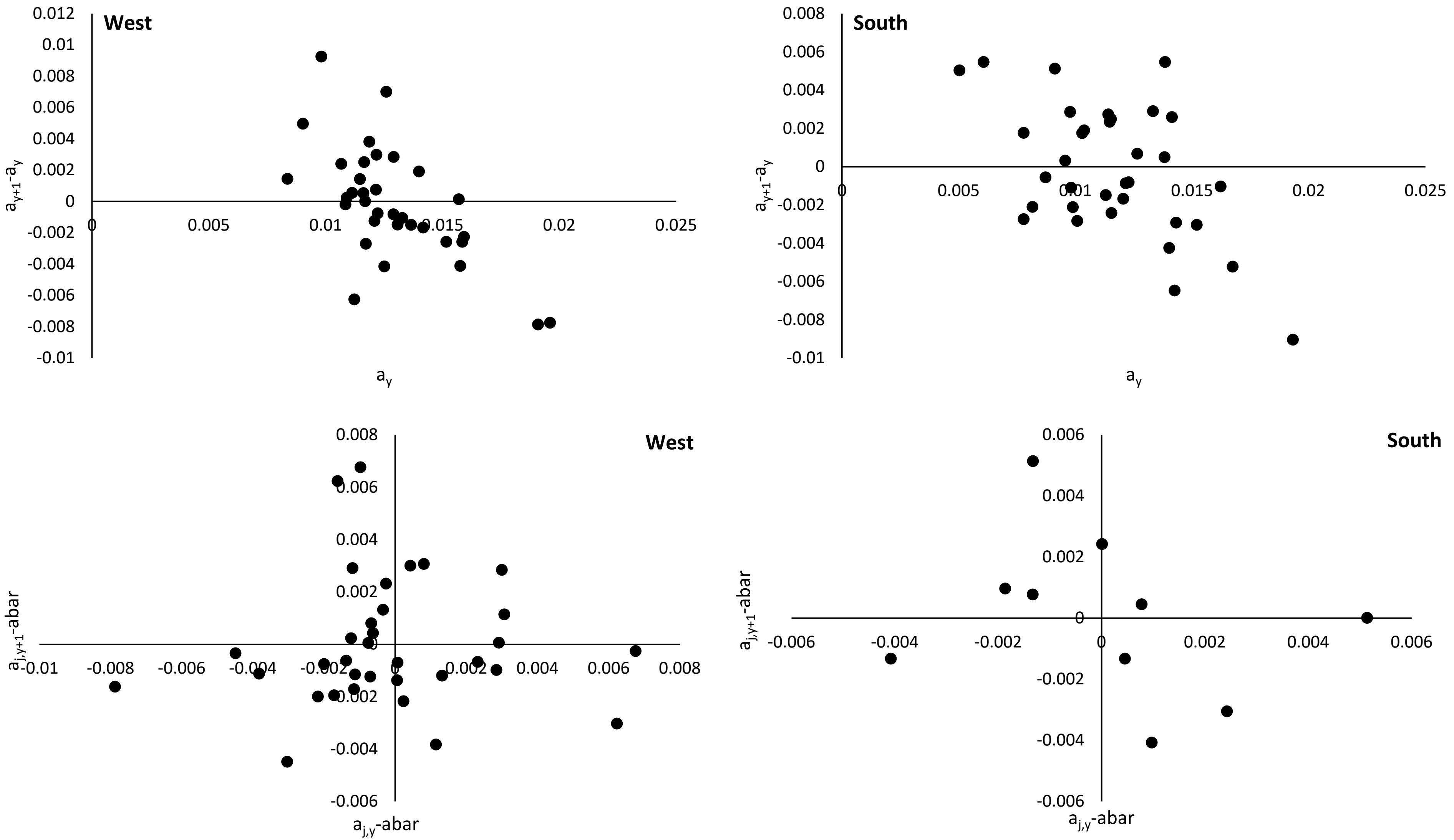


Figure A4a. Plots to assess autocorrelation in the $a_{j,y}$'s from Figure A3 for the old model. The upper plots include all data points, whereas in the lower plot for the south only the data points from 2008-2018 are included. The averages exclude the final year: $\bar{a}_{west} = \sum_{1984}^{2017} a_{west,y} = 0.013$ and $\bar{a}_{south} = \sum_{2008}^{2017} a_{south,y} = 0.009$. The autocorrelation coefficient is estimated as $\rho_{west} = 0.037$ and $\rho_{south} = -0.261$.

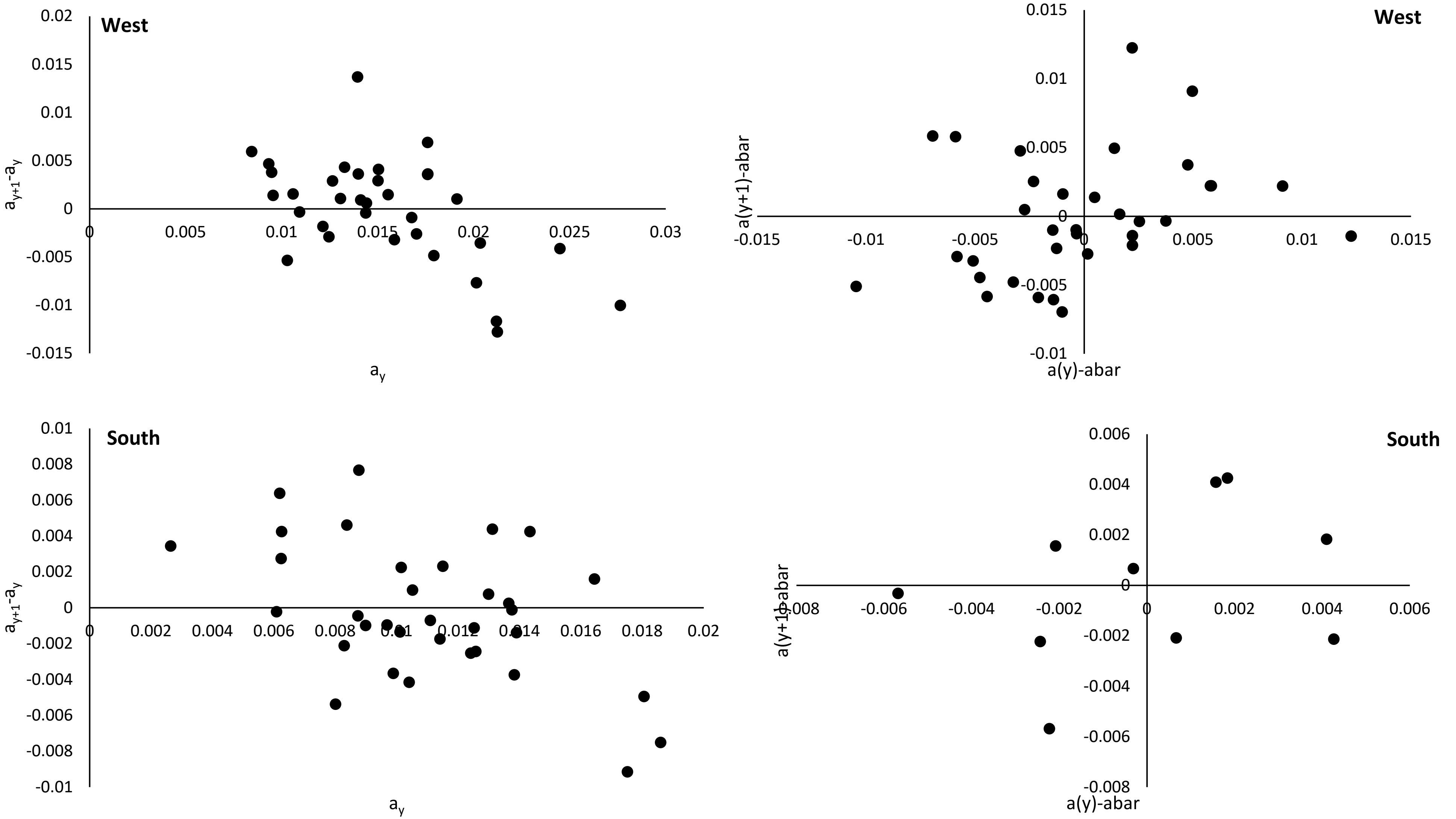


Figure A4b. Plots to assess autocorrelation in the $a_{j,y}$'s from Figure A3 for the revised model. The upper plots include all data points, whereas in the lower plot for the south only the data points from 2008-2018 are included. The averages exclude the final year: $\bar{a}_{west} = \sum_{1984}^{2017} a_{west,y} = 0.015$ and $\bar{a}_{south} = \sum_{2008}^{2017} a_{south,y} = 0.008$. The autocorrelation coefficient is estimated as $\rho_{west} = 0.291$ and $\rho_{south} = 0.314$.

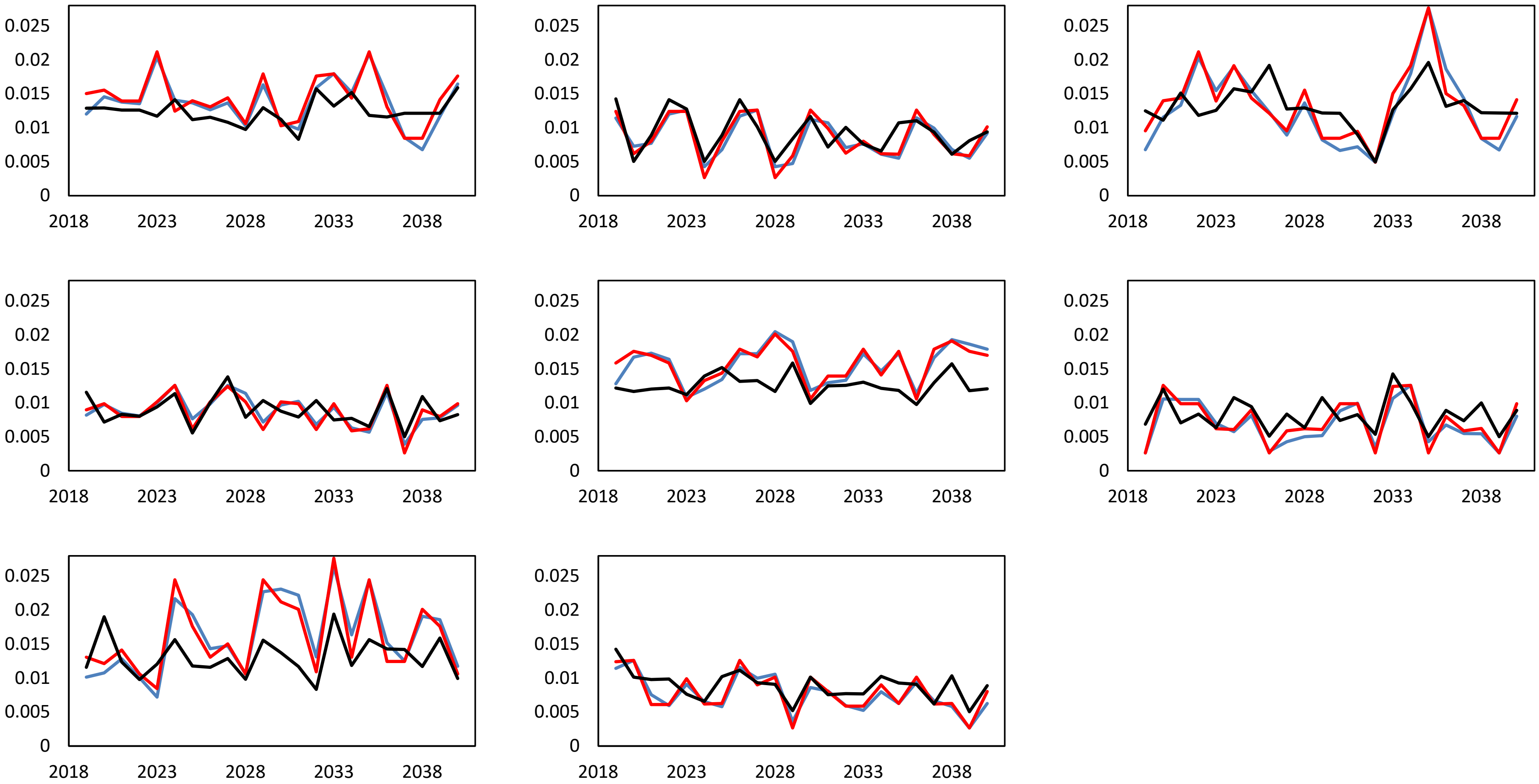


Figure A5. Some example timeseries of future $a_{west,y}$ for the old model of de Moor (2019a) (black), the revised model of de Moor (2019c) (red) and the revised model with $\rho_j = 0$ blue).

Appendix B. Further tables of results

Table B1a. The additive increase (or decrease) in effective spawning biomass (in '000t) from November 2018 to November 2019, assuming $\mathrm{move}_{y,1} = 0.3$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

					West component				South component				20% west
Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	5%ile	20%ile	30%ile	50%ile	difference
Old	0	0	0	0	33	56	62	78	28	53	65	102	
	10	3.5	1.5	5	30	53	58	75	27	52	64	100	0.95
	15*	7	3	5	28	51	56	73	26	51	63	99	0.91
	16*	4.575	1.425	10	28	51	56	73	26	52	64	100	0.90
	16.575	4.575	7	5	29	52	57	74	24	50	61	97	0.93
	25*	14	6	5	24	47	53	69	24	49	61	96	0.84
	25*	9	6	10	25	48	54	71	24	50	61	97	0.86
	26.75*	8.25	8	10.5	21	43	49	66	22	47	59	94	0.86
	26.75*	9.25	9	8.5	24	47	52	69	19	44	56	91	0.86
	35*	21	9	5	26	48	54	71	23	49	60	96	0.78
	35	14	16	5	26	48	54	71	23	48	60	95	0.83
Revised	0	0	0	0	15	24	29	38	-70	-8	-8	53	
	10	3.5	1.5	5	12	21	26	35	-70	-10	-9	51	0.86
	15	7	3	5	10	19	24	33	-71	-11	-10	50	0.80
	16	4.575	1.425	10	10	19	24	32	-71	-10	-9	51	0.78
	16.575	4.575	7	5	11	20	25	34	-72	-12	-12	48	0.83
	25	14	6	5	8	17	22	30	-72	-13	-12	48	0.71
	25	9	6	10	8	17	22	30	-72	-13	-12	48	0.71
	26.75	8.25	8	10.5	8	17	22	30	-73	-14	-13	47	0.70
	26.75	9.25	9	8.5	8	17	22	30	-73	-14	-13	46	0.72
	35	21	9	5	6	15	20	29	-73	-14	-13	46	0.63
	35	14	16	5	8	17	22	30	-75	-17	-16	42	0.70
Revised, $\rho_j = 0$	0	0	0	0	25	35	40	50	-70	6	6	70	
	10	3.5	1.5	5	22	32	37	46	-70	5	5	69	0.91
	15	7	3	5	20	30	35	44	-71	4	4	68	0.85
	16	4.575	1.425	10	20	29	35	44	-71	4	5	68	0.85
	16.575	4.575	7	5	21	31	36	46	-72	2	2	66	0.88
	25	14	6	5	18	28	33	41	-72	2	2	65	0.79
	25	9	6	10	18	27	33	42	-72	2	2	65	0.78
	26.75	8.25	8	10.5	18	27	33	42	-73	1	1	64	0.78
	26.75	9.25	9	8.5	18	28	33	42	-73	0	1	64	0.79
	35	21	9	5	16	25	31	40	-73	0	1	63	0.73
	35	14	16	5	18	27	32	41	-75	-3	-2	60	0.78
Revised, alt 2018 data, $\rho_j = 0$	0	0	0	0	8	17	23	35	-92	-36	-33	16	
	10	3.5	1.5	5	5	14	20	33	-92	-37	-33	16	0.86
	15	7	3	5	4	13	18	31	-92	-37	-34	15	0.77
	16	4.575	1.425	10	4	13	18	31	-92	-37	-33	15	0.77
	16.575	4.575	7	5	5	14	19	32	-93	-39	-35	13	0.82
	25	14	6	5	1	10	15	29	-93	-39	-35	13	0.60
	25	9	6	10	2	11	16	30	-93	-39	-35	13	0.66
	26.75	8.25	8	10.5	2	11	16	30	-94	-39	-36	12	0.66
	26.75	9.25	9	8.5	2	11	16	30	-94	-40	-36	12	0.66
	35	21	9	5	-2	7	11	25	-94	-40	-37	11	0.42
	35	14	16	5	1	10	14	28	-95	-42	-39	9	0.58

* In these cases the full catch could not be realised in only one out of 100 simulations.

Table B1b. The multiplicative increase (or decrease) in effective spawning biomass from November 2018 to November 2019, assuming $\mathrm{move}_{y,1} = 0.3$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

					West component				South component				20% west
Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	5%ile	20%ile	30%ile	50%ile	difference
Old	0	0	0	0	2.87	3.42	3.59	3.83	1.35	1.89	1.98	2.36	
	10	3.5	1.5	5	2.58	3.22	3.45	3.72	1.33	1.86	1.95	2.34	0.92
	15*	7	3	5	2.53	3.12	3.38	3.68	1.33	1.84	1.94	2.32	0.88
	16*	4.575	1.425	10	2.51	3.09	3.36	3.67	1.33	1.85	1.95	2.33	0.86
	16.575	4.575	7	5	2.56	3.17	3.41	3.71	1.31	1.82	1.91	2.30	0.90
	25*	14	6	5	2.37	2.93	3.22	3.54	1.31	1.81	1.90	2.29	0.80
	25*	9	6	10	2.45	2.99	3.24	3.58	1.31	1.82	1.91	2.29	0.82
	26.75*	8.25	8	10.5	2.45	2.99	3.24	3.59	1.30	1.81	1.89	2.27	0.82
	26.75*	9.25	9	8.5	2.46	3.00	3.25	3.59	1.30	1.80	1.88	2.27	0.83
	35*	21	9	5	2.13	2.79	3.06	3.37	1.29	1.78	1.87	2.25	0.74
	35	14	16	5	2.32	2.91	3.20	3.53	1.26	1.72	1.82	2.20	0.79
Revised	0	0	0	0	1.70	2.13	2.40	2.83	0.45	0.94	0.94	1.41	
	10	3.5	1.5	5	1.56	1.98	2.24	2.68	0.45	0.92	0.93	1.40	0.87
	15	7	3	5	1.50	1.92	2.16	2.59	0.44	0.92	0.92	1.39	0.81
	16	4.575	1.425	10	1.46	1.89	2.14	2.58	0.45	0.92	0.93	1.40	0.79
	16.575	4.575	7	5	1.53	1.95	2.20	2.64	0.44	0.90	0.91	1.37	0.84
	25	14	6	5	1.40	1.82	2.07	2.49	0.44	0.90	0.91	1.37	0.73
	25	9	6	10	1.39	1.81	2.05	2.48	0.44	0.90	0.91	1.37	0.72
	26.75	8.25	8	10.5	1.39	1.81	2.05	2.48	0.43	0.89	0.90	1.36	0.72
	26.75	9.25	9	8.5	1.40	1.83	2.06	2.49	0.43	0.89	0.90	1.36	0.73
	35	21	9	5	1.31	1.72	1.98	2.40	0.43	0.89	0.89	1.36	0.64
	35	14	16	5	1.38	1.80	2.04	2.47	0.41	0.86	0.87	1.33	0.71
Revised, $\rho_j = 0$	0	0	0	0	2.20	2.67	2.95	3.40	0.45	1.05	1.05	1.55	
	10	3.5	1.5	5	2.04	2.51	2.78	3.24	0.45	1.04	1.04	1.54	0.91
	15	7	3	5	1.95	2.43	2.69	3.16	0.45	1.03	1.03	1.53	0.86
	16	4.575	1.425	10	1.93	2.42	2.68	3.15	0.45	1.03	1.04	1.53	0.85
	16.575	4.575	7	5	2.00	2.47	2.74	3.20	0.44	1.01	1.02	1.51	0.88
	25	14	6	5	1.84	2.33	2.59	3.02	0.44	1.01	1.02	1.51	0.80
	25	9	6	10	1.83	2.32	2.57	3.03	0.44	1.01	1.02	1.51	0.79
	26.75	8.25	8	10.5	1.83	2.32	2.57	3.03	0.86	1.09	1.20	1.41	0.79
	26.75	9.25	9	8.5	1.85	2.33	2.58	3.04	0.87	1.10	1.20	1.41	0.80
	35	21	9	5	1.77	2.23	2.49	2.93	0.43	1.00	1.01	1.49	0.73
	35	14	16	5	1.83	2.30	2.56	3.00	0.41	0.97	0.98	1.46	0.78
Revised, alt 2018 data, $\rho_j = 0$	0	0	0	0	1.23	1.52	1.69	2.08	0.30	0.72	0.75	1.13	
	10	3.5	1.5	5	1.16	1.44	1.61	2.00	0.30	0.72	0.74	1.12	0.86
	15	7	3	5	1.12	1.40	1.56	1.95	0.30	0.71	0.74	1.11	0.77
	16	4.575	1.425	10	1.12	1.40	1.56	1.96	0.30	0.72	0.74	1.12	0.77
	16.575	4.575	7	5	1.15	1.42	1.59	1.98	0.29	0.70	0.73	1.10	0.82
	25	14	6	5	1.03	1.31	1.45	1.86	0.29	0.70	0.73	1.10	0.60
	25	9	6	10	1.07	1.34	1.49	1.89	0.29	0.70	0.73	1.10	0.66
	26.75	8.25	8	10.5	1.07	1.34	1.49	1.90	0.29	0.70	0.72	1.09	0.66
	26.75	9.25	9	8.5	1.07	1.34	1.49	1.90	0.29	0.70	0.72	1.09	0.66
	35	21	9	5	0.93	1.21	1.35	1.77	0.29	0.69	0.72	1.09	0.41
	35	14	16	5	1.03	1.30	1.44	1.85	0.28	0.68	0.70	1.06	0.57

* In these cases the full catch could not be realised in only one out of 100 simulations.

Table B1c. The west component effective spawning biomass in November 2019 compared to November 2007 (the risk threshold), assuming $\mathrm{move}_{y,1} = 0.3$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	20% diff
Old	0	0	0	0	1.00	1.80	1.91	2.34	
	10	3.5	1.5	5	0.93	1.72	1.83	2.26	0.95
	15*	7	3	5	0.89	1.68	1.79	2.22	0.93
	16*	4.575	1.425	10	0.88	1.66	1.78	2.21	0.92
	16.575	4.575	7	5	0.91	1.70	1.81	2.24	0.94
	25*	14	6	5	0.80	1.59	1.71	2.13	0.88
	25*	9	6	10	0.83	1.61	1.73	2.16	0.89
	26.75*	8.25	8	10.5	0.83	1.61	1.73	2.16	0.89
	26.75*	9.25	9	8.5	0.83	1.61	1.73	2.16	0.90
	35*	21	9	5	0.72	1.51	1.63	2.05	0.84
	35	14	16	5	0.79	1.58	1.70	2.12	0.88
Revised	0	0	0	0	0.79	1.02	1.11	1.32	
	10	3.5	1.5	5	0.73	0.95	1.04	1.25	0.93
	15	7	3	5	0.69	0.91	1.01	1.21	0.90
	16	4.575	1.425	10	0.68	0.90	1.00	1.20	0.88
	16.575	4.575	7	5	0.71	0.93	1.02	1.23	0.91
	25	14	6	5	0.65	0.87	0.97	1.15	0.85
	25	9	6	10	0.64	0.86	0.96	1.15	0.85
	26.75	8.25	8	10.5	0.64	0.86	0.96	1.15	0.85
	26.75	9.25	9	8.5	0.65	0.87	0.96	1.15	0.85
	35	21	9	5	0.61	0.82	0.92	1.12	0.81
	35	14	16	5	0.64	0.86	0.96	1.14	0.84
Revised, $\rho_j = 0$	0	0	0	0	1.02	1.26	1.37	1.58	
	10	3.5	1.5	5	0.95	1.18	1.30	1.51	0.94
	15	7	3	5	0.91	1.15	1.26	1.47	0.91
	16	4.575	1.425	10	0.90	1.14	1.25	1.46	0.90
	16.575	4.575	7	5	0.93	1.17	1.28	1.49	0.93
	25	14	6	5	0.87	1.09	1.20	1.40	0.86
	25	9	6	10	0.86	1.09	1.20	1.41	0.86
	26.75	8.25	8	10.5	0.86	1.09	1.20	1.41	0.87
	26.75	9.25	9	8.5	0.87	1.10	1.20	1.41	0.87
	35	21	9	5	0.83	1.06	1.16	1.36	0.84
	35	14	16	5	0.86	1.08	1.19	1.39	0.86
Revised, alt 2018 data, $\rho_j = 0$	0	0	0	0	0.91	1.09	1.24	1.53	
	10	3.5	1.5	5	0.86	1.04	1.18	1.47	0.95
	15	7	3	5	0.83	1.00	1.14	1.44	0.92
	16	4.575	1.425	10	0.83	1.01	1.14	1.44	0.92
	16.575	4.575	7	5	0.85	1.02	1.16	1.46	0.94
	25	14	6	5	0.77	0.94	1.06	1.38	0.86
	25	9	6	10	0.79	0.96	1.09	1.40	0.88
	26.75	8.25	8	10.5	0.79	0.97	1.09	1.40	0.88
	26.75	9.25	9	8.5	0.79	0.96	1.09	1.40	0.88
	35	21	9	5	0.70	0.87	0.99	1.31	0.80
	35	14	16	5	0.76	0.93	1.05	1.37	0.85

* In these cases the full catch could not be realised in only one out of 100 simulations.

Table B2a. The additive increase (or decrease) in effective spawning biomass (in '000t) from November 2018 to November 2019, using the revised model, but setting $\rho_W = \rho_S = 0$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

					West component				South component				20% west
Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	5%ile	20%ile	30%ile	50%ile	difference
Baseline	0	0	0	0	25	35	40	50	-70	6	6	70	
	10	3.5	1.5	5	22	32	37	46	-70	5	5	69	0.91
	15	7	3	5	20	30	35	44	-71	4	4	68	0.85
	16	4.575	1.425	10	20	29	35	44	-71	4	5	68	0.85
	16.575	4.575	7	5	21	31	36	46	-72	2	2	66	0.88
	25	14	6	5	18	28	33	41	-72	2	2	65	0.79
	25	9	6	10	18	27	33	42	-72	2	2	65	0.78
	26.75	8.25	8	10.5	18	27	33	42	-73	1	1	64	0.78
	26.75	9.25	9	8.5	18	28	33	42	-73	0	1	64	0.79
	35	21	9	5	16	25	31	40	-73	0	1	63	0.73
	35	14	16	5	18	27	32	41	-75	-3	-2	60	0.78
$\text{move}_{y,1} = 0.1$	0	0	0	0	35	48	52	65	-72	1	1	63	
	10	3.5	1.5	5	31	43	48	61	-72	0	1	62	0.90
	15	7	3	5	28	41	45	59	-73	0	0	61	0.85
	16	4.575	1.425	10	28	40	45	58	-72	0	0	62	0.84
	16.575	4.575	7	5	30	42	47	60	-74	-2	-2	59	0.89
	25	14	6	5	26	37	42	55	-74	-2	-2	59	0.78
	25	9	6	10	26	37	42	55	-74	-2	-2	59	0.78
	26.75	8.25	8	10.5	26	37	42	56	-75	-3	-3	58	0.78
	26.75	9.25	9	8.5	26	37	42	56	-75	-4	-3	57	0.79
	35	21	9	5	24	35	40	53	-75	-4	-3	57	0.73
	35	14	16	5	26	37	42	55	-77	-7	-7	53	0.78
$\text{move}_{y,1} = 0.5$	0	0	0	0	15	24	29	35	-68	11	11	77	
	10	3.5	1.5	5	13	21	26	32	-68	9	10	76	0.90
	15	7	3	5	12	20	25	31	-69	8	9	74	0.84
	16	4.575	1.425	10	12	20	24	31	-69	8	9	75	0.83
	16.575	4.575	7	5	12	21	25	32	-70	6	7	72	0.87
	25	14	6	5	11	18	23	29	-70	6	7	72	0.77
	25	9	6	10	10	18	23	29	-70	5	7	72	0.76
	26.75	8.25	8	10.5	10	18	23	29	-71	4	6	71	0.76
	26.75	9.25	9	8.5	10	18	23	29	-71	4	5	70	0.77
	35	21	9	5	9	17	21	28	-71	4	5	69	0.70
	35	14	16	5	10	18	22	28	-73	1	2	66	0.75
$\sigma_{R,j} = 0.80$	0	0	0	0	25	35	40	50	-70	6	6	70	
	10	3.5	1.5	5	22	32	37	47	-70	5	5	69	0.91
	15	7	3	5	20	30	35	45	-71	4	4	68	0.87
	16	4.575	1.425	10	20	30	35	45	-70	4	5	68	0.86
	16.575	4.575	7	5	21	31	36	46	-72	2	2	66	0.89
	25	14	6	5	18	28	33	42	-72	2	2	65	0.80
	25	9	6	10	18	28	33	43	-72	2	3	65	0.80
	26.75	8.25	8	10.5	18	28	33	43	-73	1	2	64	0.81
	26.75	9.25	9	8.5	18	28	33	43	-73	0	1	64	0.81
	35	21	9	5	16	27	32	41	-73	0	1	63	0.76
	35	14	16	5	18	27	33	42	-75	-3	-2	60	0.79
$w^S_{j,2019,l} = w^S_{j,2018,l}$	0	0	0	0	7	7	7	7	1	2	2	2	
	10	3.5	1.5	5	4	4	4	4	0	0	0	0	0.59
	15	7	3	5	3	3	3	3	-1	-1	-1	-1	0.44
	16	4.575	1.425	10	2	2	2	3	-1	-1	-1	-1	0.34
	16.575	4.575	7	5	3	3	4	4	-3	-3	-3	-3	0.50
	25	14	6	5	1	1	1	2	-4	-4	-3	-3	0.18
	25	9	6	10	1	1	1	1	-4	-4	-4	-3	0.16
	26.75	8.25	8	10.5	1	1	1	1	-5	-5	-5	-4	0.15
	26.75	9.25	9	8.5	1	1	1	2	-5	-5	-5	-5	0.19
	35	21	9	5	-1	-1	-1	0	-6	-6	-6	-5	-0.09
	35	14	16	5	1	1	1	1	-8	-8	-8	-8	0.12
Low start	0	0	0	0	11	17	20	24	-14	4	4	20	
	10	3.5	1.5	5	8	13	16	21	-14	3	3	18	0.80
	15	7	3	5	7	12	15	19	-15	2	2	17	0.72
	16	4.575	1.425	10	6	11	14	19	-15	3	3	18	0.68
	16.575	4.575	7	5	7	13	15	20	-16	0	1	15	0.75
	25	14	6	5	5	10	12	17	-16	0	1	15	0.61
	25	9	6	10	6	11	14	18	-16	1	1	15	0.68
	26.75	8.25	8	10.5	5	10	12	17	-17	-1	0	14	0.59
	26.75	9.25	9	8.5	5	10	13	17	-17	-1	-1	13	0.61

Table B2b. The multiplicative increase (or decrease) in effective spawning biomass from November 2018 to November 2019, using the revised model, but setting $\rho_W = \rho_S = 0$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

					West component				South component				20% west difference
Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	5%ile	20%ile	30%ile	50%ile	
Baseline	0	0	0	0	2.20	2.67	2.95	3.40	0.45	1.05	1.05	1.55	
	10	3.5	1.5	5	2.04	2.51	2.78	3.24	0.45	1.04	1.04	1.54	0.91
	15	7	3	5	1.95	2.43	2.69	3.16	0.45	1.03	1.03	1.53	0.86
	16	4.575	1.425	10	1.93	2.42	2.68	3.15	0.45	1.03	1.04	1.53	0.85
	16.575	4.575	7	5	2.00	2.47	2.74	3.20	0.44	1.01	1.02	1.51	0.88
	25	14	6	5	1.84	2.33	2.59	3.02	0.44	1.01	1.02	1.51	0.80
	25	9	6	10	1.83	2.32	2.57	3.03	0.44	1.01	1.02	1.51	0.79
	26.75	8.25	8	10.5	1.83	2.32	2.57	3.03	0.86	1.09	1.20	1.41	0.79
	26.75	9.25	9	8.5	1.85	2.33	2.58	3.04	0.87	1.10	1.20	1.41	0.80
	35	21	9	5	1.77	2.23	2.49	2.93	0.43	1.00	1.01	1.49	0.73
	35	14	16	5	1.83	2.30	2.56	3.00	0.41	0.97	0.98	1.46	0.78
$\text{move}_{y,1} = 0.1$	0	0	0	0	2.67	3.22	3.52	4.07	0.44	1.01	1.01	1.49	
	10	3.5	1.5	5	2.48	3.01	3.31	3.85	0.43	1.00	1.00	1.48	0.90
	15	7	3	5	2.37	2.89	3.19	3.74	0.43	1.00	1.00	1.48	0.85
	16	4.575	1.425	10	2.35	2.87	3.17	3.73	0.43	1.00	1.00	1.48	0.85
	16.575	4.575	7	5	2.43	2.96	3.26	3.80	0.42	0.98	0.98	1.46	0.89
	25	14	6	5	2.25	2.74	3.05	3.59	0.42	0.98	0.99	1.46	0.79
	25	9	6	10	2.23	2.73	3.03	3.59	0.42	0.98	0.99	1.46	0.78
	26.75	8.25	8	10.5	2.23	2.74	3.03	3.60	0.42	0.97	0.98	1.45	0.78
	26.75	9.25	9	8.5	2.25	2.75	3.04	3.60	0.42	0.97	0.97	1.45	0.79
	35	21	9	5	2.12	2.62	2.93	3.50	0.41	0.97	0.97	1.45	0.73
	35	14	16	5	2.23	2.73	3.02	3.57	0.40	0.94	0.95	1.42	0.78
$\text{move}_{y,1} = 0.5$	0	0	0	0	1.69	2.12	2.40	2.65	0.47	1.09	1.09	1.60	
	10	3.5	1.5	5	1.58	2.00	2.28	2.52	0.47	1.07	1.08	1.59	0.90
	15	7	3	5	1.53	1.94	2.20	2.45	0.46	1.06	1.07	1.58	0.84
	16	4.575	1.425	10	1.53	1.93	2.20	2.45	0.46	1.07	1.07	1.58	0.83
	16.575	4.575	7	5	1.56	1.97	2.24	2.49	0.45	1.05	1.05	1.56	0.87
	25	14	6	5	1.48	1.86	2.12	2.35	0.45	1.05	1.05	1.56	0.77
	25	9	6	10	1.46	1.86	2.11	2.37	0.45	1.04	1.05	1.56	0.77
	26.75	8.25	8	10.5	1.46	1.85	2.11	2.37	0.45	1.04	1.04	1.55	0.76
	26.75	9.25	9	8.5	1.47	1.86	2.12	2.37	0.44	1.03	1.04	1.55	0.77
	35	21	9	5	1.43	1.80	2.05	2.30	0.44	1.03	1.04	1.54	0.71
	35	14	16	5	1.46	1.84	2.10	2.33	0.91	1.03	1.56	2.01	0.75
$\sigma_{R,j} = 0.80$	0	0	0	0	2.21	2.67	2.95	3.40	0.45	1.05	1.05	1.55	
	10	3.5	1.5	5	2.05	2.50	2.81	3.25	0.45	1.04	1.04	1.54	0.90
	15	7	3	5	1.97	2.43	2.72	3.16	0.45	1.03	1.03	1.53	0.85
	16	4.575	1.425	10	1.95	2.41	2.72	3.15	0.45	1.04	1.04	1.53	0.85
	16.575	4.575	7	5	2.02	2.47	2.77	3.21	0.44	1.01	1.02	1.51	0.88
	25	14	6	5	1.87	2.32	2.62	3.03	0.44	1.02	1.02	1.51	0.79
	25	9	6	10	1.86	2.32	2.61	3.03	0.44	1.01	1.02	1.51	0.79
	26.75	8.25	8	10.5	1.86	2.32	2.61	3.03	0.43	1.01	1.01	1.50	0.79
	26.75	9.25	9	8.5	1.87	2.33	2.61	3.04	0.43	1.00	1.01	1.50	0.80
	35	21	9	5	1.77	2.24	2.54	2.94	0.43	1.00	1.01	1.49	0.74
	35	14	16	5	1.85	2.30	2.60	3.01	0.92	1.00	1.62	2.07	0.78
$w^S_{j,2019,l} = w^S_{j,2018,l}$	0	0	0	0	1.33	1.34	1.34	1.34	1.01	1.01	1.01	1.01	
	10	3.5	1.5	5	1.19	1.20	1.20	1.20	1.00	1.00	1.00	1.00	0.59
	15	7	3	5	1.15	1.15	1.15	1.16	0.99	0.99	0.99	0.99	0.44
	16	4.575	1.425	10	1.11	1.11	1.12	1.12	0.99	0.99	0.99	0.99	0.34
	16.575	4.575	7	5	1.17	1.17	1.17	1.18	0.97	0.98	0.98	0.98	0.50
	25	14	6	5	1.06	1.06	1.06	1.08	0.97	0.97	0.97	0.97	0.18
	25	9	6	10	1.05	1.05	1.05	1.07	0.97	0.97	0.97	0.97	0.15
	26.75	8.25	8	10.5	1.05	1.05	1.05	1.07	0.96	0.96	0.96	0.97	0.15
	26.75	9.25	9	8.5	1.06	1.06	1.07	1.08	0.96	0.96	0.96	0.96	0.15
	35	21	9	5	0.96	0.97	0.97	1.00	0.95	0.95	0.96	0.96	-0.09
	35	14	16	5	1.03	1.04	1.04	1.06	0.93	0.93	0.93	0.94	0.11
Low start	0	0	0	0	1.85	2.25	2.47	2.77	0.50	1.16	1.16	1.71	
	10	3.5	1.5	5	1.60	2.00	2.20	2.53	0.48	1.11	1.12	1.66	0.80
	15	7	3	5	1.51	1.90	2.09	2.41	0.46	1.08	1.09	1.62	0.72
	16	4.575	1.425	10	1.45	1.85	2.03	2.38	0.48	1.10	1.11	1.65	0.68
	16.575	4.575	7	5	1.54	1.94	2.14	2.47	0.42	1.01	1.02	1.54	0.75
	25	14	6	5	1.37	1.76	1.93	2.28	0.42	1.01	1.03	1.54	0.61
	25	9	6	10	1.46	1.85	2.03	2.36	0.42	1.02	1.03	1.55	0.68
	26.75	8.25	8	10.5	1.34	1.74	1.91	2.25	0.40	0.97	0.99	1.50	0.59
	26.75	9.25	9	8.5	1.36	1.76	1.93	2.27	0.39	0.96	0.97	1.48	0.61
	35	21	9	5	1.22	1.63	1.78	2.13	0.38	0.94	0.96	1.47	0.50
	35	14	16	5	1.34	1.73	1.90	2.24	0.59	0.87	1.39	1.87	0.58

Table B2c. The west component effective spawning biomass in November 2019 compared to November 2007 (the risk threshold), using the revised model, but setting $\rho_W = \rho_S = 0$. Grey cells indicate cases for which the selectivity function needed modification to enable the catch to be taken. Dark grey cells indicate cases for which the full catch could still not be realised after selectivity was modified.

Model	Total	West	South	Bycatch	5%ile	20%ile	30%ile	50%ile	20% diff
Baseline	0	0	0	0	1.02	1.26	1.37	1.58	
	10	3.5	1.5	5	0.95	1.18	1.30	1.51	0.94
	15	7	3	5	0.91	1.15	1.26	1.47	0.91
	16	4.575	1.425	10	0.90	1.14	1.25	1.46	0.90
	16.575	4.575	7	5	0.93	1.17	1.28	1.49	0.93
	25	14	6	5	0.87	1.09	1.20	1.40	0.86
	25	9	6	10	0.86	1.09	1.20	1.41	0.86
	26.75	8.25	8	10.5	0.86	1.09	1.20	1.41	0.87
	26.75	9.25	9	8.5	0.87	1.10	1.20	1.41	0.87
	35	21	9	5	0.83	1.06	1.16	1.36	0.84
	35	14	16	5	0.86	1.08	1.19	1.39	0.86
$\text{move}_{y,1} = 0.1$	0	0	0	0	1.25	1.55	1.64	1.94	
	10	3.5	1.5	5	1.16	1.45	1.54	1.84	0.93
	15	7	3	5	1.11	1.39	1.49	1.78	0.90
	16	4.575	1.425	10	1.10	1.38	1.48	1.78	0.89
	16.575	4.575	7	5	1.14	1.43	1.52	1.82	0.92
	25	14	6	5	1.05	1.32	1.43	1.70	0.85
	25	9	6	10	1.04	1.31	1.42	1.70	0.85
	26.75	8.25	8	10.5	1.04	1.32	1.42	1.71	0.85
	26.75	9.25	9	8.5	1.05	1.32	1.43	1.71	0.85
	35	21	9	5	0.99	1.26	1.37	1.65	0.81
	35	14	16	5	1.04	1.31	1.42	1.69	0.85
$\text{move}_{y,1} = 0.5$	0	0	0	0	0.81	1.01	1.10	1.25	
	10	3.5	1.5	5	0.76	0.95	1.05	1.20	0.94
	15	7	3	5	0.73	0.91	1.02	1.17	0.91
	16	4.575	1.425	10	0.72	0.91	1.01	1.16	0.90
	16.575	4.575	7	5	0.74	0.93	1.03	1.18	0.93
	25	14	6	5	0.70	0.87	0.98	1.12	0.87
	25	9	6	10	0.69	0.87	0.98	1.12	0.86
	26.75	8.25	8	10.5	0.69	0.87	0.97	1.12	0.86
	26.75	9.25	9	8.5	0.69	0.87	0.98	1.12	0.87
	35	21	9	5	0.67	0.84	0.95	1.10	0.83
	35	14	16	5	0.69	0.86	0.97	1.11	0.86
$\sigma_{R,j} = 0.80$	0	0	0	0	1.02	1.26	1.37	1.58	
	10	3.5	1.5	5	0.97	1.20	1.30	1.52	0.95
	15	7	3	5	0.93	1.17	1.26	1.48	0.92
	16	4.575	1.425	10	0.92	1.16	1.26	1.48	0.92
	16.575	4.575	7	5	0.95	1.19	1.28	1.50	0.94
	25	14	6	5	0.88	1.11	1.22	1.42	0.88
	25	9	6	10	0.88	1.12	1.21	1.43	0.89
	26.75	8.25	8	10.5	0.87	1.12	1.21	1.43	0.89
	26.75	9.25	9	8.5	0.88	1.12	1.21	1.43	0.89
	35	21	9	5	0.85	1.08	1.18	1.39	0.85
	35	14	16	5	0.87	1.11	1.20	1.41	0.88
$w^S_{j,2019,l} = w^S_{j,2018,l}$	0	0	0	0	0.60	0.62	0.62	0.63	
	10	3.5	1.5	5	0.54	0.55	0.56	0.56	0.89
	15	7	3	5	0.52	0.53	0.54	0.54	0.86
	16	4.575	1.425	10	0.50	0.51	0.52	0.53	0.83
	16.575	4.575	7	5	0.52	0.54	0.55	0.55	0.87
	25	14	6	5	0.48	0.49	0.50	0.51	0.80
	25	9	6	10	0.47	0.49	0.49	0.50	0.79
	26.75	8.25	8	10.5	0.47	0.49	0.49	0.50	0.79
	26.75	9.25	9	8.5	0.48	0.49	0.50	0.51	0.80
	35	21	9	5	0.44	0.45	0.46	0.47	0.73
	35	14	16	5	0.47	0.48	0.49	0.50	0.78
Low start	0	0	0	0	0.56	0.68	0.75	0.84	
	10	3.5	1.5	5	0.48	0.60	0.67	0.76	0.89
	15	7	3	5	0.46	0.57	0.63	0.73	0.84
	16	4.575	1.425	10	0.44	0.56	0.61	0.72	0.82
	16.575	4.575	7	5	0.47	0.59	0.65	0.75	0.86
	25	14	6	5	0.41	0.53	0.58	0.69	0.78
	25	9	6	10	0.44	0.56	0.61	0.71	0.82
	26.75	8.25	8	10.5	0.40	0.52	0.58	0.68	0.77
	26.75	9.25	9	8.5	0.41	0.53	0.58	0.69	0.78
	35	21	9	5	0.37	0.49	0.54	0.64	0.72
	35	14	16	5	0.40	0.52	0.57	0.68	0.77