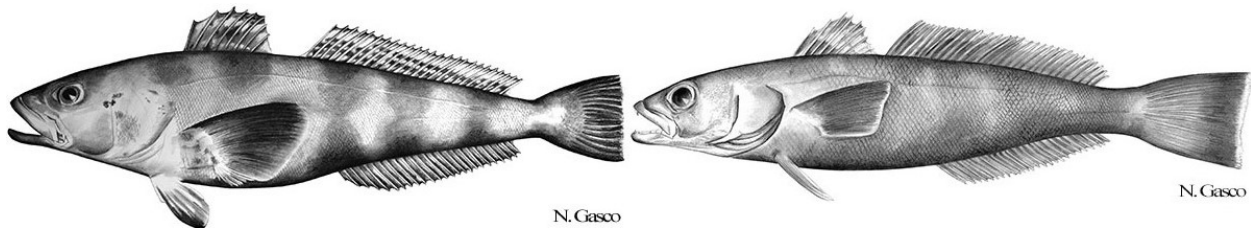


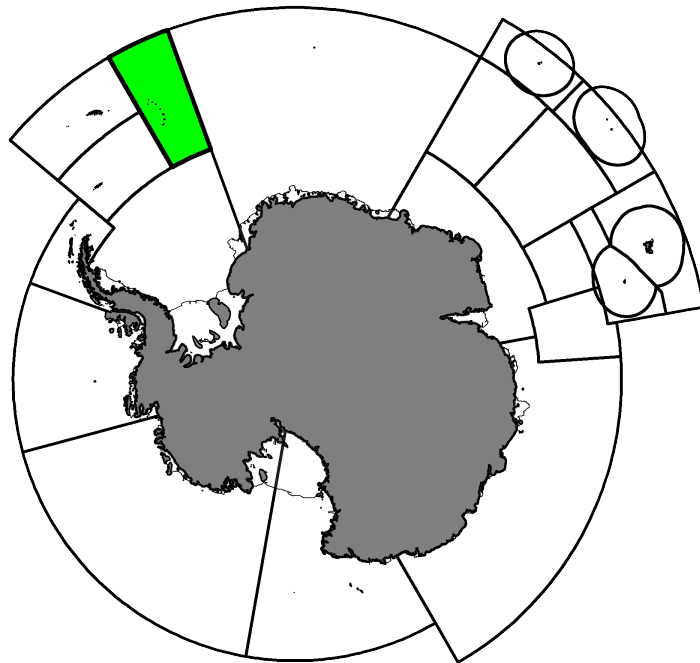
Stock Assessment Report 2025: *Dissostichus eleginoides* and *Dissostichus mawsoni* in Subarea 48.4

CCAMLR Secretariat

02 March 2026



Antarctic toothfish *Dissostichus mawsoni* Norman, 1937, and, Patagonian toothfish *Dissostichus eleginoides* Smitt, 1898.



Map of the management areas within the CAMLR Convention Area. The region discussed in this report is shaded in green. Coastlines and ice shelves: UK Polar Data Centre/BAS and Natural Earth. Projection: EPSG 6932.



CCAMLR

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Assessment of Patagonian Toothfish (*Dissostichus eleginoides*) in Subarea 48.4

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Abstract

This paper describes an update of the assessment of Patagonian toothfish (*D. eleginoides*) in Subarea 48.4. The assessment data are updated with the observations for the 2023 and 2024 seasons¹. In addition to the inclusion of two further years' data, alternative approaches to data-weighting for age-length observations used in the model are considered. Projections indicate that the stock was at 65% of B_0 in 2025 and that a yield of 33 tonnes in 2026 and 2027 is consistent with the application of the CCAMLR Decision Rule.

Based on this assessment, we propose two recommendations from Working Group FSA to the Scientific Committee:

1. that the Francis weighting be applied to the age-length observations in the Casal2 stock assessment,
2. that the catch limit for *D. eleginoides* in Subarea 48.4 should be set at 33 tonnes for 2025/26 and 2026/27.

1. Introduction

Fishing for Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4 occurred briefly in 1992/93, and then paused until the 2005 season, when a catch of 27 tonnes was taken. Data for the stock assessment are taken from the 2005 season onwards and have been updated to include the observations from the 2023 and 2024 seasons. The history of the stock assessment is outlined in the Stock Annex (Readdy and Earl 2025a). In 2025, after the inclusion of 2023 and 2024 data, further developments towards the 2025 final assessment were carried out in Casal2 version v24.10 2024-10-11 05:52:17 UTC (rev. 0eab0fee7). Changes that have been implemented since the assessment presented at WG-FSA-2023 (Readdy and Earl, 2023) are shown in Table 1.1. Switching model optimiser from BetaDiff to the ADOL-C automatic differentiation tool used for previous model runs, and setting a smaller convergence tolerance level, the default value, following the recommended practice by the Casal2 Development Team (2024).

Casal2 implementation

During the updates from Run01 to Run10, and subsequent iterations, input files were modified to incorporate a likelihood multiplier syntax line for age-length observations. For Run10 to Run20 the multiplier was set to 1, maintaining consistency with Run01.

¹ Seasons are referred to by the year that the CCAMLR season ends in, as this is when the fishing occurs, e.g. the 2024 season runs from 1st December 2023 to 30th November 2024.

Table 1.1. 2025 assessment development.

Model description	Objective	Model run
2023 final assessment (Readdy and Earl, 2023)	Base model. Casal2 v22.10-2022-10-09 22:54:45 UTC (rev. e3805a5)	Run01
Casal2 v24.10 compatibility with base case	Replicate results from Casal2 v22.10 (Run01) in Casal2 v24.10 2024-10-11 05:52:17 UTC (rev. 0eab0fee7)	Run10
Change to ADOLC minimiser	Replicate results from Run10 using ADOLC minimiser and tolerance acceptance 1E-05	Run11
2025 base model	Run 11 with Inclusion of observation data for years 2023 and 2024 and catch from 2025	Run20
Final model	Run 20 with reweighting of Age-Length observations using a likelihood multiplier	Run21

1.1. Fishery

Historically catches fluctuated from 18.7 tonnes (2006) to 97.6 tonnes (2008), generally averaging around 40 tonnes. Since 2016, catches have declined in line with the revised assessment and application of the CCAMLR Decision Rule targets. The recent periods, 2023 and 2024, catches have undershot the catch limit by 78.65% and 77.55%, respectively. The undershoot in catch limits is mainly driven by reaching Antarctic toothfish catch limits, and the likelihood of further exceeding them given the mixing of the species across the Subarea (Thompson *et al.* 2025).

Catch per unit effort (CPUE) data for *D. eleginoides*, across all vessels and the whole of Subarea 48.4, fluctuate with a declining trend since 2016 (Table 1.2). Fishing effort by season and tagging release sites are shown in Annex 1.

Until 2012, the stocks of both toothfish species found in Subarea 48.4 were divided into northern and southern components for assessment and management purposes (Figure 1.1). The northern component was assessed as a single species (*D. eleginoides*) whilst the southern component was assessed as a species complex of both *D. eleginoides* and *D. mawsoni*. Since 2013, the assessment for *D. eleginoides* was expanded to cover the entire 48.4 Subarea and included the southern component into the assessment model. Data for the stock assessment are taken from the 2005 season onwards, and the resulting catch limit applies to the entire Subarea for *D. eleginoides*.

Both species are caught throughout Subarea 48.4 although *D. eleginoides* is predominantly caught in the north (Table 1.2) whilst *D. mawsoni* is mainly caught in the south (Thompson *et al.*, 2025).

Table 1.2. Catch history for Patagonian toothfish in Subarea 48.4. Catch (tonnes) and CPUE (kg/hook) of *D. eleginoides* in Subarea 48.4. (Source: CCAMLR C2 data).

Year	North catch (tonnes)	North CPUE (kg/hook)	All TOP catch (tonnes)	All CPUE (kg/hook)
1990	0.20	<0.01	0.20	<0.01
1992	39.34	0.15	39.34	0.15
2005	26.88	0.17	26.88	0.17
2006	18.73	0.06	18.73	0.06
2007	54.04	0.11	54.04	0.11
2008	97.63	0.15	97.63	0.15
2009	58.90	0.12	74.40	0.07
2010	39.77	0.15	57.47	0.06
2011	35.81	0.09	38.65	0.06
2012	44.10	0.10	55.41	0.08
2013	61.94	0.18	72.35	0.10
2014	41.67	0.30	43.84	0.16
2015	40.89	0.18	41.70	0.11
2016	40.42	0.13	41.60	0.08
2017	25.79	0.09	27.93	0.05
2018	14.00	0.09	16.72	0.04
2019	14.53	0.08	17.39	0.04
2020	14.92	0.07	18.64	0.04
2021	14.97	0.05	15.90	0.03
2022	12.71	0.08	13.81	0.03
2023	4.24	0.05	4.91	0.02
2024	3.63	0.05	4.27	0.02
2025	4.86	0.07	6.39	0.03

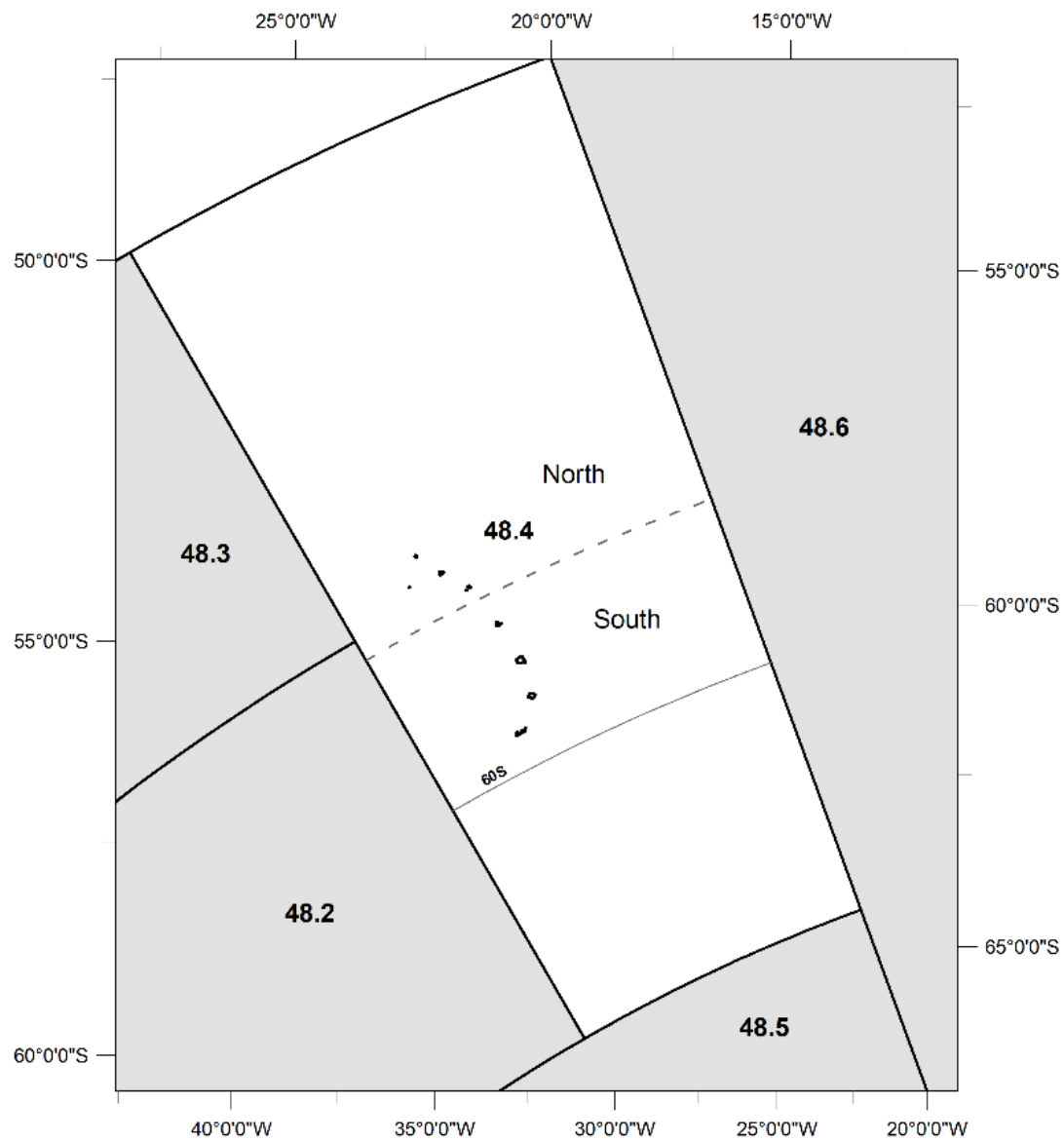


Figure 1.1. Map of Subarea 48.4. Dashed line at 57.33°S indicates previous North and South rectangles, which since 2012 have been combined into a single assessment.

2. Input data

Input data are included in this assessment up to the end of the 2024 season. Following the recommendation of WG-FSA-17, paragraph 3.20 (CCAMLR, 2017), the total catch from the 2025 season, of 6.4 tonnes², is included.

The following data sources are used in the updated assessment (See Readdy and Earl (2025b) Figures 1 and 2):

- **Catch tonnage:** Catch tonnage for the 2024 and 2025 seasons were added.
- **Scanned length distribution:** Observations for the 2023 and 2024 seasons were added.
- **Tag release data:** Observations for the 2022 and 2023 seasons were added.
- **Tag recapture data:** Observations for the 2023 and 2024 seasons were added.
- **Otolith aging data from a sample of the catch:** Observations for the 2023 and 2024 seasons were added.
- **Age-length pairs from a sample of the catch:** Age-length observation for the 2023 and 2024 seasons were added.

All data, except for 2025 catch tonnage and otolith age data, were taken from the CCAMLR data extraction dated 17/07/2024. Age-length observations are obtained from British Antarctic Survey (King Edward Point research) who process and read the otoliths collected during the fishing operations.

3. Length and age distributions

The length composition of the catch is determined from the observer sampling of the catch and is raised to the reported vessel catch. The length distribution of fish caught for the period 2005 to 2024 (Figure 3.1) tracks one peak of potentially several year classes throughout the timeseries, suggesting a single large recruitment event (or perhaps multiple events) in the early/mid-1990s, and fish from this cohort progressively entering the fishery. As the cohort has progressed through the population its dominance of the length distribution decreased in relation to the preceding and subsequent weaker year classes until 2018, when the peak became undistinguishable. Recent, 2023 and 2024, length and age composition data show a peak at around 55cm and age 5, suggesting a strong incoming recruitment pulse.

The age distribution of the catches has been determined annually since 2011 by random sampling of otoliths from the catch (Figure 3.1). All otoliths, where viable, have been read and a total of 64 and 97 fish caught in 2023 and 2024 were used to calculate the age distribution of the 2023 and 2024 catch, respectively. An age-length key is calculated independently for each year (Figure 3.2) and used to raise the length distribution observed in the catch to an age distribution (Figure 3.3). Additionally, the resulting age-length-key (ALK) is included in the assessment to provide the data to estimate the

² https://circs.ccamlr.org/system/files/2025-08/comm_25_83sc_25_60-en.pdf

growth parameters of a von Bertalanffy growth model which provide the necessary information to transform the length-based observations of tag releases and recaptures to ages.

The number of otoliths read for construction of the ALK is given in Table 3.1 and shows that the sample size for age determination has varied over time. There is good overlap between the lengths sampled for otolith collection and the length distributions of the catch, with an overlap statistic of 86% and 92% for 2023 and 2024, respectively (Figure 3.2). Consecutive age compositions (Figure 3.3) show similar patterns with a mode around 18 - 19 years, and a limited ability to track cohorts between years, even for the dominant year classes apparent in the length distributions (Figure 3.1). The age distributions for 2022 – 2024 show both younger and older year classes than seen previously. The younger age classes are in agreement with the length distributions, where small lengths in the catch have been recorded. These years show the first over 30-year-olds. In order to investigate whether this was caused by a change in otolith reading, a partial re-read of 49 otoliths from 2019-2024 was undertaken, which identified no systematic differences between readers.

Table 3.1. Sample size for D. eleginoides age determination collected by scientific observers in Subarea 48.4.

Year	Sample size for age determination
2011	85
2012	191
2013	63
2014	151
2015	208
2016	158
2017	76
2018	235
2019	314
2020	199
2021	231
2022	149
2023	64
2024	97

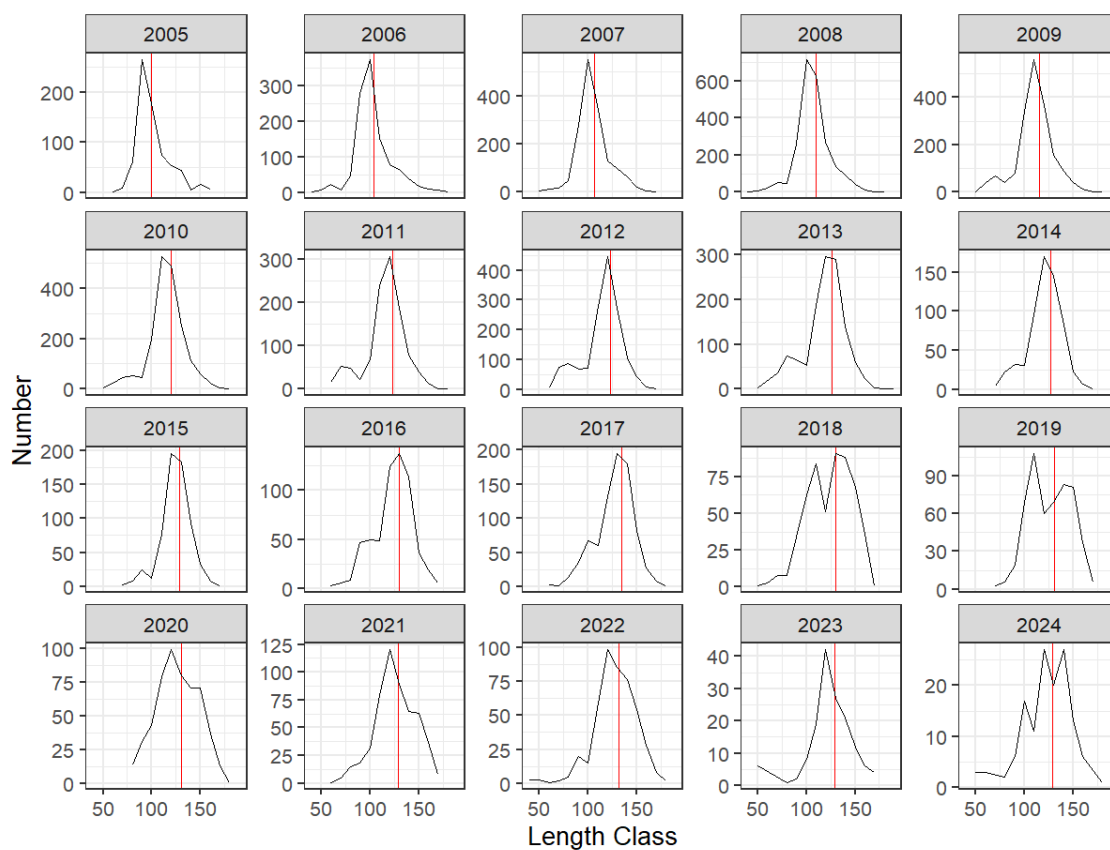


Figure 3.1. Catch length frequency by 10cm length bin from 2005 - 2024. Red lines represent the median length for each year.

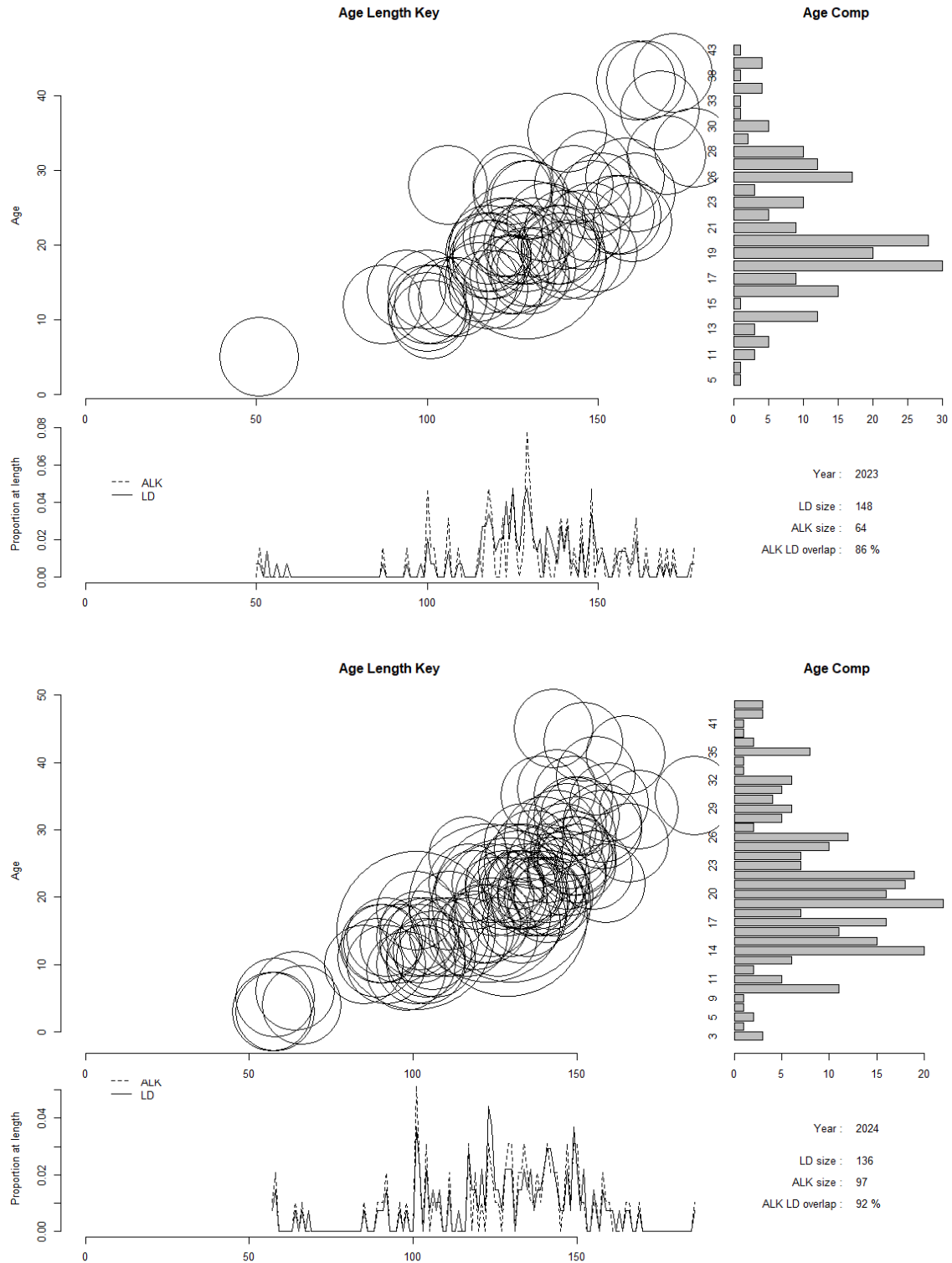


Figure 3.2. 2023 and 2024 ALKs. Lower panel of each plot shows the length distribution of the fishery (solid) and aged samples (dotted). The upper left panel shows the age and length of aged fish, with size of circles indicating the number of samples. The right panel shows the derived age composition.

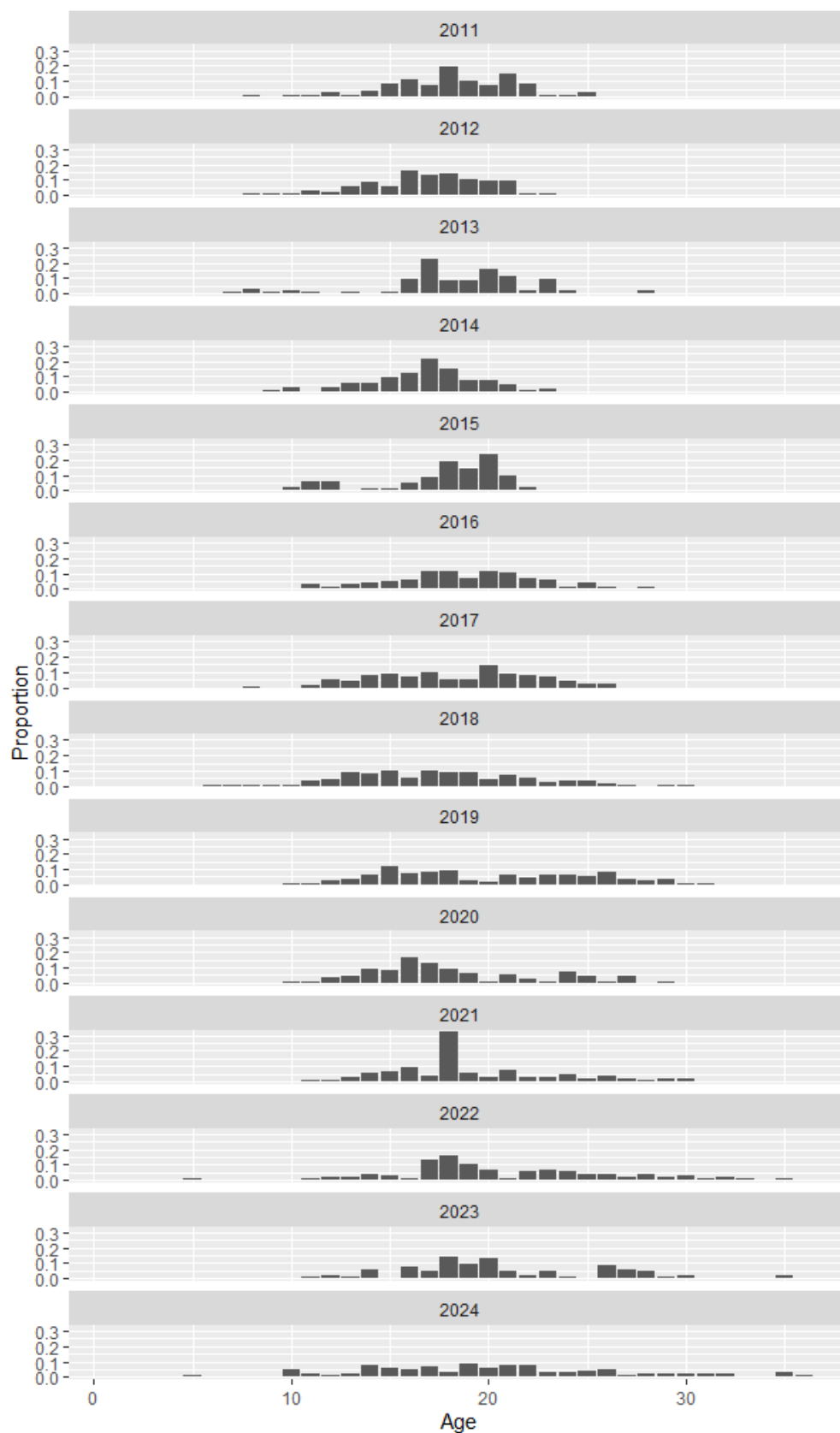


Figure 3.3. Raised age composition of otolith samples from the catch by year 2011-2024.

4. Tagging data

The *Dissostichus* spp. tag release-recapture programme in Subarea 48.4 has been in operation since 2005 providing 19 years of tag release and recapture data. Between 2005 and 2024, a total of 4,287 *D. eleginoides* were tagged and released in Subarea 48.4 (Table 4.1). To date, a total of 571 were recaptured in 48.4 (Table 4.1) having been released in 48.4. This Subarea encompasses both *D. eleginoides* and *D. mawsoni*; only fish that have been identified as *D. eleginoides* at release and recapture are included.

Eighteen fish were misidentified upon release, and a further 211 *D. eleginoides* were released in 48.4 but recaptured in 48.3; all are currently excluded from the assessment.

The 26 fish that were recaptured in 48.4 in 2023 and 2024 (Table 4.1) had been released across a range of years, with some releases occurring 9 and 10 years prior. Notably, one tagged fish released in 2008 was recaptured in 2021, marking a record for this area of 13 years at liberty (Table 4.1), other areas have documented up to 15 years at liberty (Burch *et al.* 2019).

Table 4.1. Tag-recaptures of *D. eleginoides* in 48.4. Numbers in green indicate the tag returns used in the assessment.

	Releases	Recapture year																		Total recapture
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
2005	42	0	2	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	6
2006	134	2	8	5	2	1	2	2	0	0	2	1	0	0	0	0	0	0	0	25
2007	291	0	13	12	1	4	5	4	2	1	0	0	2	2	0	0	0	0	0	46
2008	504	0	0	8	11	8	11	10	4	3	7	6	2	3	2	1	0	0	0	76
2009	551	0	0	3	16	12	12	9	3	5	3	4	0	1	4	1	0	0	0	73
2010	419	0	0	0	2	13	2	12	4	1	4	3	2	2	3	0	1	0	0	49
2011	220	0	0	0	0	0	0	2	3	0	4	2	1	1	1	0	1	0	0	15
2012	303	0	0	0	0	0	0	7	3	2	2	3	5	3	1	0	1	0	0	27
2013	468	0	0	0	0	0	0	0	23	19	15	7	1	4	3	2	4	1	0	79
2014	223	0	0	0	0	0	0	0	0	20	12	9	1	2	2	1	2	1	0	50
2015	226	0	0	0	0	0	0	0	0	0	11	12	7	4	1	5	2	3	3	48
2016	224	0	0	0	0	0	0	0	0	0	0	5	1	4	3	9	5	0	0	27
2017	159	0	0	0	0	0	0	0	0	0	0	1	1	1	2	5	1	3	2	16
2018	87	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0	1	1	8
2019	91	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	0	0	7
2020	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	6
2021	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	0	9
2022	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
2023	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
2024	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4287	2	23	30	32	39	32	46	42	52	60	53	23	28	28	32	23	17	9	571

5. Biological Parameters and change indicators

The biological parameters used in the assessment are provided in the Stock Annex (Readdy and Earl 2025a), there were no updates for this assessment. Following the recommendation of SC-CAMLR-2023 paragraph 2.149, information is presented in Table 5.1 summarising the evidence for changes in stock assessment parameters or processes that could be due to the effects of environmental variability including climate change, following the template provided there.

Table 5.1: Summary of evidence for changes in stock assessment parameters or processes that could be due to the effects of environmental variability including climate change.

Parameter or process			Evidence for trends and potential drivers
1a	Recruitment	Mean recruitment	No information at present. Recruitment is characterised by infrequent large events and is dominated by a single event with unknown cause.
1b		Recruitment variability	No information at present, however, the depletion rule (risk of falling below 20% of B_0) is not a constraint in this assessment.
2	Age at maturity		No information at present, Subarea 48.3 maturity at age is used and changes cannot be attributed to climate change or environmental variability at present (Earl <i>et al.</i> 2024).
3	Stock-recruit relationship		No information at present.
4a	Natural mortality	From direct predation	No information at present.
4b		Not from direct predation	No information at present.
5	Growth rates		No information at present. Growth rates vary between Subarea 48.3 and 48.4, but the cause remains uncertain (Collins <i>et al.</i> 2010).
6	Length-weight		No trends in length-weight relationships (Thompson <i>et al.</i> 2025).
7	Sex ratio changes		There is variability in the proportion of females over time, however this cannot be attributed to climate change (Thompson <i>et al.</i> 2025).
8	Spatial distribution		Preliminary analysis indicates that the spatial distribution of individuals varies annually, with observed shifts in the southern latitude they are captured; however, the underlying cause of this variation remains unclear. (Thompson <i>et al.</i> 2025).
9	Stock structure		There is currently no evidence of changing stock structure due to climate change or environmental variability (Thompson <i>et al.</i> 2025).
10	Locations of spawning and site fidelity		No information at present, however, tagging studies have shown links between Subarea 48.3 and 48.4. Subarea 48.3 spawning hotspot analysis indicates any apparent changes in spawning location are likely driven by changes in fishery distribution rather than being true signals (Bamford <i>et al.</i> 2024).
11	Depredation mortality		There are no records of Orca or sperm whale depredation.

6. Model structure

The stock assessment is described in Readdy and Earl (2025a). As in the previous assessment, the population model is a combined-sex, single-area model with an annual cycle comprising five timesteps (Table 1 in Readdy and Earl, 2025b). During the first timestep only recruitment and natural mortality occur; the second includes natural mortality, fishing and the spawning period; half the mortality in that particular period being accounted for before spawning occurs. The third timestep has the tag loss rate and in the fourth timestep only natural mortality occurs. The final, fifth timestep ages the fish into the next year class. It was assumed throughout that the proportions of natural mortality and growth occurring within each period are equal to the given period's length as a proportion of the year. The assessment was run for the years 1990 to 2025, with an initial unexploited equilibrium age structure.

The distribution of periods within the annual cycle are currently synchronised with those for Subarea 48.3. However, due to the fishing pattern of the fishery, fishing is more likely to occur during the recruitment timestep than during the spawning timestep. This will be further considered as part of the sex specific model development.

7. Data weighting

For each step of the model development, an initial run was performed using the following data weightings:

- Catch age distribution effective sample size given by the number of otoliths aged in each year.
- Age length pairs log-likelihood multiplier set to 1 and constant across all years.
- Tag dispersion constant across all years.

Subsequently runs were performed to scale the weightings applied to the data sources - catch age distributions, age-length pairs and tag recaptures:

1. Catch at age compositions were scaled according to method TA1.8 from Francis (2011) as implemented in Francis (2015).
2. Age-length pairs log-likelihood multiplier scaled according to method TA1.8 from Francis (2011).
3. Tag dispersion was updated using the ``Reweight.tags`` function (based on Francis, 2015).

The results of these steps are shown in detail for Run21 in Table 7.1 and summarised for model runs for the bridging analyses in Table 9.1.

Table 7.1 Data weighting steps in the 2025 Run21 assessment.

	Initial weighting	Update priors step 1	Weighting step 2	Weighting step 3
ESS* per otolith 2011 -2024	1	1	0.189	0.189
ALK Log-Likelihood*weighting	1	1	0.102	0.102
Tag dispersion	2.070	2.070	2.070	3.159

8. Bridging analysis

Methods

The CCAMLR accepted 2023 assessment was used as the base case for progressing the model configuration and is described in Readdy and Earl (2023). Models were implemented in either Casal2 versions v22.10-2022-10-09 22:54:45 UTC (rev. e3805a5) or v24.10 2024-10-11 05:52:17 UTC (rev. 0eab0fee7), details of which can be found in Table 1.1. To estimate the Maximum Posterior density (MPD) for all models (Readdy and Earl 2025a), each model includes a four-step process. Firstly, the model is run to obtain suitable priors for L_{inf} and k of the growth function which then replaces the values for the priors in the input files for all subsequent steps. The new priors are intended to overcome any potential convergence issue experienced in the 2021 assessment (Earl and Readdy, 2021), estimation of these parameters continues for all steps. Once updated the model is re-run and the outputs are used to calculate effective sample size using the Francis data weighting method (TA1.8 from Francis (2011) implemented in Francis (2015)). A similar approach is used to determine the weighting for the age-length pairs. The computed values (Table 9.1) were applied to the catch at age composition sample sizes and the log-likelihood weighting of age-length observations, with input files updated and re-run accordingly. Based on the outputs of the third run, the tag dispersion parameter was revised and updated following the methods described by Francis (2015) and a final run was executed.

Likelihood profiling on B_0 and MCMC runs were computed for all runs however forecasts were only computed for Run21 (final model). The final model configuration is described in the Stock Annex (Readdy and Earl, 2025a) and full diagnostics of the final model are presented in the diagnostics paper (Readdy and Earl, 2025b).

9. Results

The parameter estimates at each step of the model fitting, where effective sample size is rescaled, log-likelihood of the age-length observations is weighted and the tag dispersion parameter updated, for all model runs are presented in Table 9.1. The estimated parameters for all models were generally consistent at each step, except for B_0 , which varied across Run11, 20 and 21, indicating that the age-length observation weighting strongly affects this parameter.

In order to determine whether the version of Casal2 affects the results of the assessment, intermediary assessments were conducted. Firstly, Run10, moving from Casal 22.10 to 24.10 yielded consistent outcomes (Figure 9.1) across all diagnostics performed, including profiles and MCMC analysis.

The second step involved switching from BetaDiff to the ADOL-C³ automatic differentiation tool (Run11). This has led to differences in recruitment estimates, revealing two distinct peaks at the

³ <https://github.com/coin-or/ADOL-C>

beginning of the timeseries instead of the single broad peak (Figure 9.1) seen in Runs 01 and 10. Additionally, MCMC analysis showed consistency between both minimisers, however the Heidelberger and Welch's (1981, 1983) convergence diagnostics confirmed that all parameters and chains passed the stationarity test for Run11, but not for Run10.

Run11 was used as the base for the inclusion of the 2023 and 2024 years of observation data and the 2025 catch (Run20). With the inclusion of the additional observations the resulting derived quantities for SSB showed a perception change with lower overall SSB (Figure 9.2) and a steeper decline. Although recruitment estimates showed two distinct peaks at the beginning of the timeseries, the first peak had shifted to earlier in the timeseries. MCMC analysis revealed poorer convergence particularly for the larger recruitments at the beginning of the timeseries, as illustrated in Figure 9.3.

The age-length pair observations strongly influence the objective function, as illustrated by the contribution of data sources to the objective function (Figure 9.4) and likelihood profiles of B_0 (Figure 9.6). Casal2 v24.10 introduced the capability to weight observation; consequently, as other data types are reweighted, it is appropriate to apply a weighting to the age-length pairs as well. This adjustment was implemented using the Francis method during the same processing stage as the age composition reweighting and was applied as a likelihood multiplier. As a result, the influence of these observations on the objective function was reduced, indicated in Figure 9.5.

Adding weights to the age-length pair observations slightly improved the MPD fits (Figure 9.8 and 9.9) and comparing the MPD fits of the derived quantities for Run20 and 21 (Figure 9.2) showed a shift in SSB perception, with an overall increase and shallower decline, giving a higher B_{2023} value (Table 9.1). Recruitment exhibited a single peak at the beginning of the timeseries, around 1996, while the 2015 recruitment peak persisted at a slightly higher level. This change has resulted in improved MCMC diagnostics across all parameters, illustrated in Figures 9.10- 9.12.

Table 9.1 Key parameter values estimated at each step of the process for the six models.

		Francis weighting	B_0 1,000	k 0.092	L_{inf} 153	Age of 50% selected 8	Selectivity range (years) 4	B_{2023}	B_{2023} (% B_0)	B_{2025} (% B_0)
	Initial value									
Run01	Pre-run		693.724	0.05231	204.998	15.3574	5.29185			
	Base run		688.057	0.05167	206.488	15.4659	5.34529			
	sample size	0.159	889.708	0.05200	205.783	14.1835	5.14094			
	tag dispersion	1.974	914.093	0.05202	205.756	14.0351	5.07150	540.692	0.59	
Run10	Pre-run		693.724	0.05231	204.998	15.3574	5.29185			
	Base run		688.057	0.05167	206.488	15.4659	5.34529			
	sample size	0.159	889.708	0.05200	205.783	14.1835	5.14094			
	tag dispersion	1.974	914.093	0.05202	205.756	14.0351	5.07150	540.692	0.59	
Run11	Pre-run		687.393	0.05199	205.714	15.4452	5.33853			
	Base run		687.385	0.05199	205.714	15.4461	5.33900			
	sample size	0.159	899.608	0.05191	205.995	14.0649	5.07658			
	tag dispersion	1.984	913.205	0.05192	205.980	14.0010	5.04653	539.056	0.59	
Run20	Pre-run		684.092	0.05537	197.953	14.9522	5.27353			
	Base run		684.062	0.05536	197.957	14.9528	5.27397			
	sample size	0.189	834.546	0.05571	197.365	14.0173	5.23976			
	tag dispersion	2.638	769.715	0.05561	197.555	14.3724	5.40704	417.902	0.54	0.51
Run21	Pre-run		684.067	0.05537	197.953	14.9523	5.27357			
	Base run		684.038	0.05536	197.957	14.9529	5.27401			
	sample size	0.189	1,081.02	0.05538	197.557	13.5455	4.25174			
	tag dispersion	0.102 3.159	1,064.29	0.05564	197.092	13.9012	4.36584	708.434	0.67	0.64

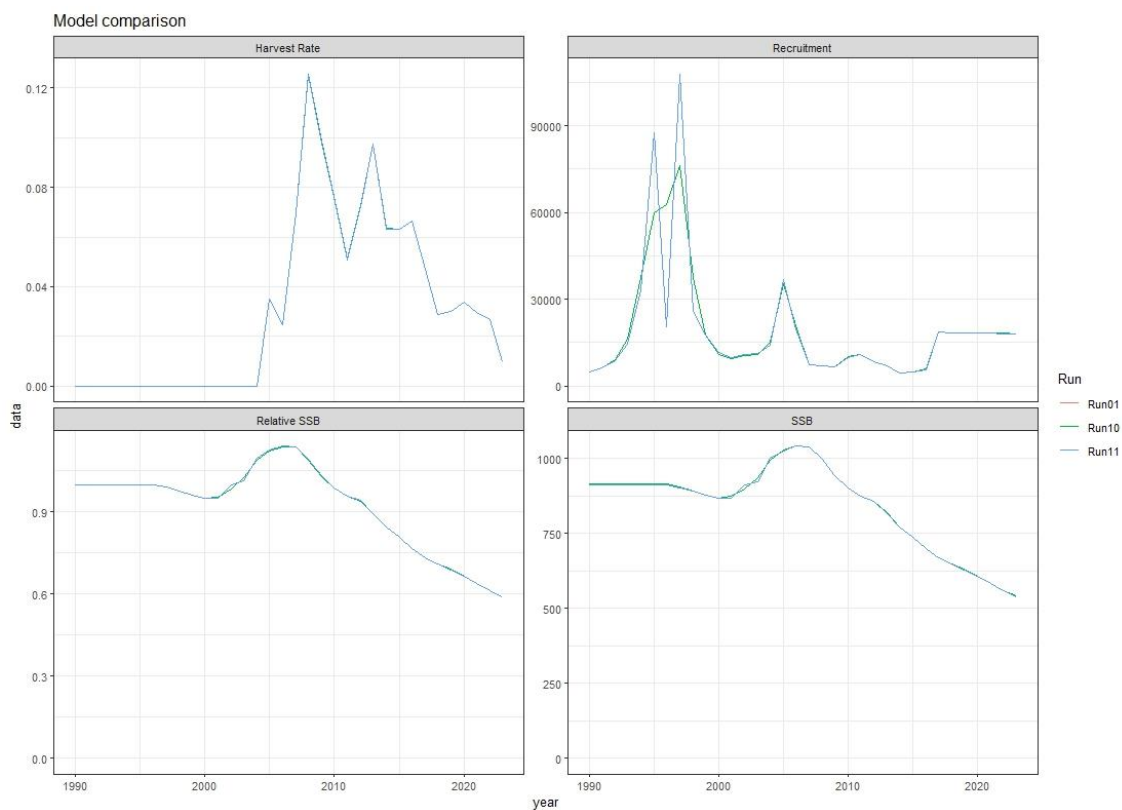


Figure 9.1. MPD derived quantities for the CASAL models: Run01 (red), Run 10 (green) and Run11 (blue).

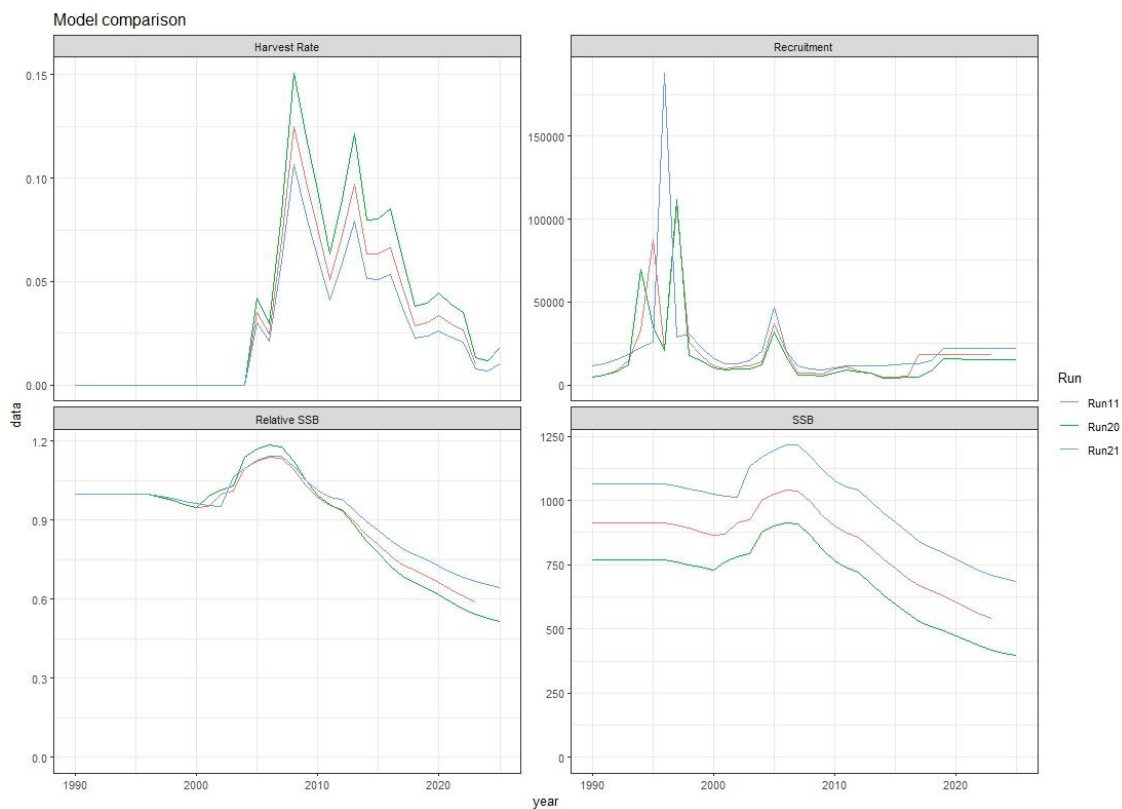


Figure 9.2. MPD derived quantities for the CASAL models: Run11 (red), Run20 (green) and Run21 (blue).

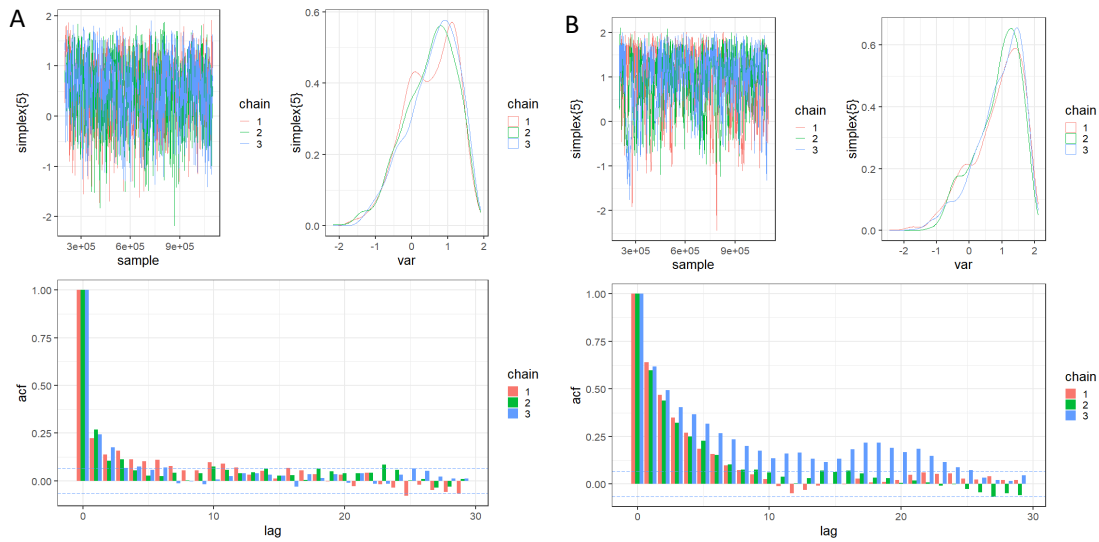


Figure 9.3. MCMC diagnostics for the 1994 recruitment (simplex(5)): MCMC trace (left), distribution (right) and autocorrelation function (bottom) for Run11 (Panel A) and Run20 (Panel B) for each of the three MCMC chains.

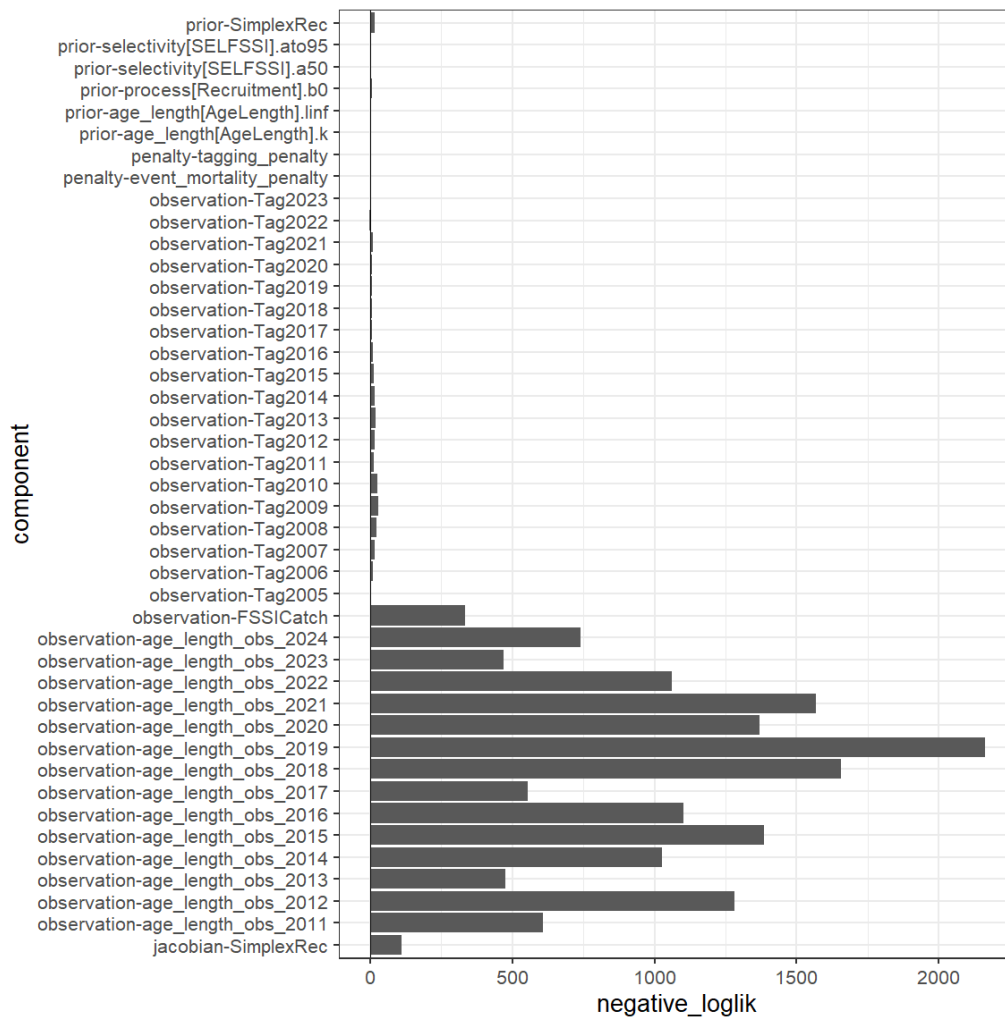


Figure 9.4. Contribution of the data sources to the objective function Run20.

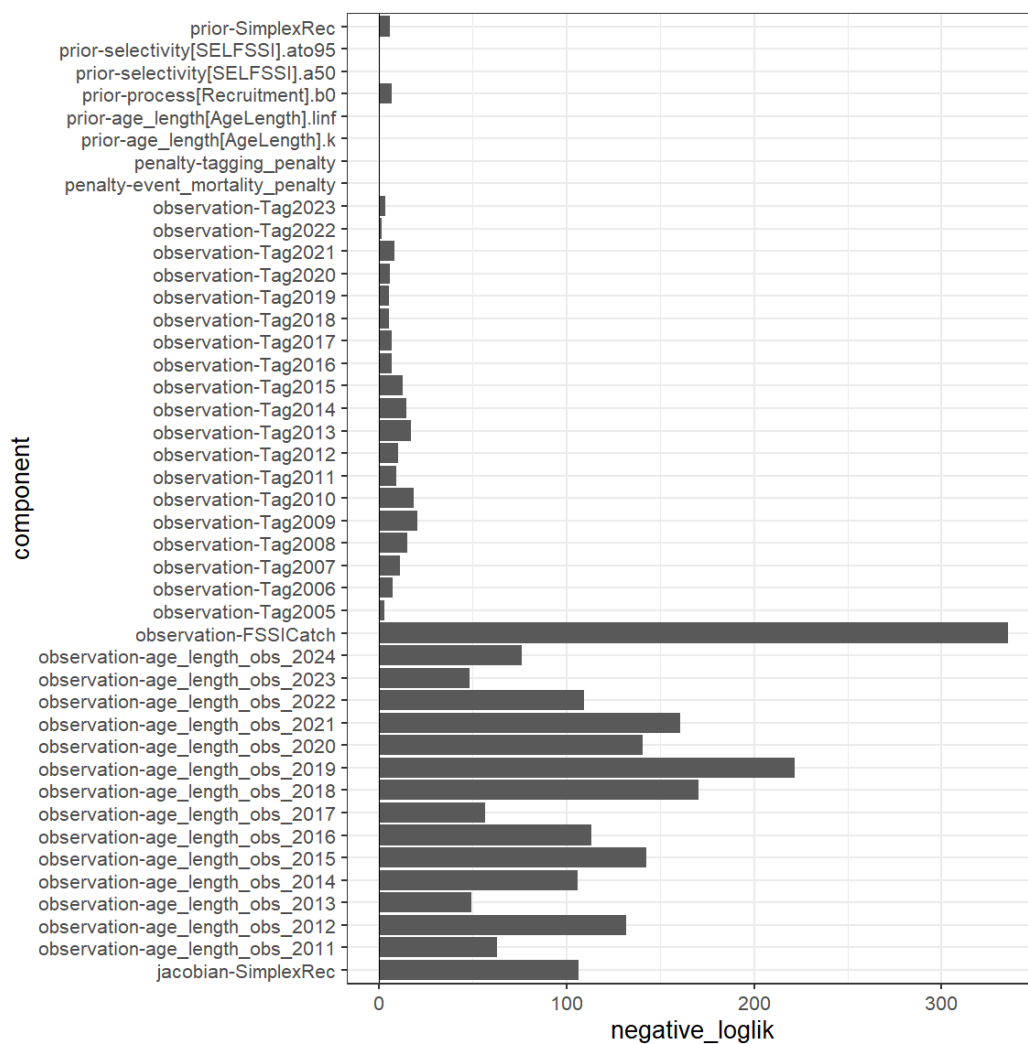


Figure 9.5. Contribution of the data sources to the objective function Run21.

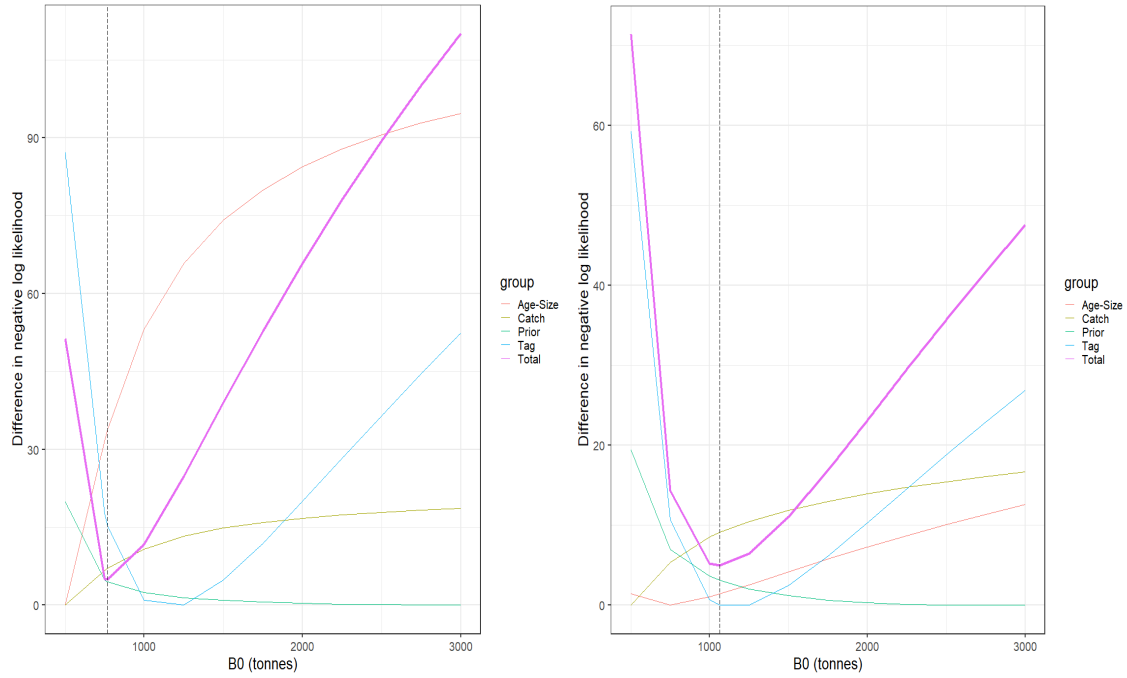


Figure 9.6. Likelihood profiles for B_0 . Left Run20; right Run21.

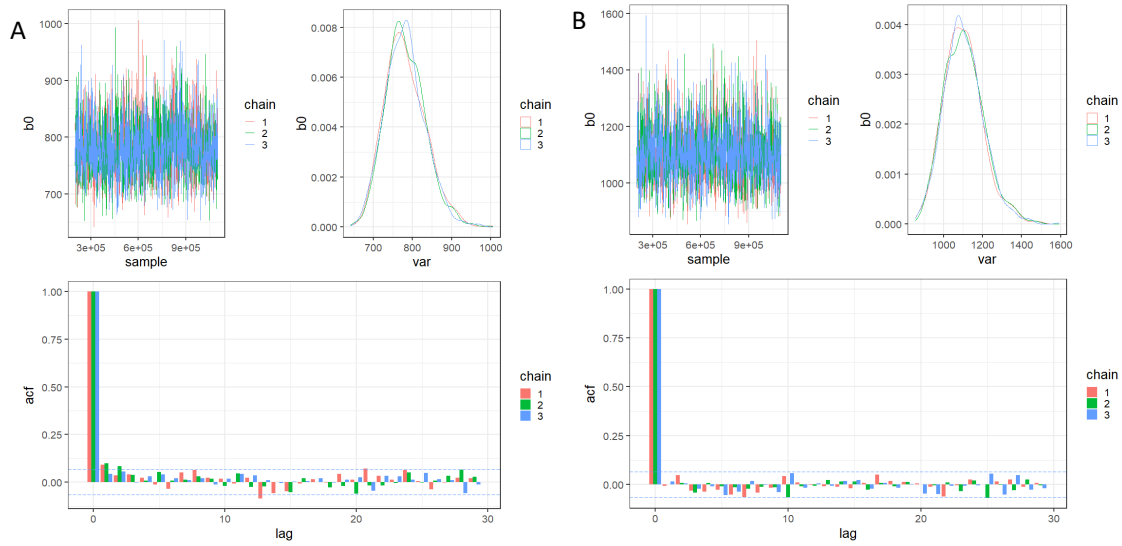


Figure 9.7. MCMC diagnostics for B_0 : MCMC trace (left), distribution (right) and autocorrelation function (bottom) for Run20 (Panel A) and Run21 (Panel B) for each of the three MCMC chains.

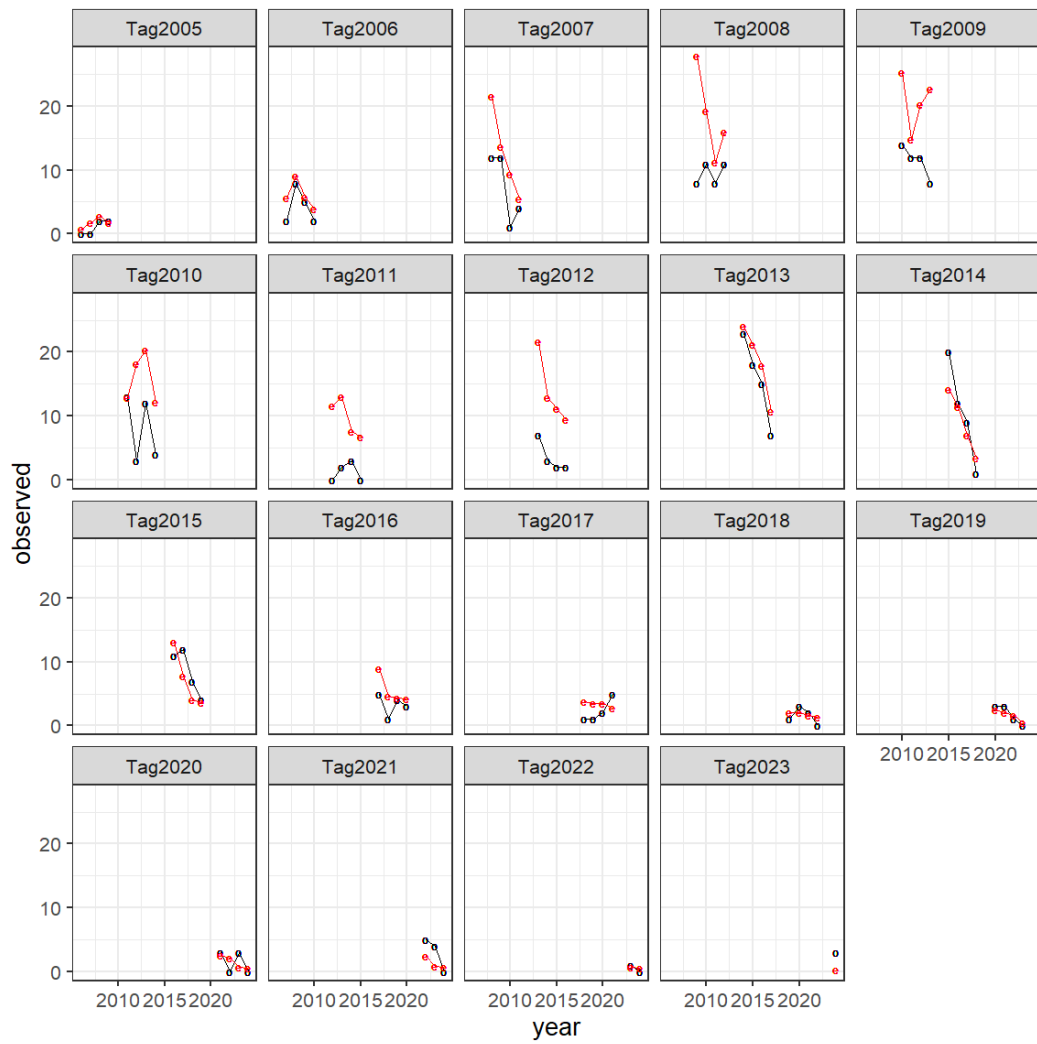


Figure 9.8. MPD fits to the number of tags recovered in each tag cohort for Run20.

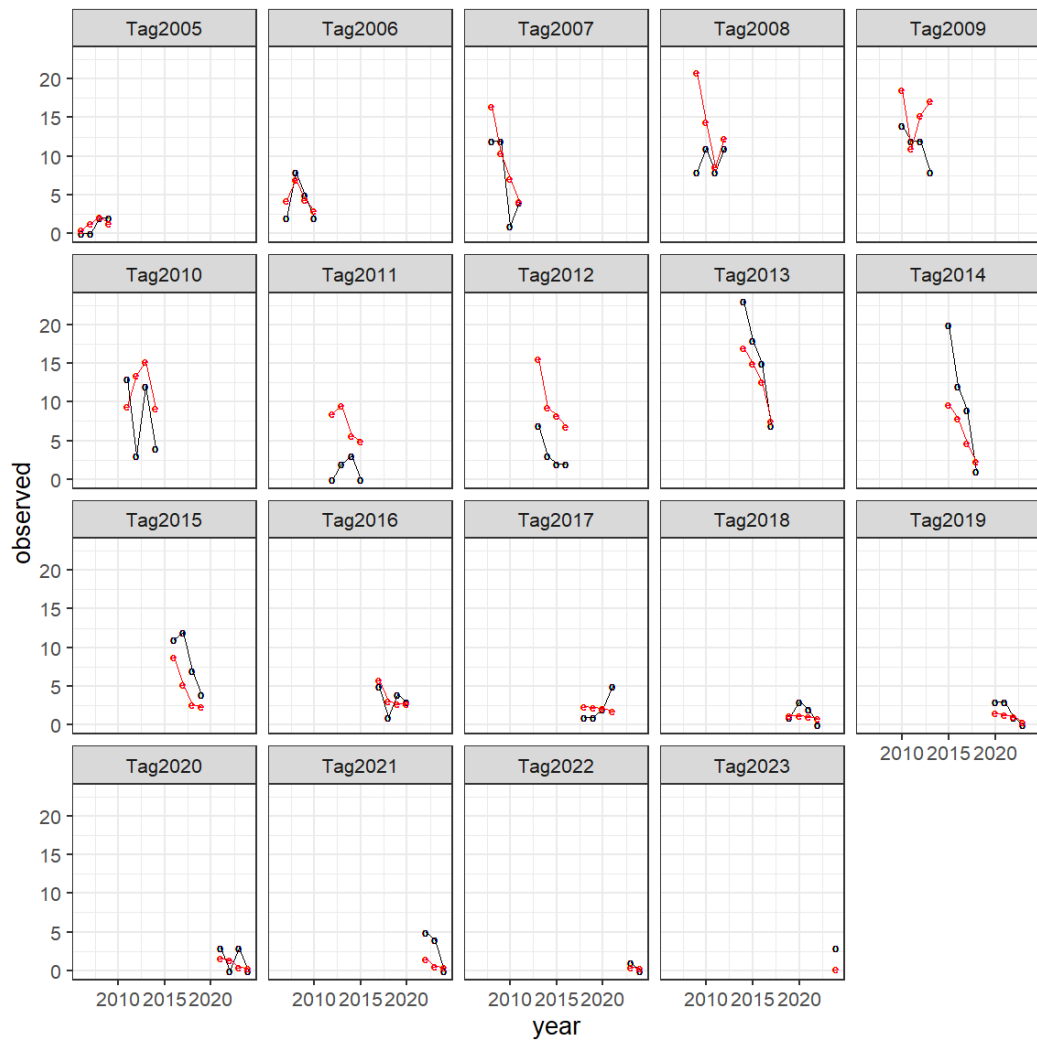


Figure 9.9. MPD fits to the number of tags recovered in each tag cohort for Run21.

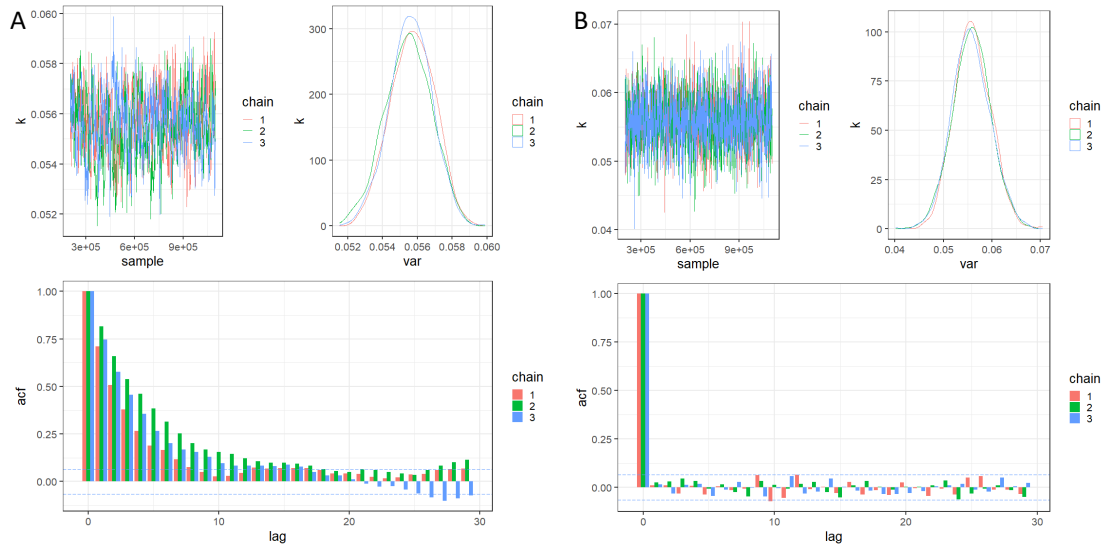


Figure 9.10. MCMC diagnostics for parameter k of the growth function: MCMC trace (left), distribution (right) and autocorrelation function (bottom) for Run20 (Panel A) and Run21 (Panel B) for each of the three MCMC chains.

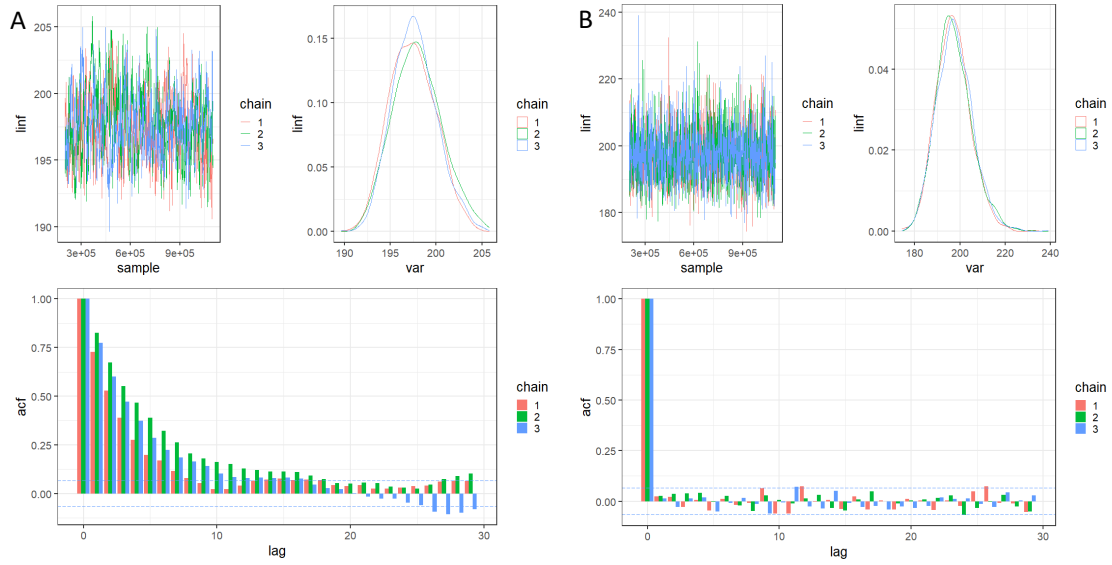


Figure 9.11. MCMC diagnostics for parameter L_{inf} of the growth function: MCMC trace (left), distribution (right) and autocorrelation function (bottom) for Run20 (Panel A) and Run21 (Panel B) for each of the three MCMC chains.

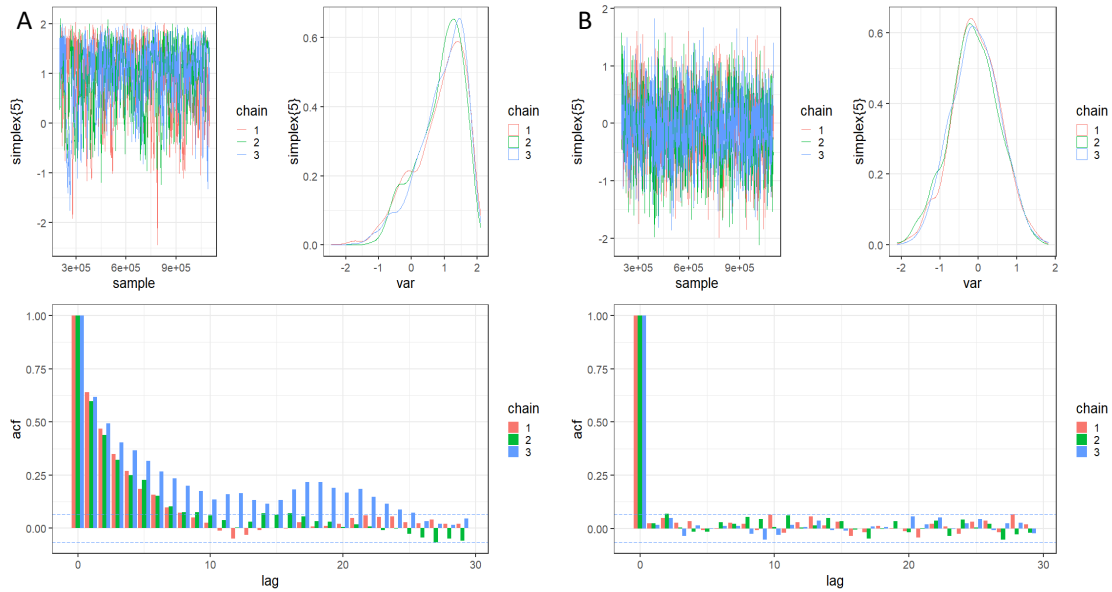


Figure 9.12. MCMC diagnostics for the 1994 recruitment (*simplex(5)*): MCMC trace (left), distribution (right) and autocorrelation function (bottom) for Run20 (Panel A) and Run21 (Panel B) for each of the three MCMC chains.

10. Final model outputs

10.1. Maximum Posterior Density (MPD) fits

The 2025 model ran without issue and the individual contributions to the overall objective function (Figure 10.1) show that age composition of the catch and 2019 size at age observations contributed most to the likelihood. Among tag recapture data, 2011 and 2012 stand out as having a lower contribution to the likelihood than neighbouring years.

The model fits (Figures 10.2 – Figure 10.6 and Figures 3 - 10 in Readdy and Earl, 2025b), show that the fit to the age compositions is variable, matching particularly well in 2012, 2016, 2017, 2019, 2021 and 2024 but less well in other years. The overall median age in the catch data is reflected in the model fit. The fits to tag number are also variable by release year, with the model over-estimating returns between 2011 and 2012. The length distribution of the recaptures fits the model in most cases with a slightly higher estimated size than is observed in the earlier years and slightly lower in the more recent years.

A von Bertalanffy curve using values from the model MPD files was plotted against the raw age-length data (Figure 8 in Readdy and Earl, 2025b) and showed that the curve fitted the data. As with previous assessments, the parameter t_0 was set to zero; it was not possible to estimate t_0 reliably because of the absence of data from fish smaller than 50cm and 6 years old.

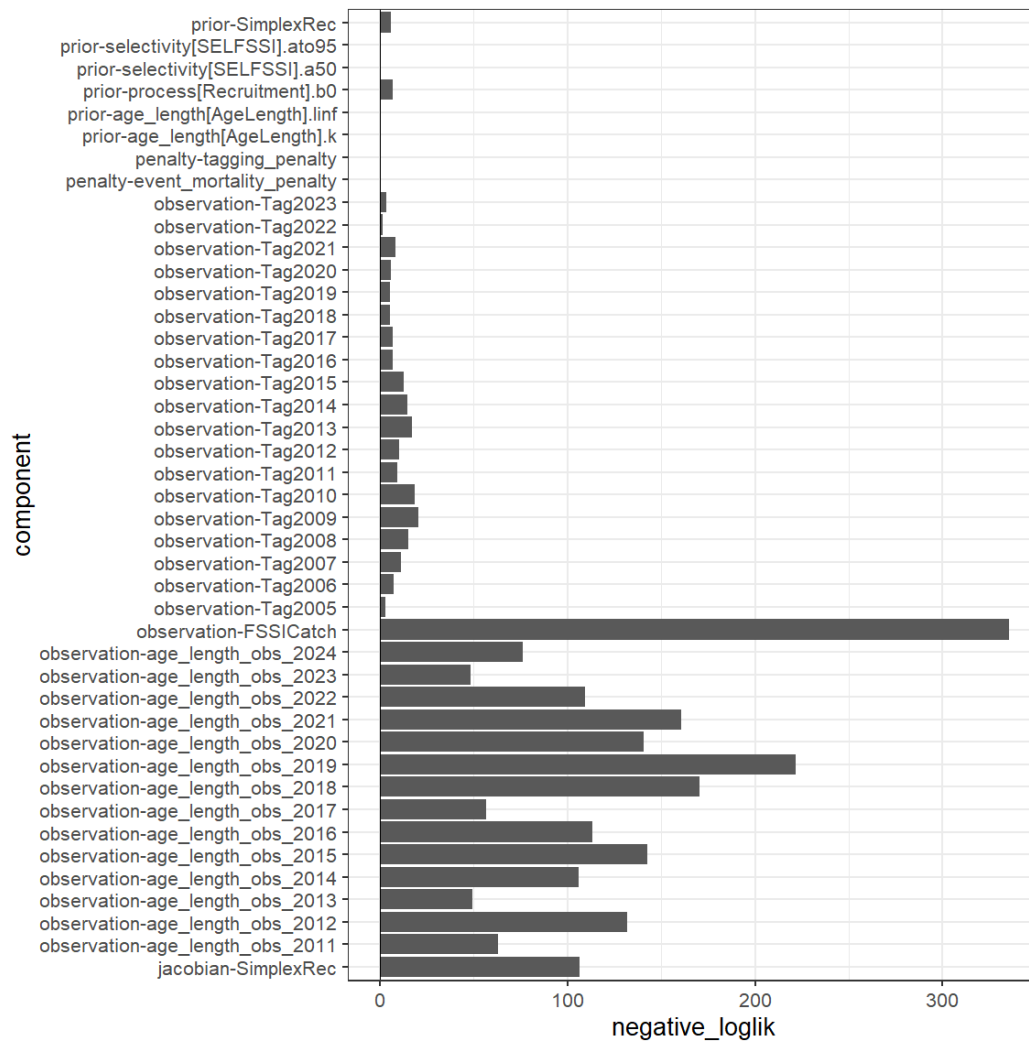


Figure 10.1. Likelihood components of the MPD fit.

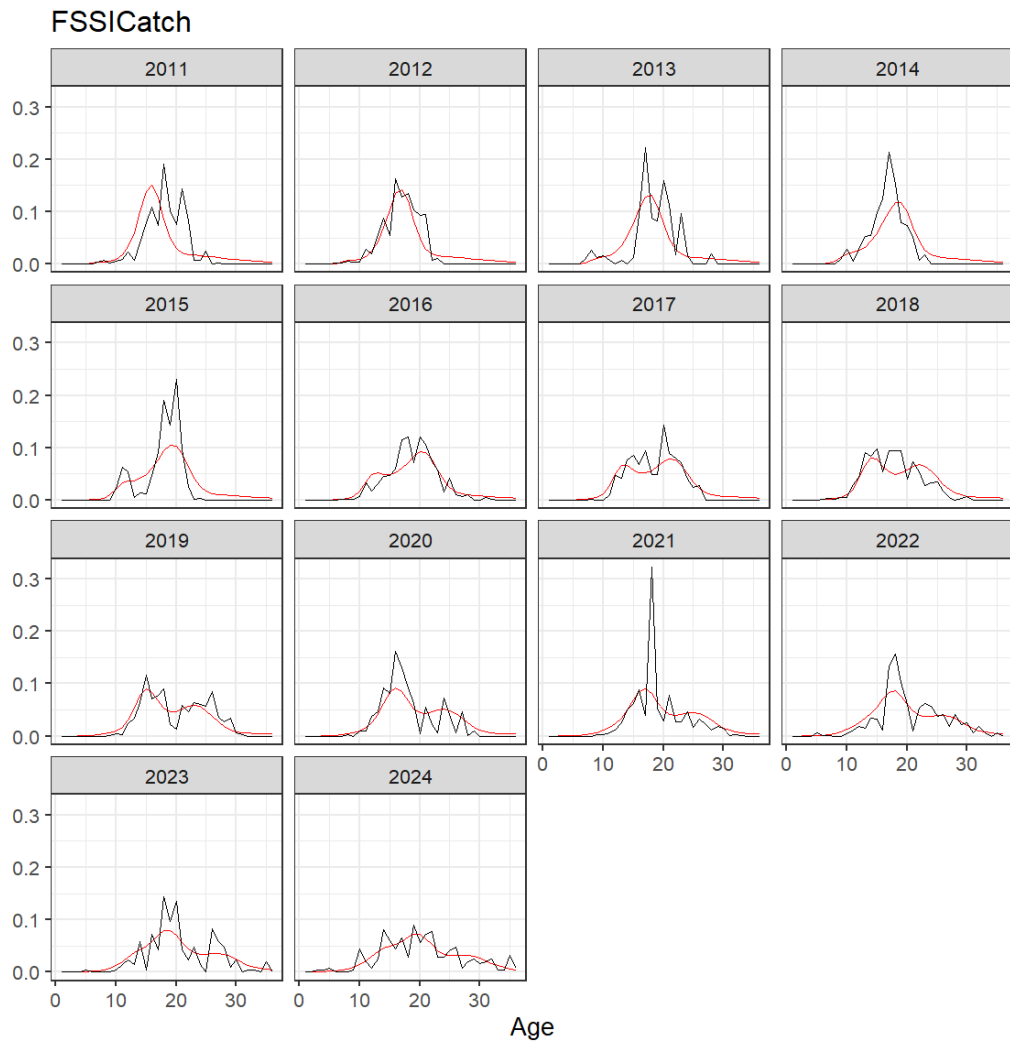


Figure 10.2. Fit to catch age composition data.

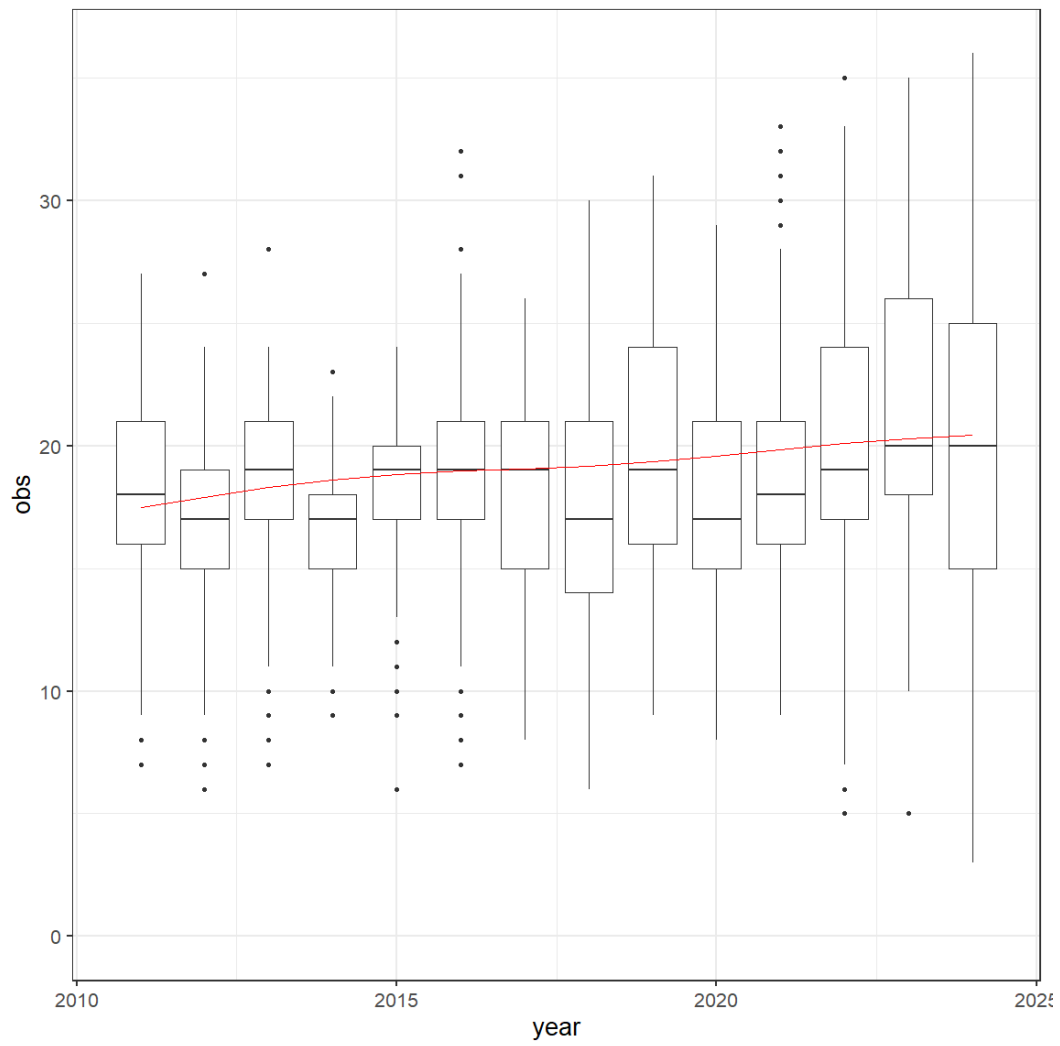


Figure 10.3. Median age in the catch estimated by the model (red line) and observed (white boxes).

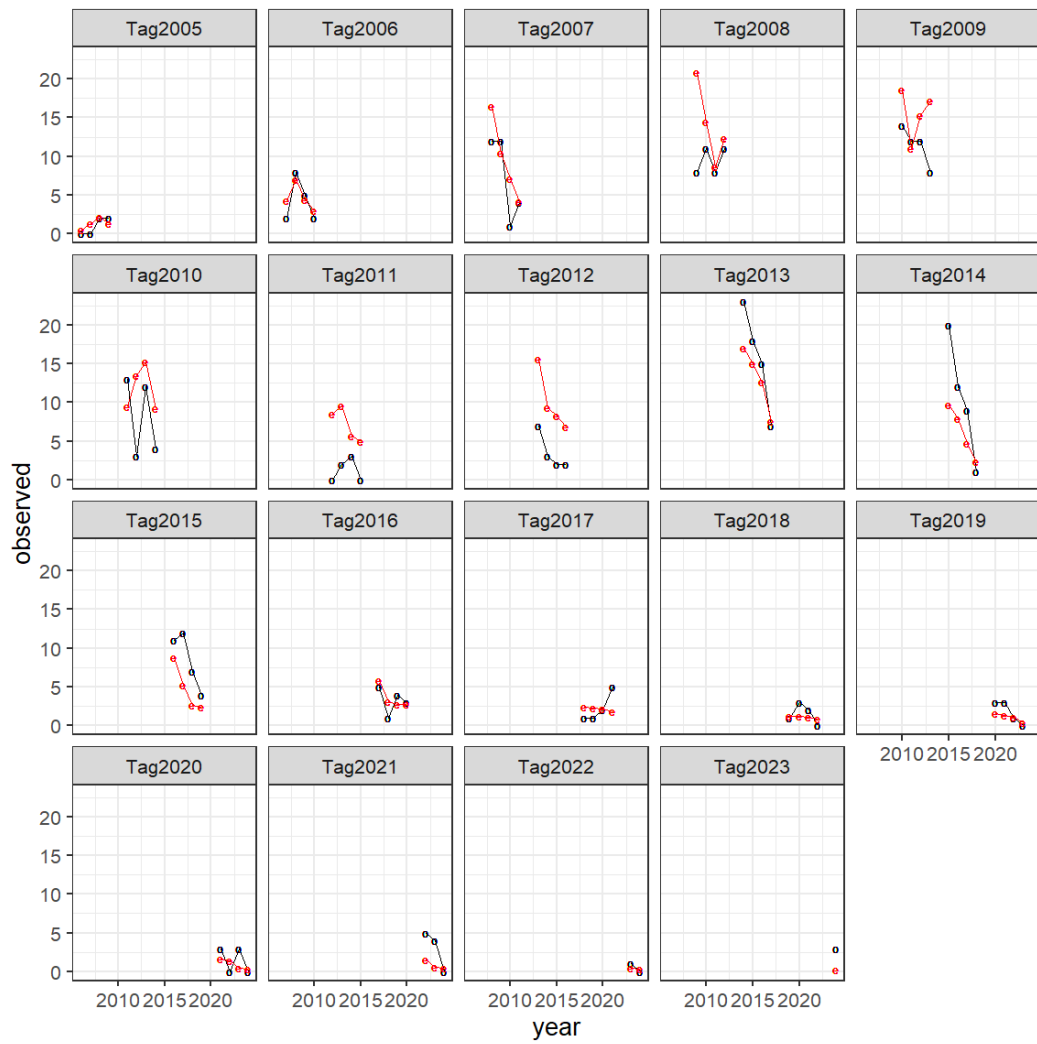


Figure 10.4. Fits to the number of tags recovered in each tag cohort.

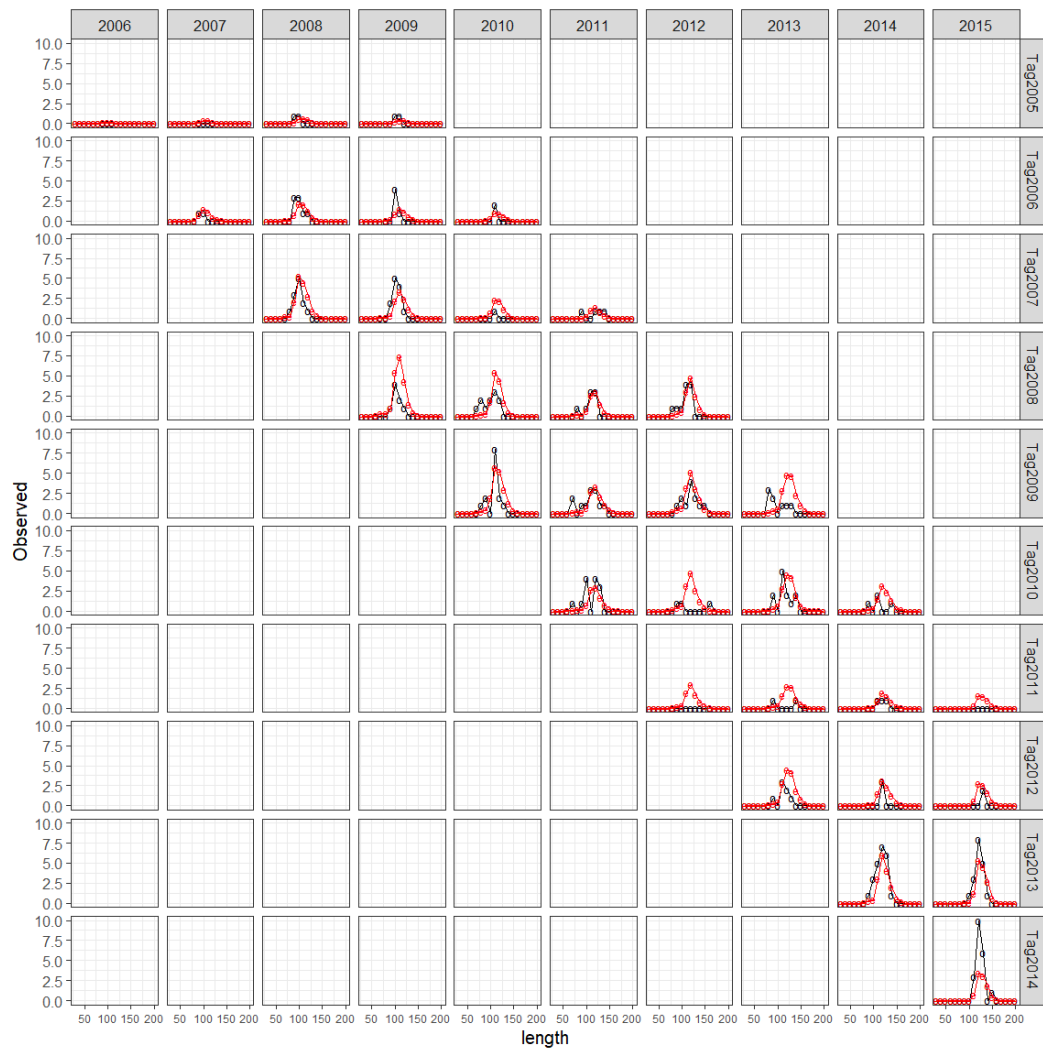


Figure 10.5. Fits to tagging data by length (releases up to 2014).

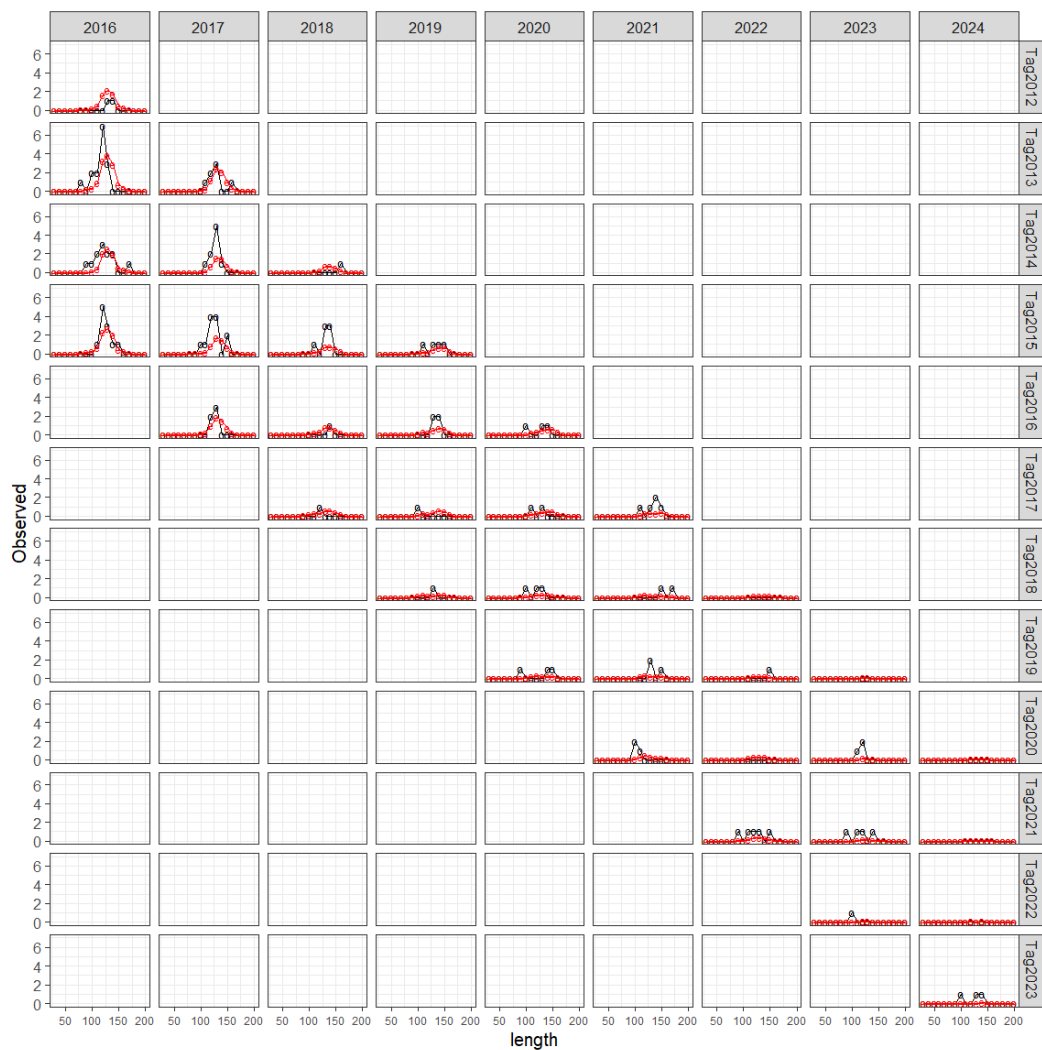


Figure 10.6. Fits to tagging data by length (releases since 2012).

10.2. Output quantities

Estimates of parameters from the previous assessment for each MPD model run are shown in Table 10.1. The parameters estimated from the 2025 assessment remain similar to those estimated previously.

Table 10.1. MPD estimated parameters from the 2017, 2019, 2021, 2023 and 2025 assessments.

	Assessment year				
	2017	2019	2021	2023	2025
B₀ (tonnes)	965	1,004	955	914	1,064
k	0.058	0.055	0.054	0.052	0.056
L_{inf} (cm)	194	200	202	206	197
Age of 50% selectivity (years)	14.1	13.7	13.6	14.0	13.9
Selectivity range (years)	5.6	5.2	4.8	5.1	4.4

The MPD assessment outputs (Figure 10.7) show a stable spawning stock biomass across the years 1990 – 2000, after which the SSB increased following the recruitment of the strong year class from the early 1990s. After this initial increase SSB declined as recruitment returned to average levels. The current spawning biomass was estimated to be at 64% of B₀ in 2025. Notably, the current model shows a greater difference in relative SSB status compared to the 2023 model than for previous model comparisons.

Exploitation began in 2005, peaked in 2008 at approximately 10% and following the introduction of more restrictive catch limits based on the application of the CCAMLR Decision Rule, has subsequently averaged at around 2%. The 2025 harvest rate has been revised down substantially with a slight increase on the 2024 rate.

Following the exceptional strong 1995-year class, shown as age 1 in 1996, recruitment has been stable except for a strong peak in 2005. Recruitment is estimated to have increased since 2009, the lowest value of the timeseries, although the recent estimates will have a high uncertainty associated with them. The recruitment peak in 1996 appears to be consistent with the potential year-class evident in the raw age data compositions (Figure 3.3), which indicate an abundance of fish around age 18 in 2011, and at higher ages in subsequent years until 2015. Similarly, the recruitment peak in 2005 coincides with the peak in the age composition in 2015 at around age 10, which reappears in subsequent years.

10.3. Retrospective analysis

The historic retrospective (Figure 10.7), comparing the 2023 assessment and the final assessment, shows that with the changes made and the addition of two more years of observations the perception of the stock has changed showing a single large recruitment for 1996 and a steady, but shallow increase from low levels in 2009. SSB is estimated to be at a higher level than that estimated in the 2023 assessment with a slower decline towards 50% B_0 . The update assessment shows increased uncertainty resulting from the application of the Francis reweighting method across all data sources. By achieving a more balanced fit among multiple data sources rather than optimising fit to age-length data, the model estimates have slightly greater overall uncertainty.

An analytical retrospective analysis was performed using the final assessment with a five-year peel. The resulting MPD estimates, presented in Figure 10.8, illustrates the effect of successively removing years of data while keeping the model structure and data weighting process consistent as described in Section 7. This analysis shows reasonable consistency between relative SSB and recruitment with some perception shifts in SSB. The estimates of SSB in the assessment show an overall decrease with successive peels as estimates of B_0 decrease with the addition of observations. There is minimal bias observed in the revisions of relative SSB, however, there is some bias shown in recruitment, particularly for the 2005 year-class where the value is revised upward with each year of additional observations, when more is known about the strength of this year class.

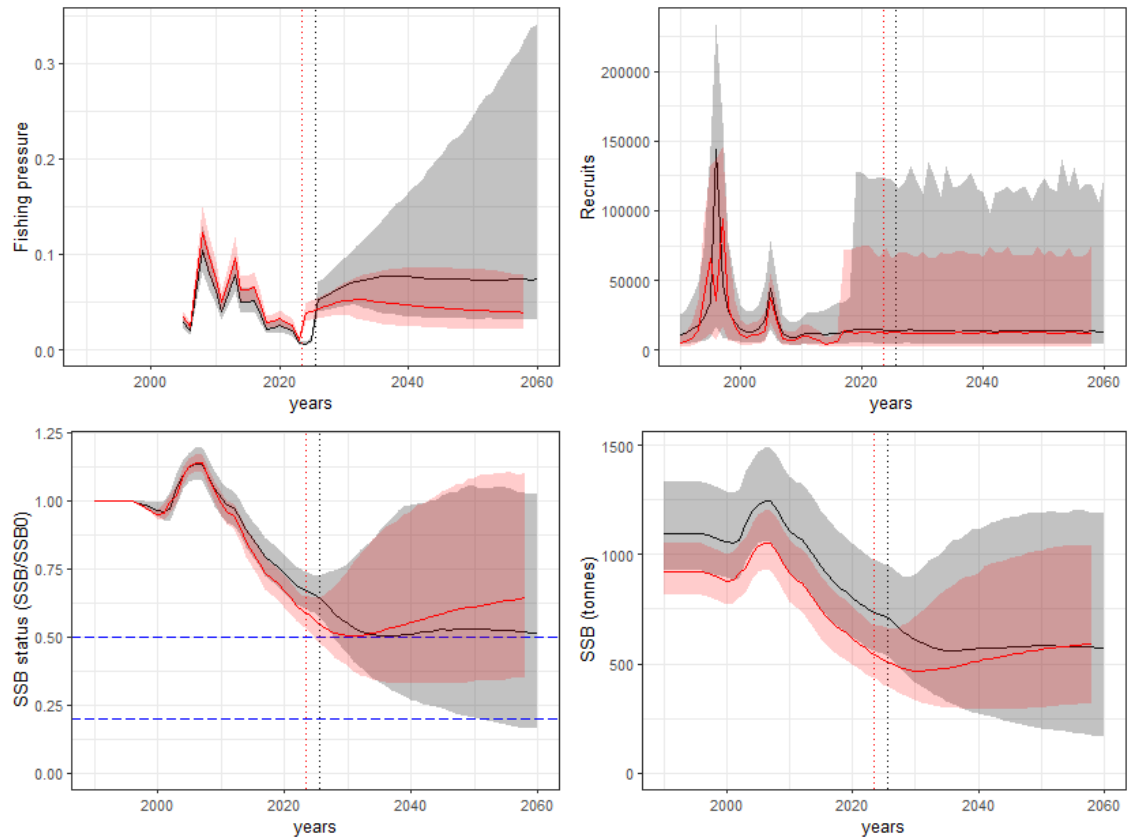


Figure 10.7. MCMC projections of harvest rate, Recruitment (age 1), relative spawning biomass, and spawning biomass of *D. eleginoides* in Subarea 48.4; median (black line) with 95% credible intervals (grey shading) compared to the previous (2023) assessment MCMC median (red line) with 95% credible intervals (red shading). The blue horizontal lines show the 50% and 20% reference points used in the CCAMLR decision rule and vertical dashed red and black lines denotes the beginning of the projection period for the 2023 and 2025 assessments, respectively.

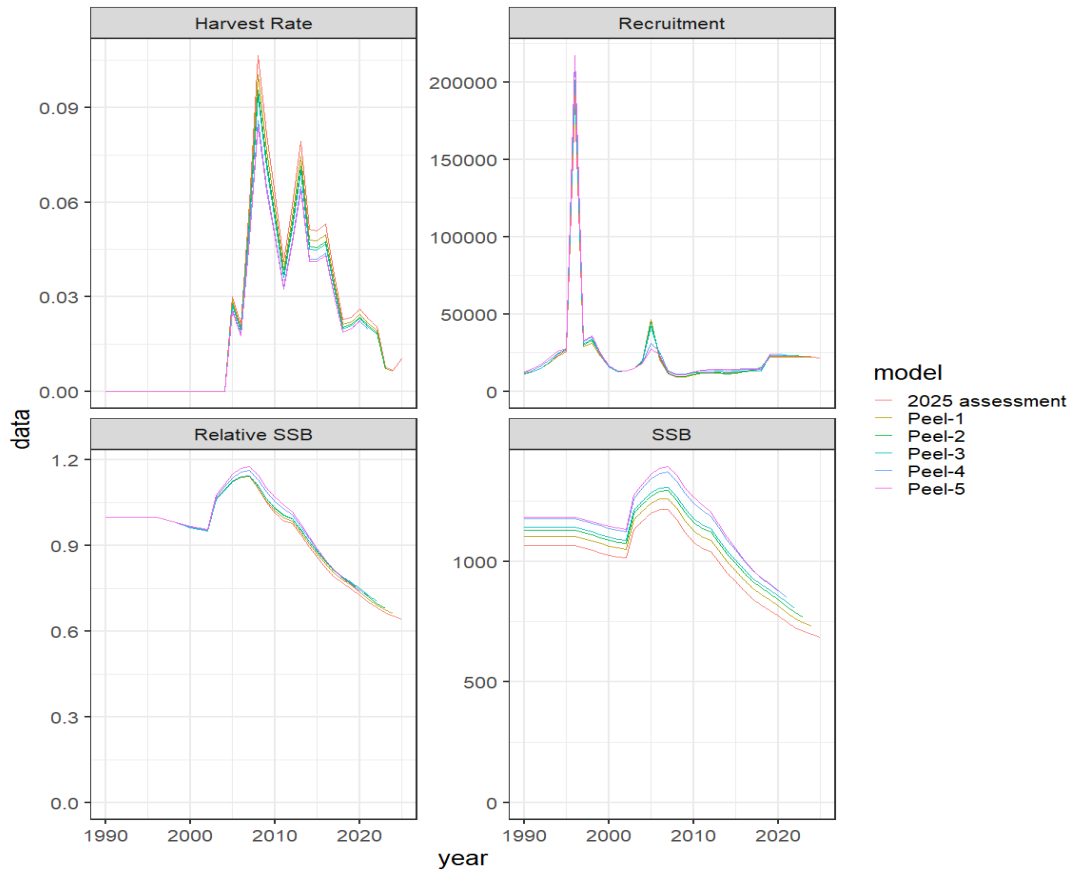


Figure 10.8. MPD analytical retrospective analysis of harvest rate, recruitment, relative spawning biomass and spawning biomass.

10.4. Profiling on B_0

Likelihood profiles for B_0 (Figure 10.9) show that the tag data overall indicate an estimate of virgin biomass of around 1,200 tonnes. Estimates derived from catch data and priors suggest a lower B_0 . The likelihood profiles for each year of tagging data (Figures 16 - 18 in Readdy and Earl, 2025b) demonstrate that three years of tagging data, 2013 to 2015, convey a different profile to other years. The release years from 2013 to 2015 have a particularly high number of tags recovered in the four years following release (Table 4.1), so we see a more well-defined estimate.

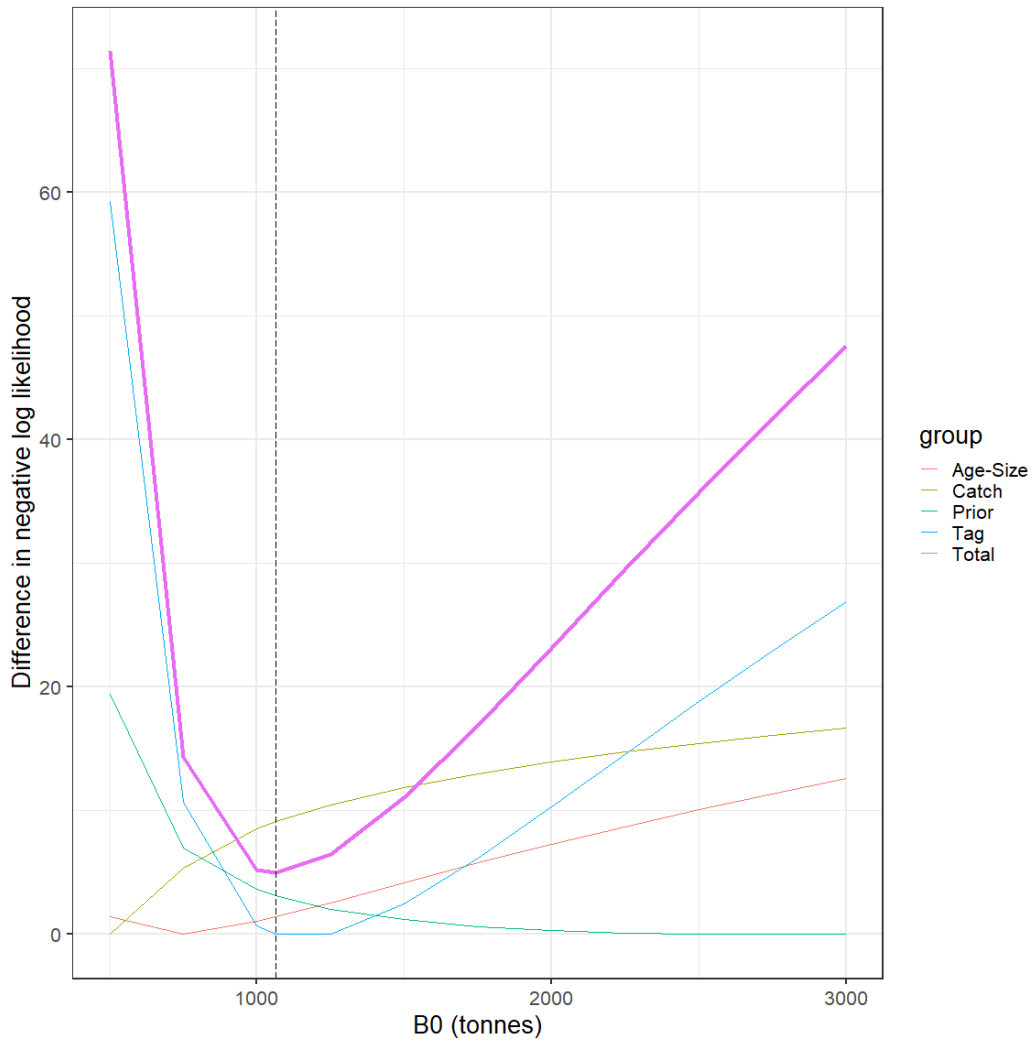


Figure 10.9. Likelihood profiles for B_0 .

10.5. Markov chain Monte Carlo (MCMC) fit

An MCMC analysis was run for the 2025 final model assessment to give an indication of the uncertainty in the MPD model fit and provide a basis for the stochastic projection. Estimated parameters were derived from 900,000 samples following an initial burn-in of 200,000 iterations and subsequently thinned at a rate of 1,000. Convergence to the posterior distribution for all estimable parameters was tested using the coda (output analysis and diagnostics for MCMC) package in R and illustrated in Figure 10.10 and Readdy and Earl, 2025b. Geweke convergence tests indicated successful convergence of the estimated parameters, though not all. Heidelberger and Welch tests indicated stationarity in all but one estimated parameter, however chain length for most of the recruitment estimates may be insufficient. A test of autocorrelation showed significant autocorrelation for three recruitment estimates (Figure 29-31 in Readdy and Earl, 2025b). In general, MCMC analyses performed adequately, but showed some susceptibility to poor convergence, which was probably due to the model's reliance on a relatively small quantity of data. Table 10.2 provides the MCMC outcomes for spawning biomass for the initial equilibrium SSB (B_0), the final year SSB

($B_{current}$) and the ratio of current to initial SSB, including uncertainty, for each CCAMLR accepted assessment.

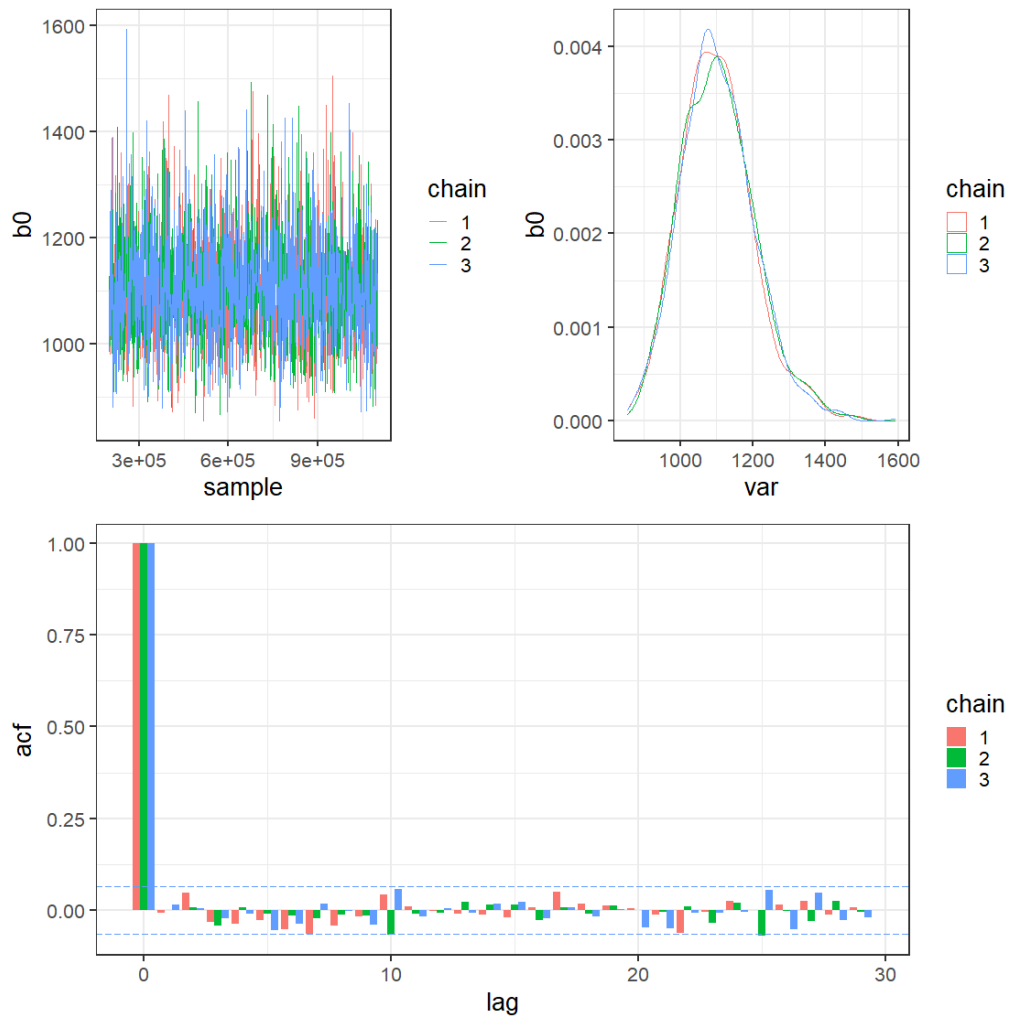


Figure 10.10. Three MCMC traces for B_0 (top left), distribution (top right) and autocorrelation diagnostic (bottom) after trimming and removal of burn-in period.

Table 10.2. MCMC Median spawning biomass and 95% CIs for the initial equilibrium SSB (B_0), the current SSB_y, ($B_{current}$) and the ratio of current to initial SSB for the 2013-2025 assessments.

Assessment year	B_0 (tonnes)	$B_{current}$ (tonnes)	$B_{current}/B_0$
2013 ¹	1,311	1,070	0.82
2015 ¹	1,434	1,133	0.79
2017	982 (851 - 1142)	663 (522 – 836)	0.68 (0.61 – 0.73)
2019	1,002 (874 – 1196)	674 (535 – 882)	0.67 (0.61 – 0.74)
2021	979 (849 – 1149)	636 (502 – 822)	0.65 (0.59 – 0.71)
2023	924 (816 - 1054)	549 (440 - 683)	0.59 (0.54 – 0.65)
2025	1,097 (927 – 1335)	719 (544 – 958)	0.65 (0.59 – 0.72)

1. MPD derived quantities.

10.6. Projections

WG-FSA and WG-SAM have previously highlighted the importance of recruitment assumptions when calculating catch limits using the CCAMLR decision rules. As proposed by WG-SAM-2024, paragraph 5.19 (CCAMLR, 2024), empirical resampling of the recent period should be performed if a trend is present. For this assessment recruitment does not show a trend but does exhibit large sporadic recruitment pulses, therefore, empirical resampling of the full timeseries was implemented.

A constant catch projection was run for a 35-year period based on the MCMC samples from the final assessment and used to determine catch levels consistent with the CCAMLR Decision Rules.

Expected recruitment for the most recent seven years for which age data are not available and future recruitment are calculated as described in the Stock Annex (Readdy and Earl, 2025a).

Projections with a constant TAC of 33 tonnes are illustrated in Figures 10.11 – 10.12 (in more detail in Readdy and Earl 2025b) show that the stock will be above 50% of B_0 at the end of the projection period with a greater than 50% probability. These projections show that 1.4% of the simulations fall below 20% of B_0 during the 35-year period. The associated statistics are shown in Table 10.3.

following the procedure agreed by SC-CCAMLR-38 (para. 3.70), this implies that the TAC of 33 tonnes would be consistent with the CCAMLR Decision Rules.

Table 10.3: Forecast summary values

Quantity	Value
Proposed yield (t)	33
MPD B_0 (t)	1,064
MCMC median B_0 (t)	1,097
Total objective function value	2,231
P (SSB<50% SSSB ₀)	0.472
P (SSB<20% SSSB ₀)	0.014

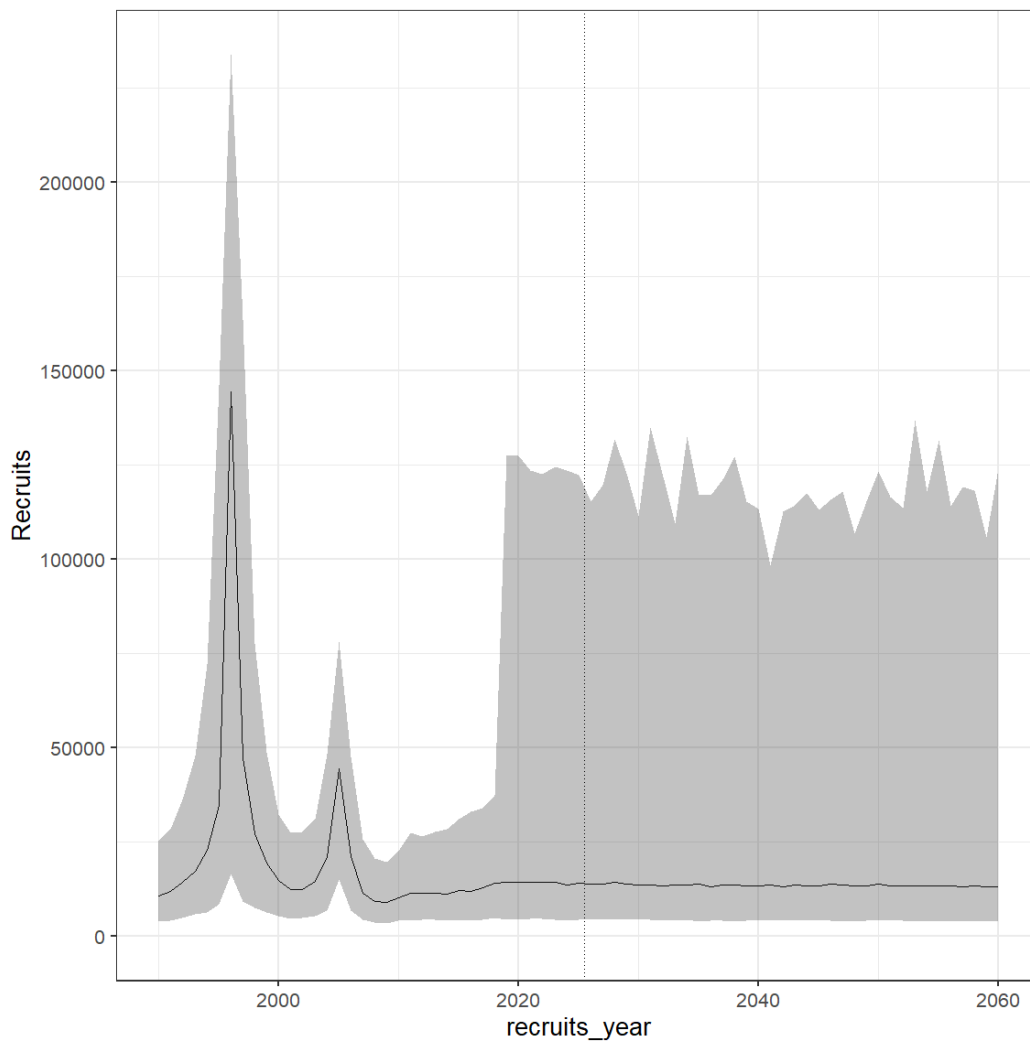


Figure 10.11. MCMC recruitment projections; median (black line) with 95% credible intervals (shaded).

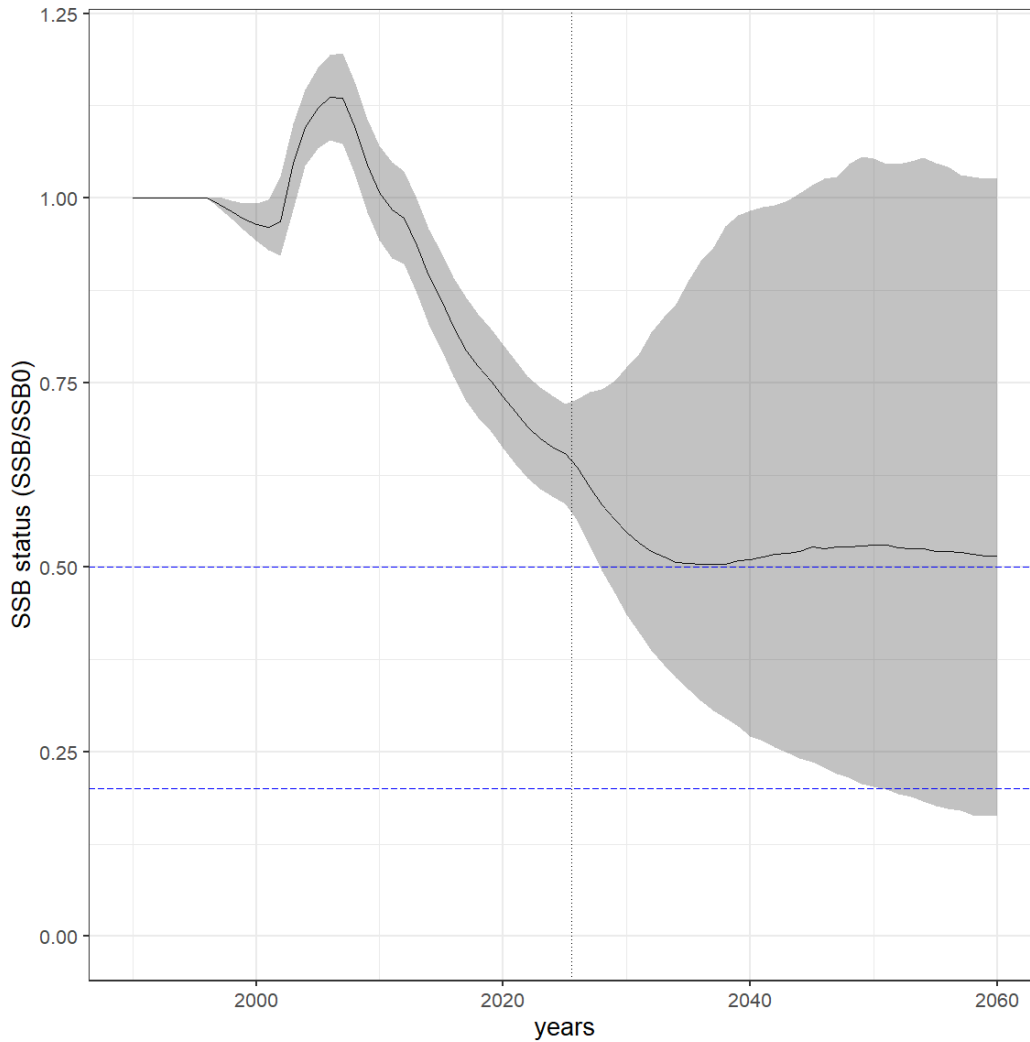


Figure 10.12. MCMC SSB projections relative to B_0 ; median (black line) with 95% credible intervals (shaded). The blue horizontal lines show the 50% and 20% reference points used in the CCAMLR decision rule.

10.7. Management procedures

Following the recommendations of WG-SAM-2024, paragraph 6.10 (CCAMLR, 2024), an evaluation of the candidate Harvest Control Rules (HCRs) was undertaken. Using the outcomes from the final assessment a set of 1,000 simulations based on a random set of MCMC samples was used. The same recruitment scenario as that used in the projections was tested which included all years and no discounting of the historical mean YCS. The description of the rules applied are provided in Table 10.4 and two performance indicators are shown in Figures 10.13 and 10.14 identifying the probability of being below 20% of B_0 and 50% of B_0 , respectively. The candidate HCRs evaluated provided catch limits of 44-47 tonnes, which is marginally higher than the limit established under a constant catch using the CCAMLR Decision Rule. This is because the stock is estimated to be above

the target level. All HCRs showed a negligible probability of being at or below 20% of B_0 with a probability median of 50% (range from 28% to 71%) of being below 50% of B_0 .

Displaying these rules on the Kobe plot (Figure 10.15) shows that the current exploitation rate (U) is very low relative to the estimated stock status and that harvest rates since 2013 have remained well below the candidate HCRs for the upcoming seasons.

Table 10.4: Estimated values of the reference harvest rate $U_{50\%B_0}$, and implied catch limit and the expected long-term mean catch ($E(\text{catch})$) and standard deviation of the catch ($sd(\text{catch})$) for each candidate HCR.

Rule	Description	$U_{50\%B_0}$	Catch(2026) tonnes	$E(\text{catch})$ tonnes	$sd(\text{catch})$ tonnes
Rule 1	Constant	0.061	44	35.4	10.5
Rule 3	Ramp (0.2 – 0.5)	0.065	47	35.1	13.1
Rule 6	Ramp (0.3 – 0.3+M)	0.063	46	35.1	12.5

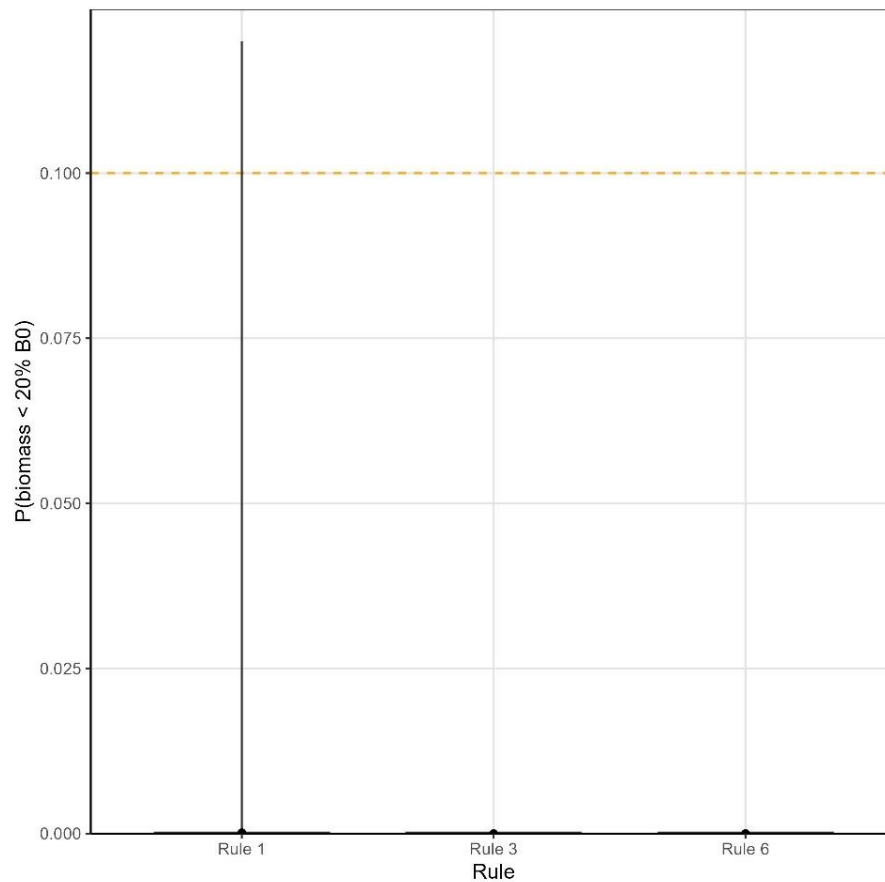


Figure 10.13: Performance indicator for the distribution of the probability of being below the limit reference point (20% B_0) using the reference $U_{50\%B_0}$ for each candidate HCR. Boxes indicate the 80% quantiles and the range (minimum-maximum) by the vertical line. The bold horizontal line indicates the median and the mean is shown by the point. Horizontal dashed line indicates the 10% risk of being below the limit reference point (LRP) of 20% B_0 .

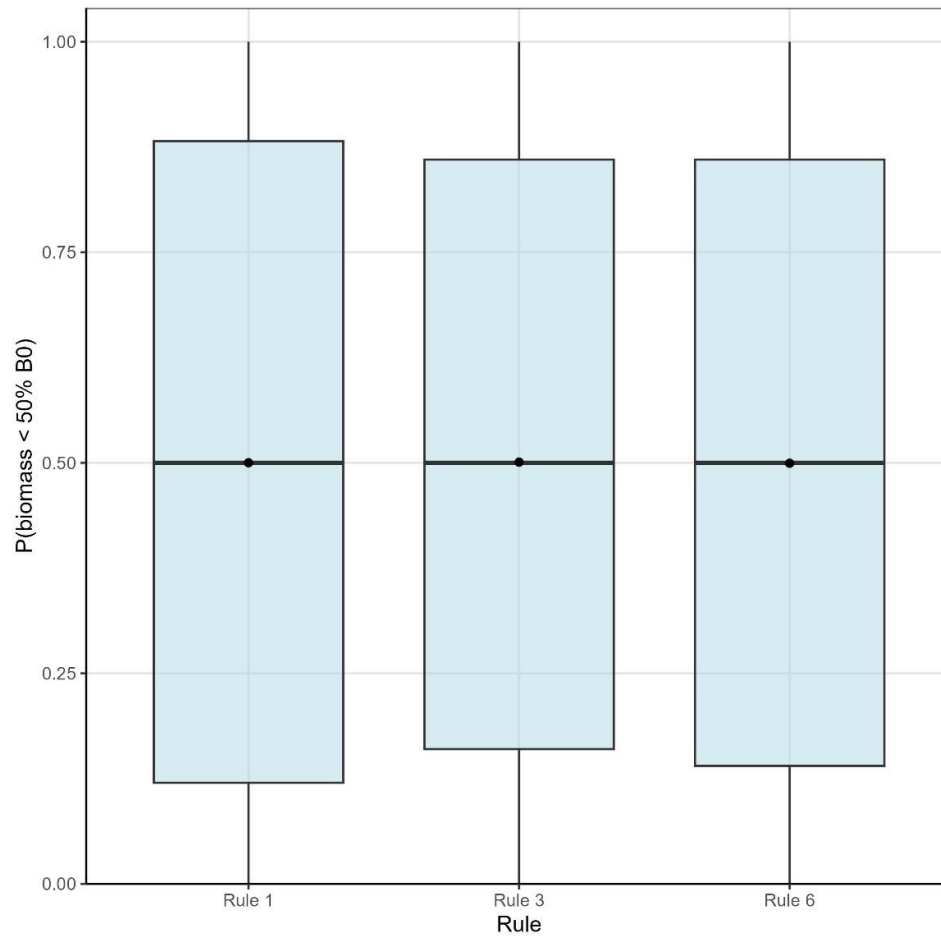


Figure 10.14: Performance indicator for the distribution of the probability of being below the target reference point (50% B_0) using the reference $U_{50\%B_0}$ for each candidate HCR. Boxes indicate the 80% quantiles and the range (minimum-maximum) by the vertical line. The bold horizontal line indicates the median and the mean is shown by the point.

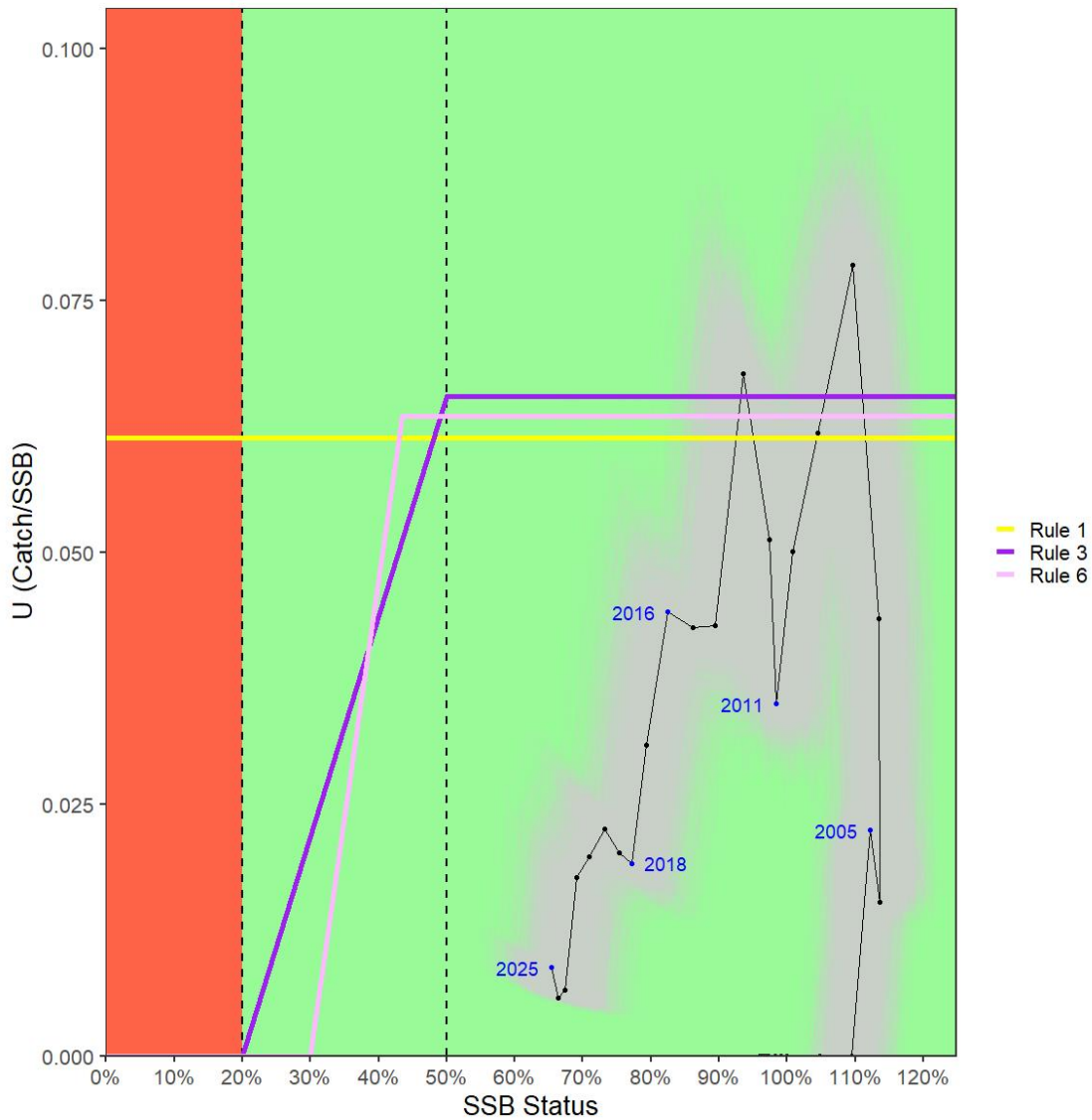


Figure 10.15: Kobe plot (phase plot) of MCMC SSB projections relative to B_0 compared to harvest rate U ; median (black line) with MCMC uncertainty range (grey). Coloured lines show the U -based rules proposed by WG-SAM-2024.

11. Summary

The model estimates of stock size continue to fluctuate slightly between assessments due to variability in recruitment and the influence of the additional data as highlighted in the bridging analysis and the historical and analytical retrospective analyses (Figures 10.7 and 10.8). Despite this, the estimates of recruitment, stock status and diagnostics remain consistent across all models, although a marked improvement on performance is noted for the final assessment.

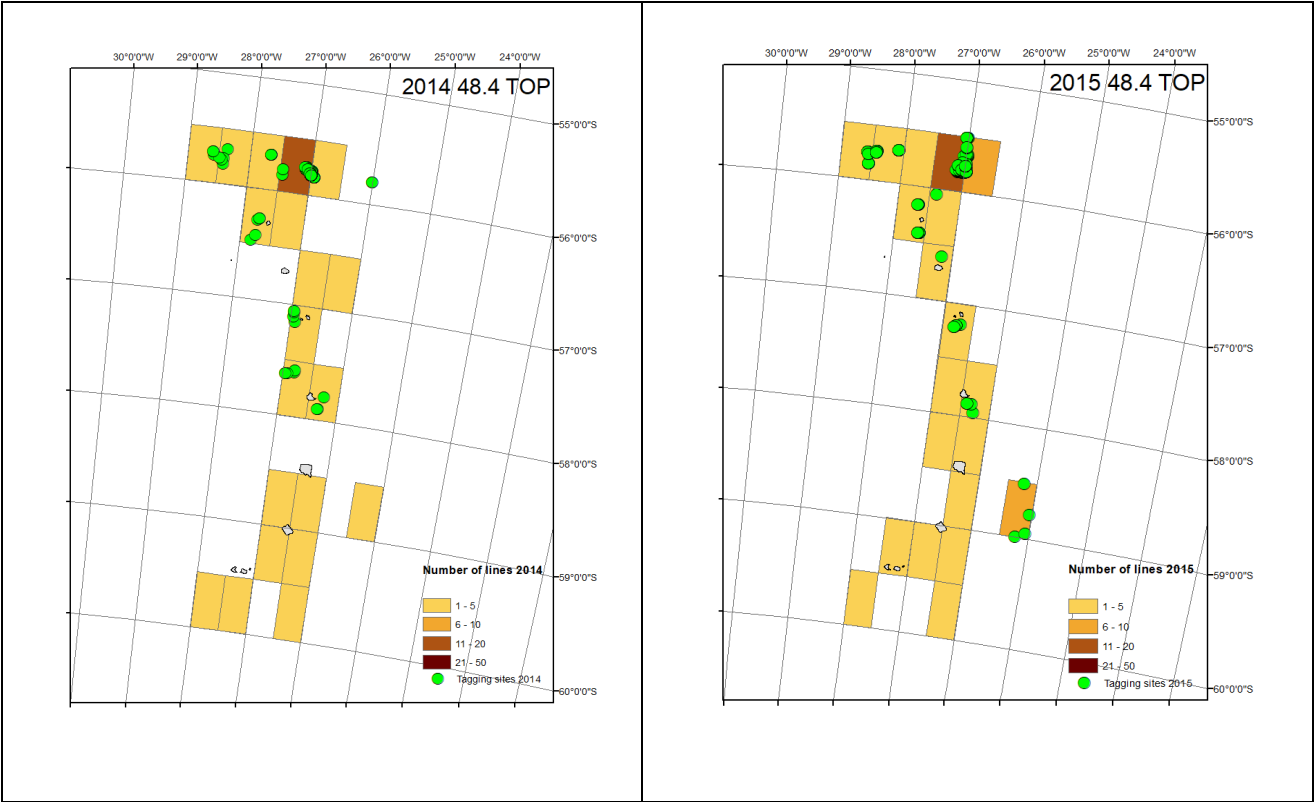
The results of the final assessment show that current stock status of the stock is at 65% of B_0 and that a TAC of 33 tonnes is consistent with the CCAMLR Decision Rule. This would be expected to achieve an SSB of just above 52% of B_0 after the 35-year period, with a very low probability of falling below 20% of B_0 .

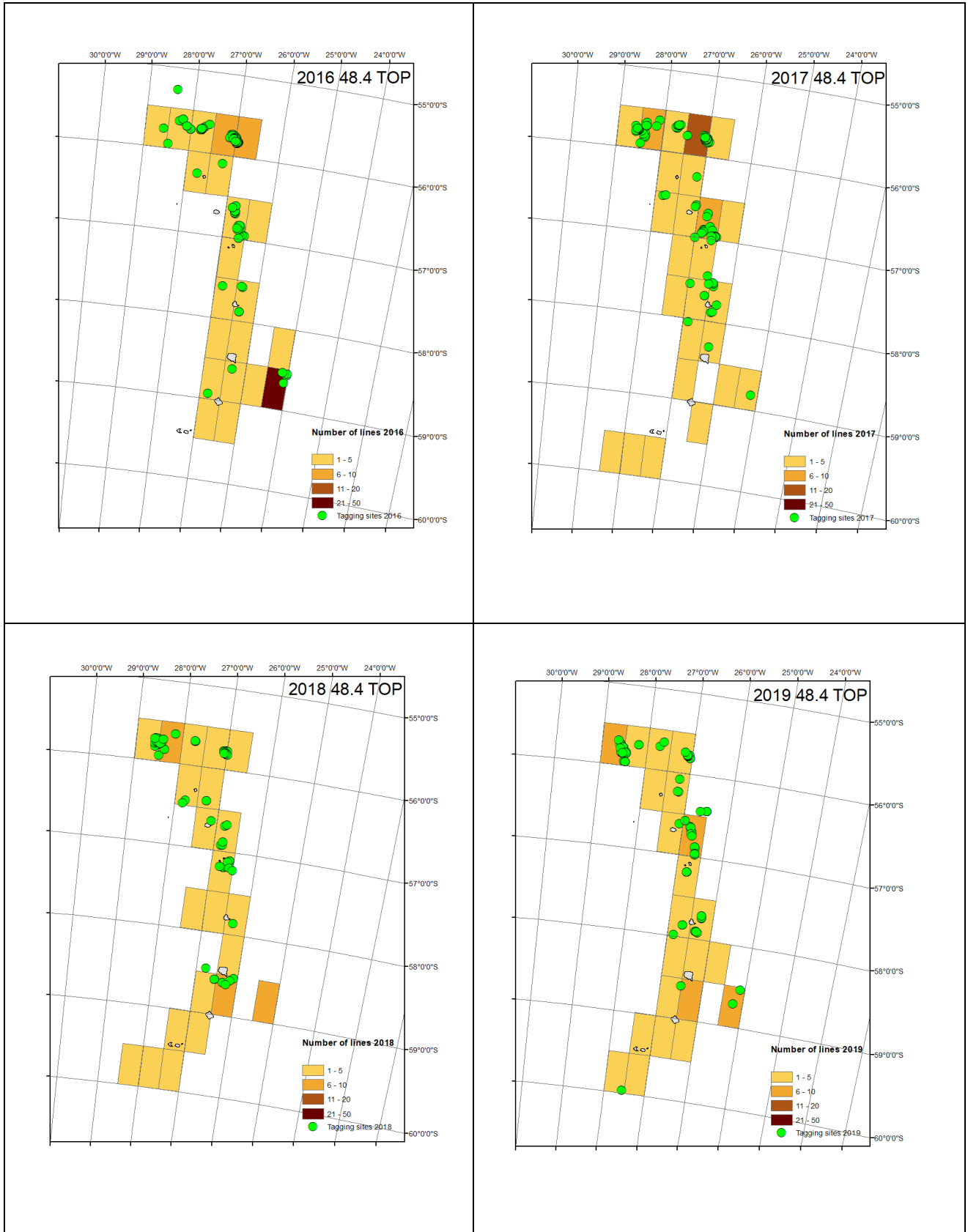
12. References

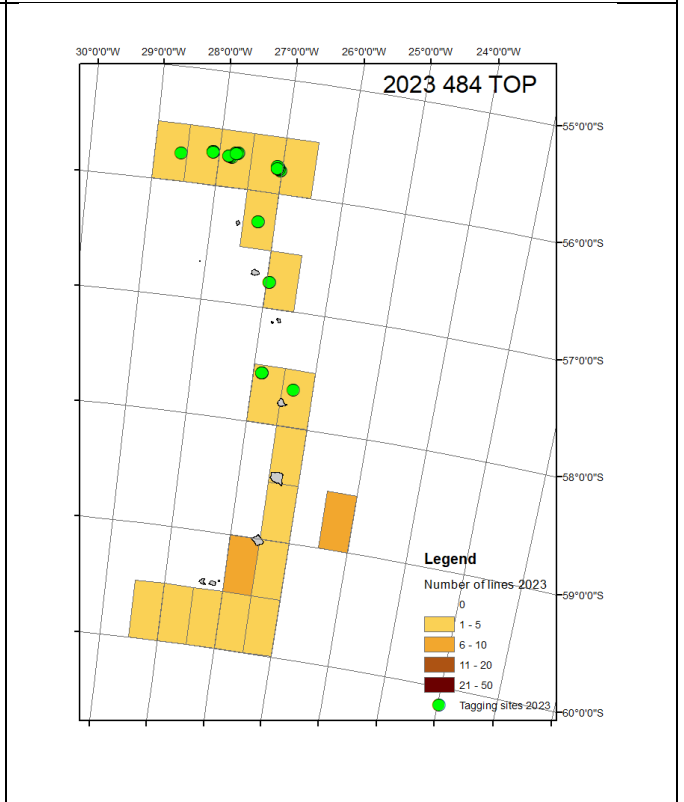
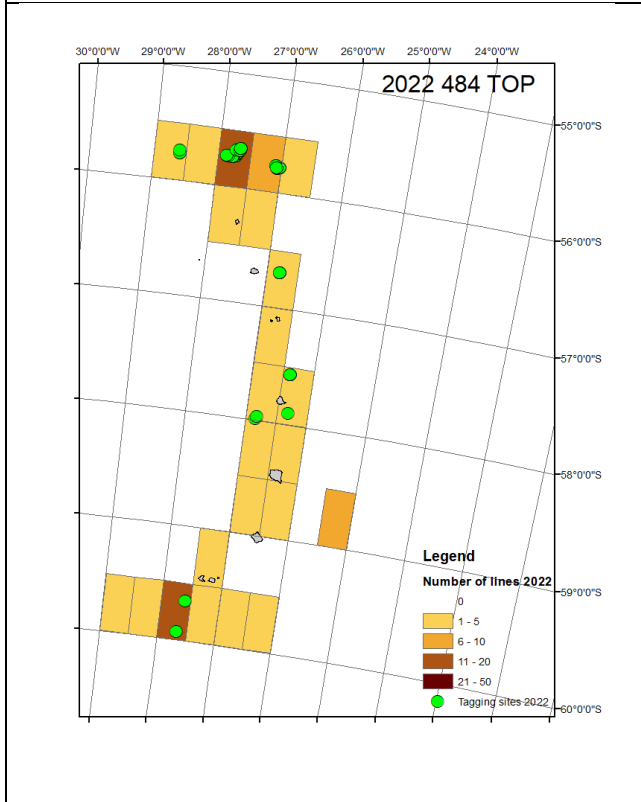
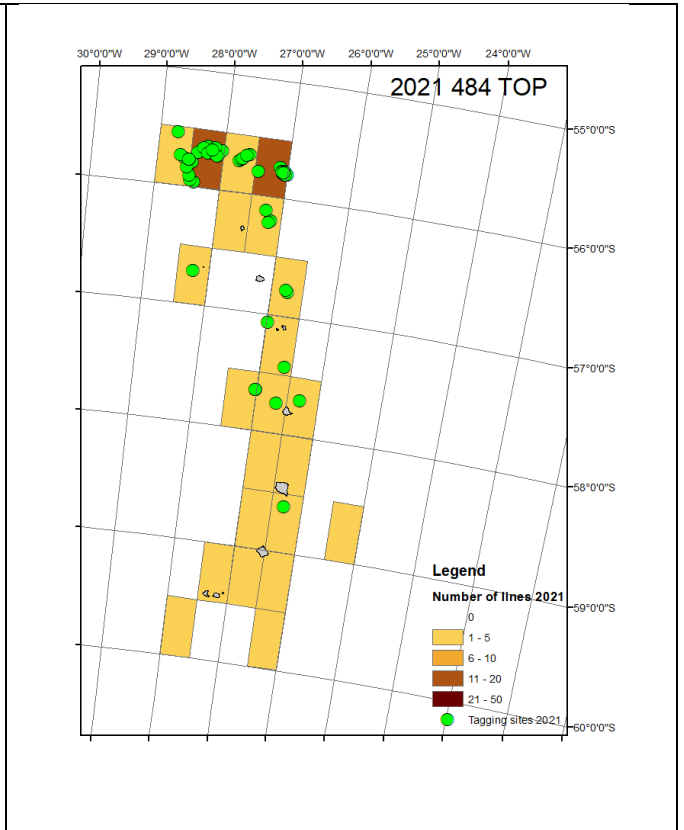
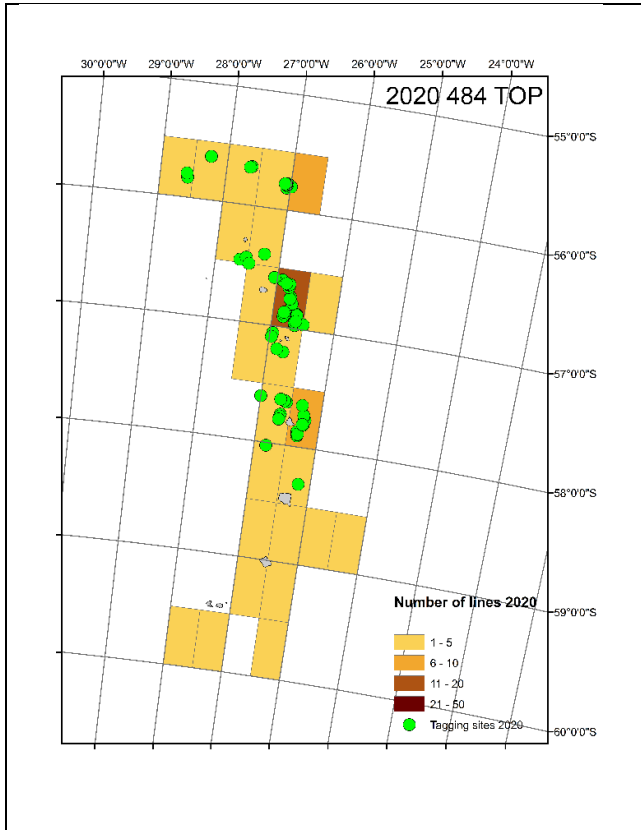
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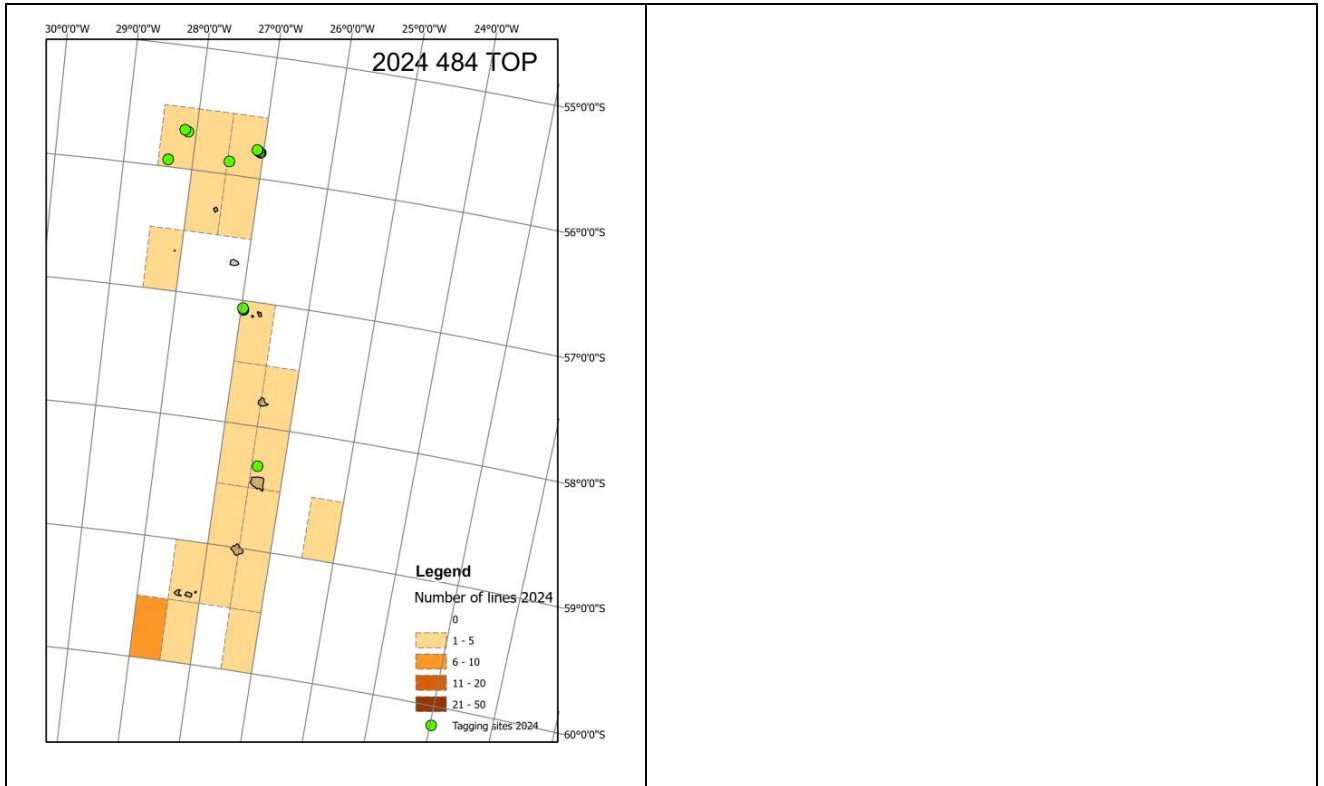
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- Thompson, A., Alewijnse, S. R., Earl, T., Readdy, L. and Riley, A. 2025. Fishery characterisation for Antarctic toothfish (*Dissostichus mawsoni*) and Patagonian toothfish (*D. eleginoides*) in Subarea 48.4. Submitted to CCAMLR WG-FSA-2025.

Annex 1: Plots of fishing effort for Patagonian toothfish in Subarea 48.4.











CCAMLR

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Population assessment of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4 – 2025/26 fishing season update

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Abstract

The local biomass of Antarctic toothfish (*Dissostichus mawsoni*) in CCAMLR Subarea 48.4 is estimated from tagging returns, giving a five-year average of 846 tonnes. Applying the CCAMLR agreed harvest rate of 3.8 % results in a 2025/26 catch limit of 32 tonnes. We recommend that this is used to set the catch limit for the 2025/26 season.

Following the recommendation of WG-FSA-IMAF-2024, we developed a length-based Casal2 model to determine an appropriate harvest rate for this stock which is consistent with the CCAMLR Decision Rules. We implemented constant catch scenarios to explore various harvest rates ranging from the current 3.8 % up to 15 % and projected forward for 35 years. Applying an analogue of the reference point of the CCAMLR Decision Rules in maintaining vulnerable biomass at 50 % of the initial estimate would result in a much higher harvest rate of 12 – 15 %, compared to the current 3.8 %.

Given that the parameters in the Casal2 model were largely borrowed and may not reflect the unique dynamics in Subarea 48.4, we do not propose to move away from the harvest rate of 3.8 % at this time, but welcome feedback on developing approaches to managing fisheries which form part of a larger stock.

1 Introduction

In Subarea 48.4 (Figure 1), exploitation of *Dissostichus* spp. recommenced in the North of Subarea 48.4 in 2005, and in 2009 extended into the South of Subarea 48.4, with a pilot tagging program initiated in 2005. Between 2009 and 2021, the fishery was carried out by two vessels, and by one vessel from 2022 onwards. Annual Antarctic toothfish (*Dissostichus mawsoni*) catches ranged from 15-59 tonnes (Table 1). The management and assessment of the two species was historically carried out as one species complex separated spatially into northern (between latitudes 55°30'S and 57°20'S and longitudes 25°30'W and 29°30'W) and southern (bounded by latitudes 57°20'S and 60°00'S and longitudes 24°30'W and 29°00'W) parts of Subarea 48.4 (Scott, 2012; Figure 1). In the northern area, the bulk of *Dissostichus* spp. catches comprise Patagonian toothfish (*D. eleginoides*) with the southern area comprising mainly Antarctic toothfish (Thompson *et al.* 2025). Since 2013, the two species have been assessed separately over the combined northern and southern parts of Subarea 48.4. The stock of Patagonian toothfish is assessed biennially, using an age based Casal2 assessment model (Readdy & Earl, 2025), whereas Antarctic toothfish stock status is estimated annually, using a mark-recapture approach.

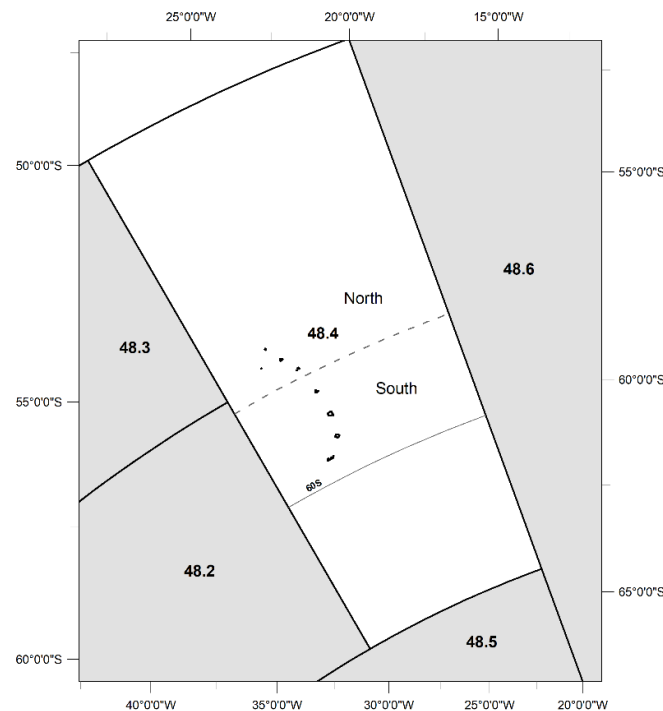


Figure 1 Map of Subarea 48.4. Dashed line at 57.33° S indicates previous North and South rectangles, which since 2012 have been combined into species-specific assessments for Antarctic and Patagonian toothfish.

Table 1 Catch and catch per unit effort of the Antarctic toothfish in Subarea 48.4. Altamar* was previously named Argos Georgia until 2018 when it was subsequently renamed, and a new vessel acquired the name, Argos Georgia.

Year	Vessel	Fishing period	Total catch (kg)	CPUE (kg per hook)
2009	San Aspiring	21/03-23/04	26629	0.05
2009	Altamar*	02/03-18/05	32464	0.06
2010	San Aspiring	21/03-14/04	30710	0.09
2010	Argos Froyanes	26/03-01/05	25601	0.04
2011	Altamar	31/03-25/04	10315	0.02
2011	San Aspiring	03/04-06/06	4843	0.02
2012	San Aspiring	30/03-08/06	5906	0.01
2012	Altamar	01/04-23/04	16331	0.06
2013	San Aspiring	18/03-14/04	24295	0.07
2013	Argos Froyanes	22/03-12/04	15236	0.04
2014	Altamar	20/03-29/03	11992	0.13
2014	San Aspiring	07/03-24/03	11897	0.07
2015	San Aspiring	27/03-08/04	13683	0.08
2015	Altamar	05/04-20/04	13957	0.07
2016	San Aspiring	26/03-14/04	17549	0.06
2016	Tronio	06/05-24/05	10226	0.04
2017	San Aspiring	21/03-12/04	17902	0.07
2017	Tronio	18/04-09/05	1486	0.01
2018	San Aspiring	24/03-11/04	16565	0.09
2018	Argos Froyanes	07/04-25/04	15363	0.08
2019	Argos Froyanes	06/02-21/02	16834	0.11
2019	San Aspiring	07/04-29/04	16222	0.07
2020	Nordic Prince	02/03-11/03	32560	0.26
2020	San Aspiring	04/04-25/04	11334	0.04
2021	Argos Georgia	04/03-15/03	23735	0.18
2021	San Aspiring	06/04-28/04	19396	0.06
2022	Nordic Prince	05/04-12/05	32074	0.07
2023	Argos Georgia	17/03-11/04	25949	0.10
2024	Argos Georgia	05/02-24/02	42036	0.18
2025	Argos Helena	15/03-03/04	40591	0.18

1.1 Assessment history

Between 2013 to 2015, a tag-based population assessment, using a Petersen-Lincoln method mark-recapture formulation to estimate abundance (Hillary, 2008; CCAMLR, 2011), was implemented for Antarctic toothfish following the CCAMLR standard method at the time.

Based on the known bias of the Petersen tag-based population abundance estimate, resulting from low tag recapture numbers, WG-FSA-14 (CCAMLR, 2014) recommended the use of the Chapman assessment method. CCAMLR agreed to use this from 2015 (CCAMLR, 2015), and this has been applied in all successive years, with a minor correction introduced in the 2016 (Wright *et al.* 2016) assessment following Walker *et al.* 2015.

Data from the Ross Sea region and Subarea 48.6 on the biology of Antarctic toothfish suggests that on seamounts, tags may not be available beyond three years (Parker & Mormede, 2014; Söffker *et al.*, 2018). The stock hypotheses for the Ross Sea region includes a migratory component to the northern seamounts from the southern regions, where Antarctic toothfish remain for up to three years before leaving the seamounts again (Mormede *et al.*, 2015). Based on the hypothesis that the Subarea 48.4 seamounts may also represent the northern extent of a more southerly stock, and noting that few Antarctic toothfish tags within Subarea 48.4 south are caught beyond three years at liberty (Table 2), WG-FSA-16 (CCAMLR, 2016) agreed that a precautionary approach to potential bias in the assessment should be applied with a three-year limitation on tags at liberty in the Chapman biomass estimation in Subarea 48.4.

WG-FSA-IMAF-2024 (CCAMLR, 2024) recommended that “*the applied harvest rate to determine catch limits for this fishery could be updated for future assessments, taking into account region-specific biological parameters.*” To this end, we have developed a length-based Casal2 model to estimate a harvest rate (U_{VB}) for this stock, which is consistent with the CCAMLR Decision Rules.

A summary of stock assessment development in Subarea 48.4 South for Antarctic toothfish is given in Table 3.

Table 2 Tag-recaptures of the Antarctic toothfish in Subarea 48.4. Cells highlighted in blue indicate the data used in the assessment. Note: only tags released and recaptured in Subarea 48.4 are included in the assessment.

Release year	Number of releases	Recapture year																	Total recaptures
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
2009	193	2	15	3	2														22
2010	202		7	4			2												13
2011	83				2			1											3
2012	147																		0
2013	179						1		1	1	2								5
2014	202							14	1	1	1								17
2015	584								12	5	1	1							19
2016	149							8	5	2	1	1	1						17
2017	104										3	3		1					7
2018	161										3	1	1	1					6
2019	168											2	6	3					11
2020	229													16	3	1			20
2021	224													12	15	3	5		35
2022	166														2	1	5	2	10
2023	150																9	1	10
2024	215																4	13	17
2025	204																	1	1
Totals	3360	2	22	7	4		3	15	22	12	12	8	8	33	20	5	23	17	213

Table 3 Summary of stock assessment development in Subarea 48.4 for Antarctic toothfish.

Year	Key changes	Estimated stock status (tonnes)
Until 2012	Combined assessment with 48.4 Patagonian toothfish. Spatially segregated into North and South.	1,368* (* = 2012)
2013	Subarea-wide Petersen tag-based assessment. Antarctic toothfish only.	640
2014	As in 2013 – no changes.	1,027
	At FSA-14: Chapman estimation with numbers of fish, individual tag release/recapture cohorts, geometric mean.	736.8
2015	As at FSA-14, but corrected numbers of fish for weight of fish.	621
	At FSA-15: Chapman estimation with numbers of fish, overall tag release/recapture cohort, geometric mean.	1,014
2016	As at FSA-15, but corrected for weight of fish (as agreed at SC-2015 p 3.120) Limit availability of tags to three years.	1,069
2017	As at FSA-16.	980
2018	As at FSA-17.	982
2019	As at FSA-18, but limited to a five-year geometric mean.	1,187
2020	As at FSA-2019.	1,381
2021	As at FSA-2020.	1,311
2022	As at FSA 2021.	1,110
2023	As at FSA 2022.	1,130
2024	As at FSA 2023.	968
2025	As at FSA 2024.	846

1.2 Tags released outside Subarea 48.4

While the majority of tags recaptured in Subarea 48.4 were released in the same Subarea, there are exceptions. Ten tags, released in Subarea 48.6, seven on the Antarctic shelf and one released ~200 km southeast of Bouvet Island, have been recaptured in Subarea 48.4, between 2017 and 2025 (Figure 2). This includes two such tags recaptured in 2025, from a female released in 2023 and a male released in 2024, both released in research block 48.6_5. All fish were large adults at recapture, with length ranging from 126-156 cm, and their maturity was recorded as developing (stage 2) or developed (stage 3), supporting the hypothesis proposed by Söffker *et al.* (2018).

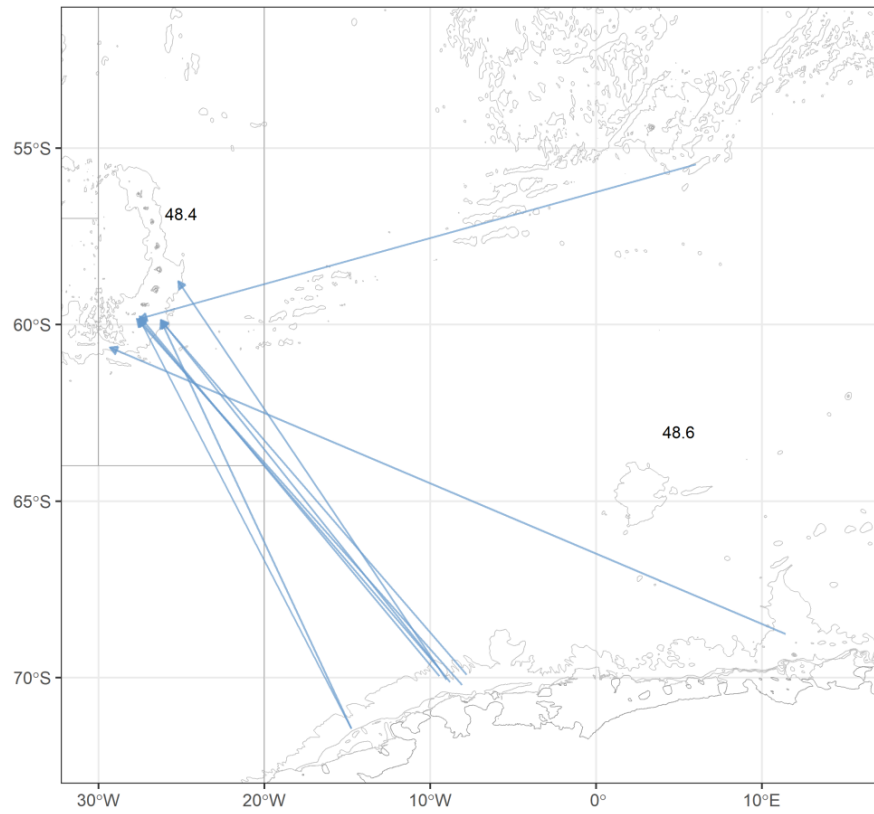


Figure 2 Map of tagged Antarctic toothfish (*Dissostichus mawsoni*) released outside of Subarea 48.4, but recaptured within Subarea 48.4.

2 Methods

2.1 Data

Primary data were checked to ensure consistency in species identification of Antarctic and Patagonian toothfish between release and recapture, as some fish were labelled differently at each stage. A total of 3,360 Antarctic toothfish have been tagged in the northern and southern parts of Subarea 48.4 during 2009-2025, of which 213 have been recaptured (Table 2), with a long-term average tag return rate of 6.3 %. Releases and recaptures south of 60°00'S, which were part of research surveys (Söffker *et al.*, 2021), are excluded.

In 2025, 17 tagged fish were recaptured in Subarea 48.4, 16 of which had been released in the past three seasons (2022-2024). One recapture was from an individual which had been released in the same year (2025, Table 2). This does not include three tags which could not be matched to a release. The fishery, though varying spatially between years, has covered the entire northern and southern areas open to fishing. Distribution of fishing effort and tag releases of Antarctic toothfish, for 2014-2025, is shown in Appendix 6.1.

2.2 Assessment

The assessment is characterised by considerable variation between annual biomass estimates, resulting from low numbers of tag returns that are highly variable (Table 2). Release years 2009, 2014, 2015, 2020, 2021 and more recently 2023 and 2024 have shown higher recaptures following the year of release. A large number of the recaptures in these years occur in single clusters around the seamounts.

Following the recommendation of WG-FSA-2014 (CCAMLR, 2014) the Antarctic toothfish stock in Subarea 48.4 was assessed using the modified Chapman method. Years with zero tag recaptures were eliminated to avoid artificial inflation of biomass in the assessment, thereby applying a precautionary approach to the assessment process (see also Walker *et al.*, 2015). Following the recommendation of WG-FSA-16 (CCAMLR, 2016) a three-year moving window on tag releases was imposed, whereby tags were only considered available for three seasons after release. Any recaptures beyond this time at liberty were excluded from the analysis. As a result, 162 tags recaptured between 2010 and 2025 were included in the assessment (Table 2).

Previously, an average biomass of all years since 2009 was used as a robustness smoother to reduce the influence of noise in the annual biomass estimates resulting from the variation in the relatively low number of tag returns. In 2019, the time range used to calculate the average

biomass was truncated to use the most recent five years to provide an estimate of recent biomass dynamics; this approach was applied to the data updated to include the 2025 season.

The estimated stock biomass in season j (B_j) was calculated using the Chapman method as (Walker *et al.*, 2015):

$$B_j = \left(\frac{(n_j + 1)(c_j + \bar{w})}{(m_j + 1)} \right) - \bar{w}$$

where:

- n_j = Total number of fish tagged and released estimated to be available for recapture in season j .
- c_j = Total weight in tonnes of all fish caught in season j .
- m_j = Total number of tagged fish recaptured in season j .
- $\bar{w}$ = Mean weight in tonnes of Antarctic toothfish caught between the 2009-2025 fishing period.

The numbers of fish estimated to be available for recapture following release is determined from the number of actual tags released in season i (N_i) corrected for tag induced instantaneous mortality (t), tag failure (f) and natural mortality (M) as follows:

$$n_j = \sum_{i=j-3}^{j-1} \left[N_i (1 - t) e^{-(M+f)(j-i)} - \sum_{k=i}^j m_{i,k} e^{-(M+f)(j-k)} \right]$$

Assumed values of $t = 0.1$, $f = 0.0064$ and $M = 0.13$ were used (WG-FSA-12/36).

The variance is estimated as:

$$var(B_j) = \frac{(n_j + 1)(c_j + \bar{w})(n_j - m_j)(c_j - m_j)}{(m_j + 1)^2(m_j + 2)}$$

And an approximate 95 % confidence interval was estimated as:

$$B_{95CI} = B_j \pm 1.965 * var(B_j)^{0.5}$$

A length-weight relationship was calculated for fish captured in 2009-2025 (Figure 3) as:

$$W = 0.00001119L^{2.988418}$$

Based on this relationship, mean weights for each year were calculated from the observed annual length-frequency distributions (Table 4). Based on the observed length-frequency distributions and length weight relationship, $\bar{w}$ was calculated to be 0.0365 tonnes. Figure 4 shows Antarctic toothfish length distribution by year (2009-2025).

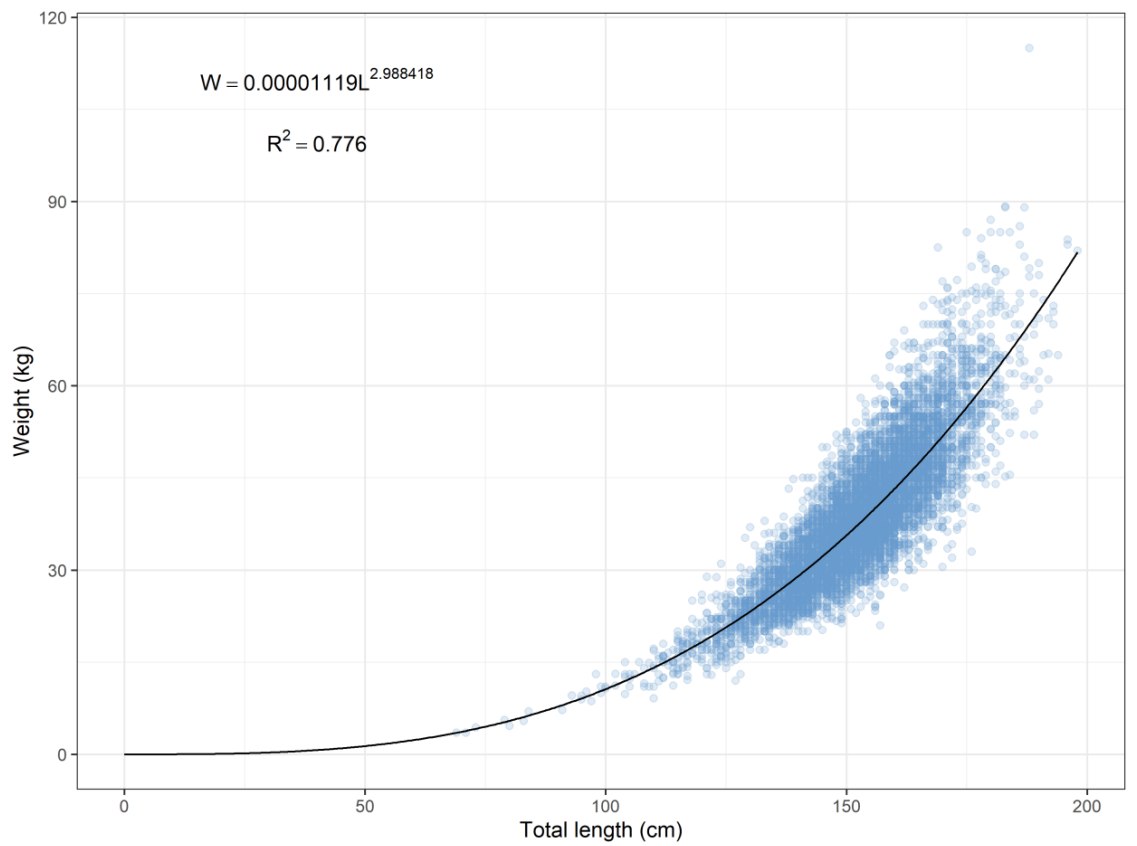


Figure 3 Length–weight relationship for Antarctic toothfish (*Dissostichus mawsoni*) caught in Subarea 48.4 between 2009 to 2025.

Table 4 Mean weight of individual Antarctic toothfish in catches at Subarea 48.4 by season.

Year	Mean weight (kg)
2009	39.8
2010	39.8
2011	38.7
2012	35.7
2013	39.3
2014	39.4
2015	40.2
2016	37.5
2017	38.7
2018	37.9
2019	39.3
2020	37.9
2021	36.9
2022	36.8
2023	38.0
2024	37.7
2025	36.5

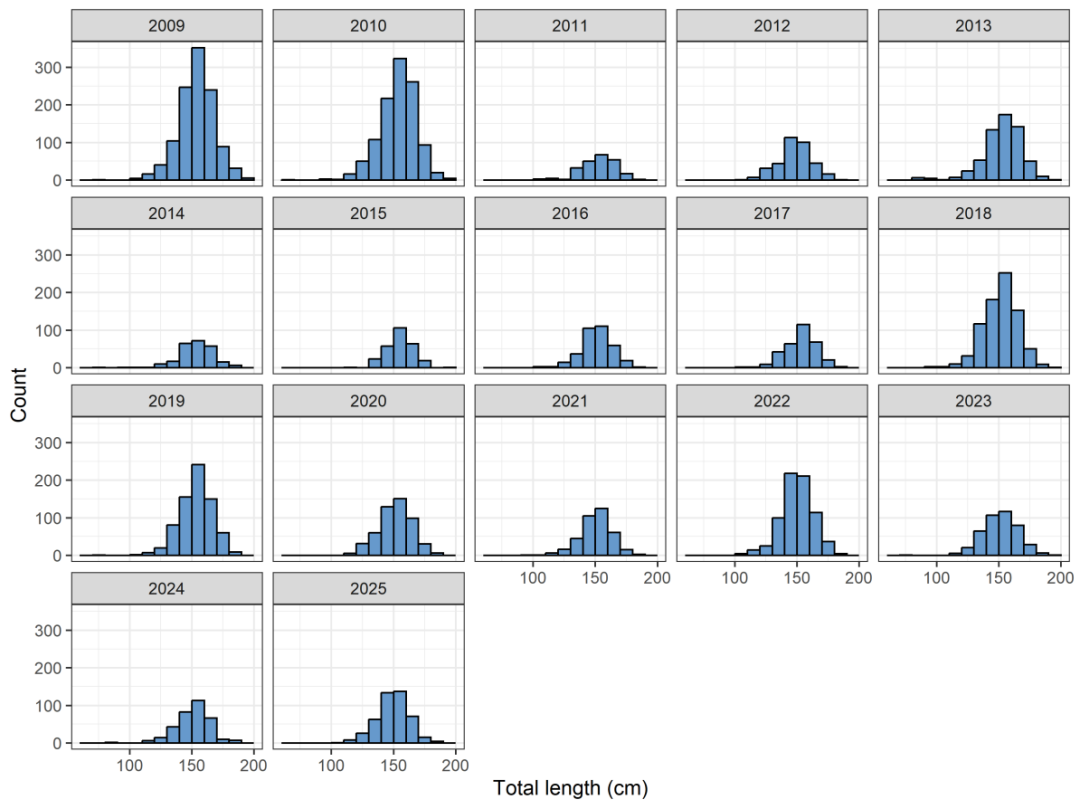


Figure 4 Total length distributions of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4, by season.

2.3 Harvest rate (U_{VB})

To estimate a suitable harvest rate for Antarctic toothfish in Subarea 48.4, we constructed a simple length-based Casal2 model. Note, this simple model was not intended to be an integrated stock assessment for management, but rather to estimate sex-disaggregated fisheries selectivity given data on the length distributions from the catch in the Subarea. As a consequence, B_0 was fixed at the upper confidence interval of the highest biomass estimate from the Chapman estimator (2014, Table 6) because the CCAMLR Decision Rule harvest rate will tend to give a precautionary estimate of target harvest rate if the stock size is over-estimated (Earl *et al.* 2025).

As age data are not currently available for the Antarctic toothfish in Subarea 48.4, the Casal2 model was length-based, and individual year class strengths were not estimated. While total catch were aggregated by sex, length composition data were sex-disaggregated. Due to the paucity of biological parameters on Antarctic toothfish in Subarea 48.4, we used parameters from the Ross Sea region as an approximation (Table 5).

After obtaining estimates from a maximum posterior density (MPD) run, we ran three Markov chain Monte Carlo (MCMC) chains for 1,100,000 iterations, following a burn-in period of 100,000 iterations, and with a thinning parameter of 1000. We checked models for convergence using the Gelman-Rubin diagnostic (R-hat), traceplots and autocorrelation function (ACF) plots. Diagnostics for key estimable parameters and derived quantities are available in Appendix 6.2, and the Casal2 input files are available in Appendix 6.3.

Table 5 Biological parameters used in the simple Casal2 model of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4.

Relationship	Parameter	Value		Source
		Female	Male	
Natural mortality	$M(y^{-1})$	0.13		Dunn & Devine (2024)
Growth (exponential)	g_{α}	14.40	16.06	Adapted from VBGF in Dunn & Devine (2024)
	g_{β}	0.84	0.35	
	L_{α}	2.5	2.5	
	L_{β}	172.5	162.5	
	CV	1.0	1.3	Adapted to approximate the VBGF
Length-weight	$a (kg\ cm^{-1})$	1.995e-05	1.640e-05	This assessment
	b	2.878	2.907	
Maturity	L_{50}	135	109	Parker & Mariott (2012)
	L_{t095}	29	28	
Steepness	h	0.75		Dunn & Devine (2024)
Unfished biomass	B_0	7370		This assessment Maximum biomass estimated across the time series (2014 estimate + CI)

Following the MCMC estimation, the model was projected forward for 35 years assuming constant catches based on different initial harvest rates (U_{VB}):

$$C = U_{VB} \times VB_{2021-2025}$$

Where C is catch, and VB is vulnerable biomass. In order to set a fixed catch across the projection period, VB was estimated as the geometric mean over the past five years. Future year class strengths were assumed to be average. The model was projected forward with different catches based on a of U_{VB} ranging from the current 3.8 % to 15 %. Given that Antarctic toothfish in Subarea 48.4 may be part of a larger stock (Söffker *et al.* 2018), with a significant portion of

the SSB possibly existing outside the VB, we analysed the effects of projected catch on both SSB and VB. We used 50% VB_0 as a reference point, analogous to the CCAMLR Decision Rule reference of 50% B_0 .

3 Results

3.1 Chapman assessment

The estimated stock biomass obtained using the Chapman method remains variable (Table 6). The geometric mean of the estimates of biomass in the past five years was 846 tonnes. Applying the agreed harvest rate of 3.8 % to the five-year average results in a catch limit of 32 tonnes.

Figure 5 shows the annual biomass estimates and the associated variance, where the dashed horizontal line represents the five-year biomass estimate at 846 tonnes and the dotted line represents 1,047 tonnes, which is the average biomass over the full timeseries.

Table 6 Biomass estimates of Antarctic toothfish in Subarea 48.4. Estimates are by year of tag recapture, using the Chapman method and restricting tag availability to three years.

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Biomass (tonnes)	478	502	1300	-	3462	655	1257	969	2301
Confidence intervals (tonnes)	213	320	1029	-	3908	312	605	517	1581

	2019	2020	2021	2022	2023	2024	2025
Biomass (tonnes)	1471	1585	744	648	1637	679	808
Confidence intervals (tonnes)	1076	1020	300	274	1201	280	362

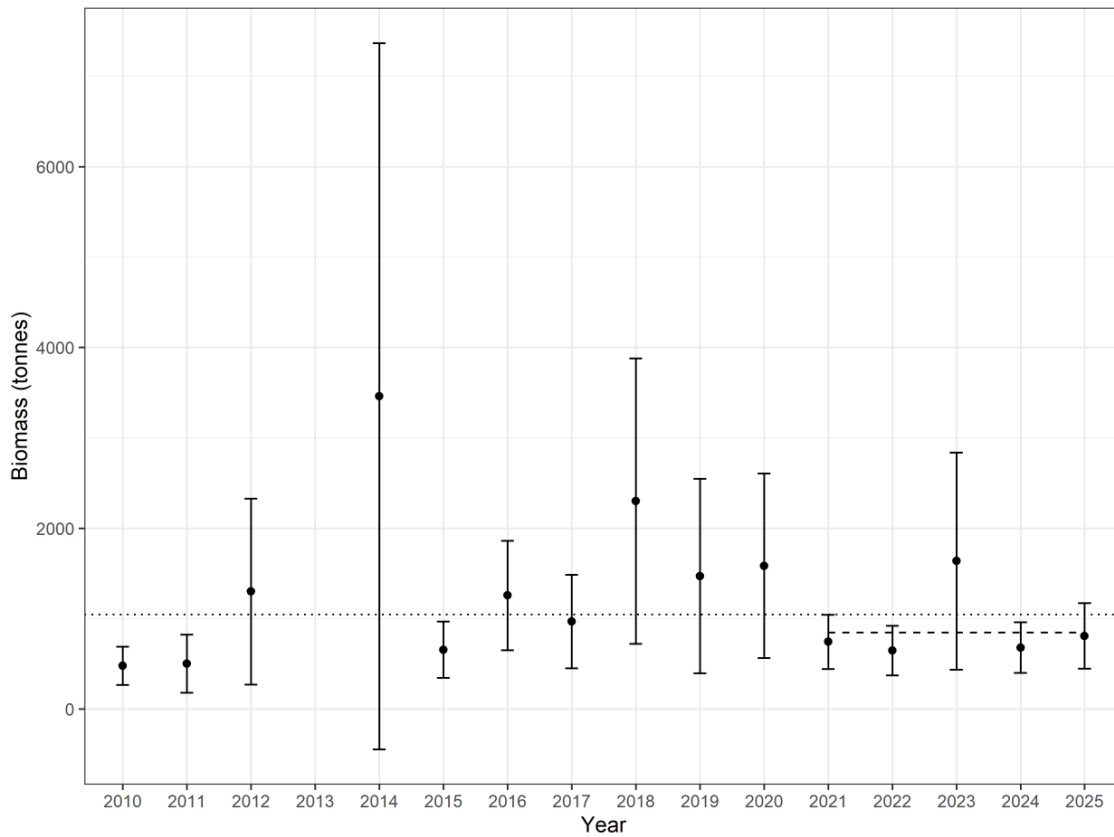


Figure 5 Stock assessment of Antarctic toothfish in Subarea 48.4. Produced using the Chapman method and restricting tag availability to three years (WG-FSA-14). Dashed line shows the five-year average biomass at 846 tonnes. Dotted line shows the historic average biomass at 1,047 tonnes.

3.2 Harvest rate (U_{VB})

The Casal2 model estimated fishery selectivities with a μ of 189.8 cm for females, and a μ of 173.5 cm for males (Figure 6). This, combined with the maturity ogives that have length at 50 % maturity of 135 cm and 109 cm respectively, means that the model estimated that a large proportion of the SSB (~90 %) are fish too small to be routinely caught in the fishery. Therefore, when projecting constant catch for 35 years, the median projected SSB did not fall below 90 % of B_0 , even when the catch was based on a harvest rate (U_{VB}) as high as 15 % (Figure 7). Considering a target of 50 % VB_0 , catches based on a U_{VB} of 12 % kept the 95 % credible intervals above 50 % VB_0 , while catches based on a U_{VB} of 15 % kept the median above 50 % VB_0 (Figure 8, Figure 9).

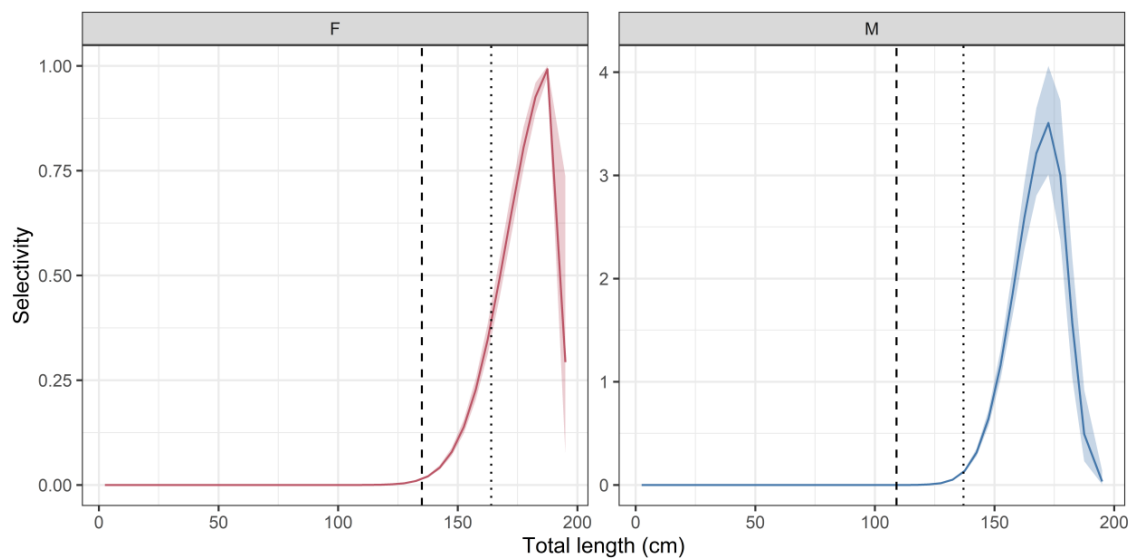


Figure 6 Selectivity for female (left) and male (right) Antarctic toothfish in Subarea 48.4. The dashed and dotted lines indicate length at 50 % maturity and length at 95 % maturity, respectively.

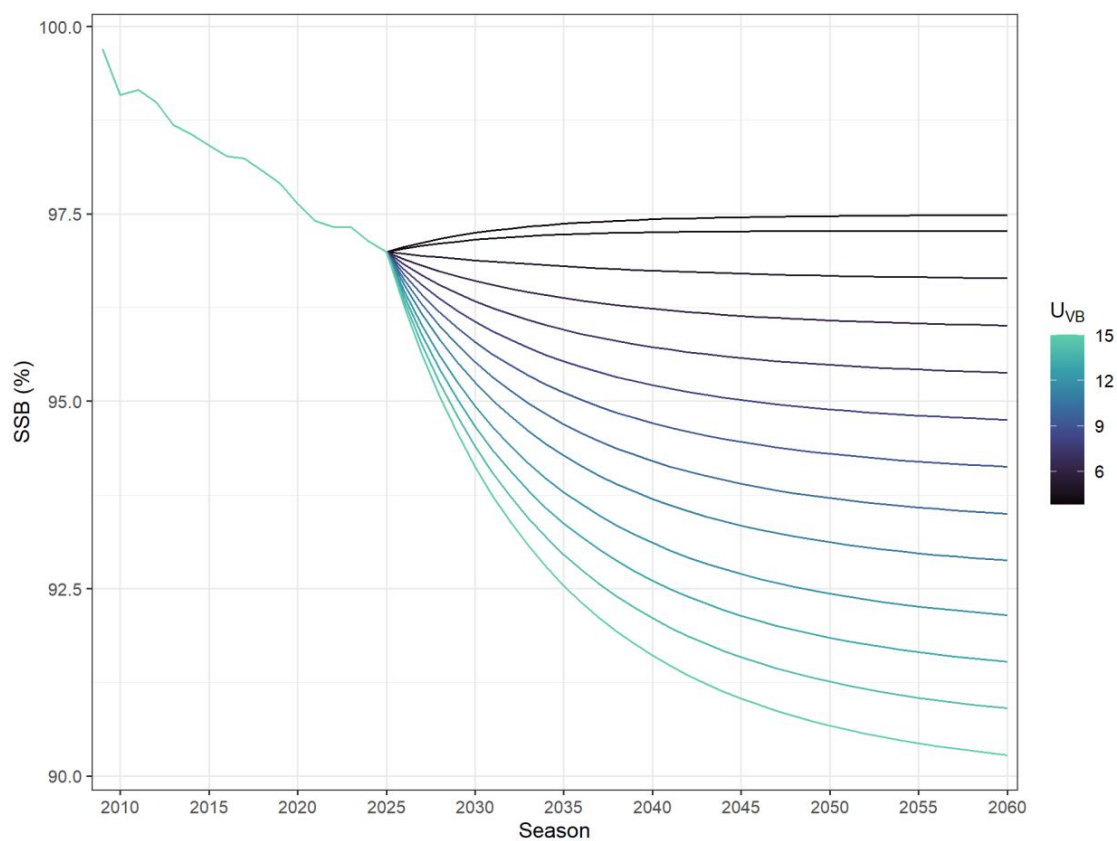


Figure 7 Projections of median spawning stock biomass (SSB) of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4. SSB is given percentage of B_0 at different harvest rates (U_{VB}). U_{VB} ranges from the current 3.8 % to 15 %.

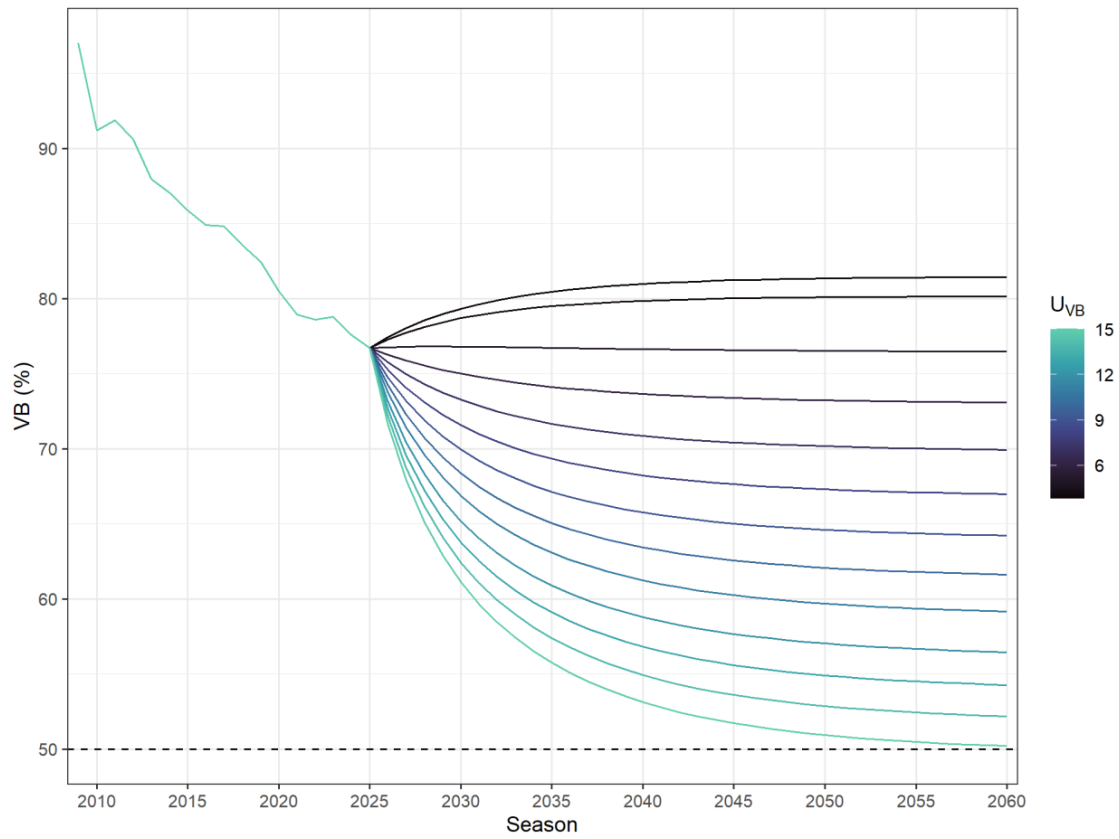


Figure 8 Projections of median vulnerable biomass (VB) of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4. VB is given percentage of VB_0 at different harvest rates (U_{VB}). U_{VB} ranges from the current 3.8 % to 15 %. The dashed line indicates 50 % VB_0 , an analogue of the reference point used in the CCAMLR Decision Rule.

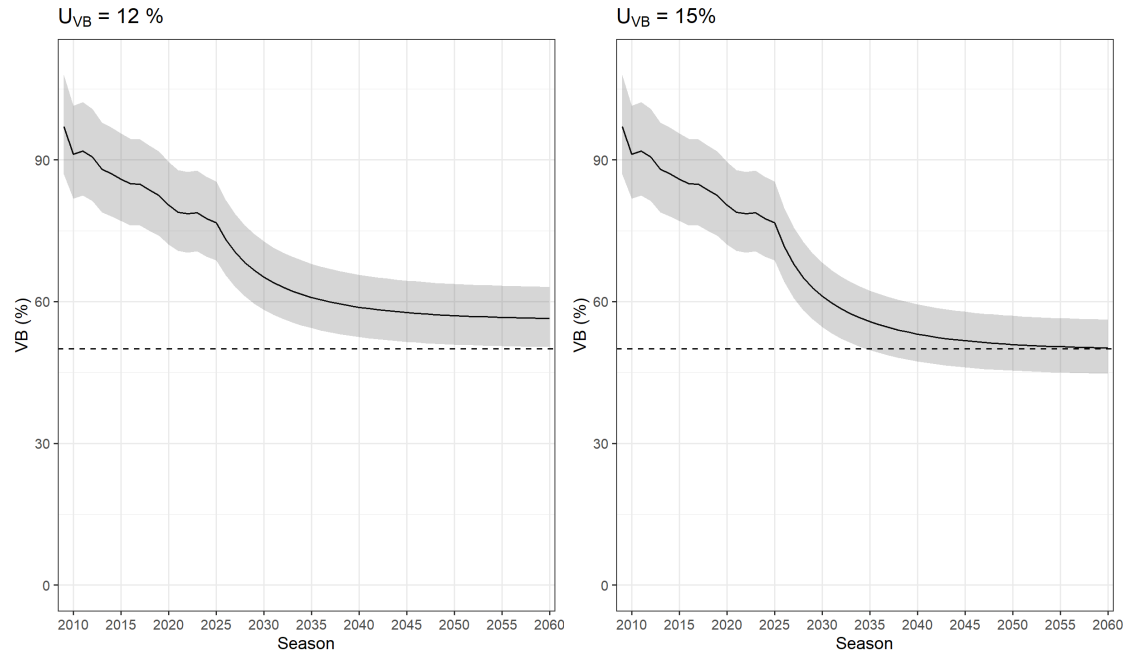


Figure 9 Projections of vulnerable biomass (VB) of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4. VB is given as percentage of VB_0 at a catch chosen to achieve a harvest rate U_{VB} of 12 % (left) and 15 % (right). The black lines indicate the median, while the grey ribbons indicate 95 % credible intervals. The dashed line indicates 50 % VB_0 , an analogue of the reference point used in the CCAMLR Decision Rule.

4 Discussion

The 2025 biomass for Antarctic toothfish in Subarea 48.4 is estimated to be 808 tonnes. Application of the previously applied harvest rate for the stock of 3.8 % (CCAMLR, 2014) using the five-year average biomass of 846 tonnes, results in a yield of 32 tonnes. We recommend that this is used to set the catch limit for the 2025/26 season.

A general issue for the Antarctic toothfish stock assessment in Subarea 48.4 has been the low numbers of recaptures, prompting the move from Petersen to Chapman estimation formulation. The variability of tag returns in some years have resulted, for example, from low exploitation rates, spatial difference in the tag releases, overlap of fishing effort and population variation. Tags have been recaptured every year since 2013, with 5-33 tags recaptured in the past five years. Therefore, the average estimated biomass over the recent five-year time period is considered more robust than estimates for individual years.

4.1 Harvest rate (U_{VB}) and stock identity

The simple Casal2 model developed here indicates that the current harvest rate (U_{VB}) of 3.8 % is likely highly precautionary, having very little impact on SSB and ensuring that VB remains well above 50 %. Applying an analogue of the reference point of the CCAMLR Decision Rules in maintaining VB at 50 % VB_0 would result in a much higher harvest rate of 12 – 15 %. Much of the development of this simple Casal2 model relied on parameters borrowed from the Ross Sea region, which may not reflect the unique dynamics at play in Subarea 48.4, where the catch largely comprises large adults. This results in a mismatch between the fishery selectivity estimated by the Casal2 model and the maturity ogives from the Ross Sea region. Therefore, we do not propose to move away from the harvest rate of 3.8 % at this time.

The results of the Casal2 model highlight important questions with regards to the stock identity in Subarea 48.4. The Antarctic toothfish around the south of Subarea 48.4 have been hypothesised as being part of a much larger stock that extends south into Subareas 48.2, 48.6 and possibly 48.5 (Söffker *et al.*, 2018). Research fishing in the South of Subarea 48.4, and in Subarea 48.2 has shown a continuous distribution of Antarctic toothfish, confirming that the toothfish caught in Subarea 48.4 are part of a larger stock distribution extending into the region south of Subarea 48.3 (Söffker *et al.*, 2021). The Casal2 model suggested that only ~10 % of the SSB exists within the vulnerable biomass in the Subarea 48.4 fishery, supporting the hypothesis

that this forms a small part of a much larger stock. Historically, the approach has been to treat the Antarctic toothfish at Subarea 48.4 as a single assessment unit, with the Chapman estimates giving an estimation of local biomass. The Casal2 model provides evidence that the existing approach ensures that the stock is above CCAMLR's target. We welcome feedback on further developing management approaches for fisheries which form part of a larger stock.

4.2 Biological change indicators

Following the recommendation of SC-CAMLR-2023 paragraph 2.149, information is presented in Table 7 summarising the evidence for changes in stock assessment parameters or processes that could be due to the effects of environmental variability or climate change, following the template provided there. Particularly relevant for Antarctic toothfish in Subarea 48.4 is the clear northward shift of the boundary between this species and Patagonian toothfish (Thompson *et al.* 2025).

Table 7 Summary of evidence for changes in stock assessment parameters or processes that could be due to the effects of environmental variability or climate change.

Parameter or process	Evidence for trends and potential drivers
Recruitment	Recruitment does not form part of the Chapman estimator used in the stock assessment. However, recruitment forms a key part of the Casal2 model, and given that the Antarctic toothfish at Subarea 48.4 likely form part of a larger stock, this should be investigated in future.
Biomass	Estimates of biomass show some fluctuations over time, while remaining at a relatively consistent level. There is no evidence of these fluctuations linking to climate change.
Length-at-maturity	Length-at-maturity does not form part of the Chapman estimator used in the stock assessment. However, length-at-maturity is a key component of the Casal2 model. Currently, values are borrowed from the Ross Sea region, which may not reflect those in Subarea 48.4, nor any temporal change. Future work should look to investigate length-at-maturity in this Subarea.
Stock-recruit relationship	Stock-recruit relationships do not form part of the Chapman estimator used in the stock assessment. However, recruitment forms a key part of the Casal2 model, and given that the Antarctic toothfish at Subarea 48.4 likely form part of a larger stock, this should be investigated in future.

Natural mortality (<i>M</i>)	Natural mortality is estimated at 0.13. There is no information at present as to whether natural mortality is changing, and if this change can be attributed to climate change.
Growth rates	Growth rates do not form part of the Chapman estimator used in the stock assessment. However, growth is a key component of the Casal2 model. Currently, values are borrowed from the Ross Sea region, which may not reflect those in Subarea 48.4, nor any temporal change. Future work should look to investigate growth rates in this Subarea.
Length-weight relationship	The length-weight relationship forms a key component of the Chapman estimator and Casal2 models, and shows variation with year. Preliminary analysis (Appendix 6.4) shows a negative effect of year on the relationship, however, the effect size is small, and further work would be needed to link this to climate change.
Sex-ratio changes	Sex-ratios do not form part of the Chapman estimator used in the stock assessment. However, sex-ratio data suggest a decrease in the proportion of females since 2022, however, this remains in-line with regular fluctuations (Thompson <i>et al.</i> 2025).
Spatial distribution	There is clear evidence for a northward shift in the boundary between the Antarctic and Patagonian toothfish populations in Subarea 48.4. The CPUE of Antarctic toothfish is predicted to increase at latitudes of 60 to 57°S in Subarea 48.4 (Thompson <i>et al.</i> 2025).
Stock structure and spawning locations	The Antarctic toothfish around the south of Subarea 48.4 have been hypothesised as being part of a much larger stock that extends south into Subareas 48.2, 48.6 and possibly 48.5 (Söffker <i>et al.</i> , 2018). Given the catch in Subarea 48.4 mostly comprises older adults, spawning likely occurs elsewhere. Future work should investigate the natal origins of toothfish at Subarea 48.4.
Depredation	There is ongoing monitoring of depredation as part of the fishery, but depredation has not been observed in Subarea 48.4.

5 References

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6 Appendices

6.1 Distribution of fishing effort and tag releases

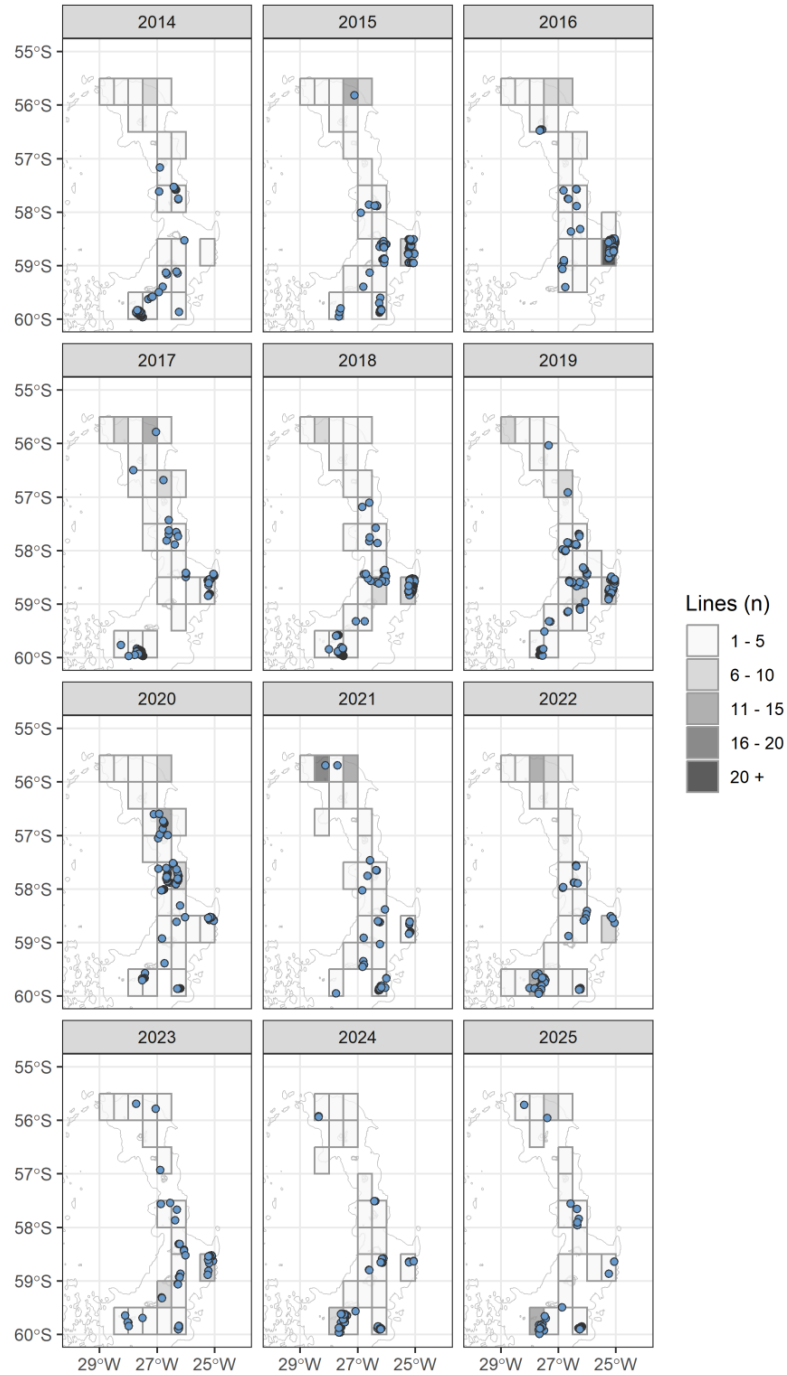


Figure 10 Fishing effort for toothfish in Subarea 48.4, as number of lines (shaded cells), overlaid with Antarctic toothfish tag release locations (blue dots) by year.

6.2 Diagnostics for Casal2 model

6.2.1 Female selectivity

Table 8 Diagnostic metrics for female selectivity parameters for Antarctic toothfish in Subarea 48.4. Includes the Gelman-Rubin diagnostic (*R*-hat), and bulk and tail effective sample size (*ESS*).

Parameter	R-hat	Bulk ESS	Tail ESS
μ	1.00	1134	2288
σ_L	1.00	1255	2253
σ_R	1.02	161	145

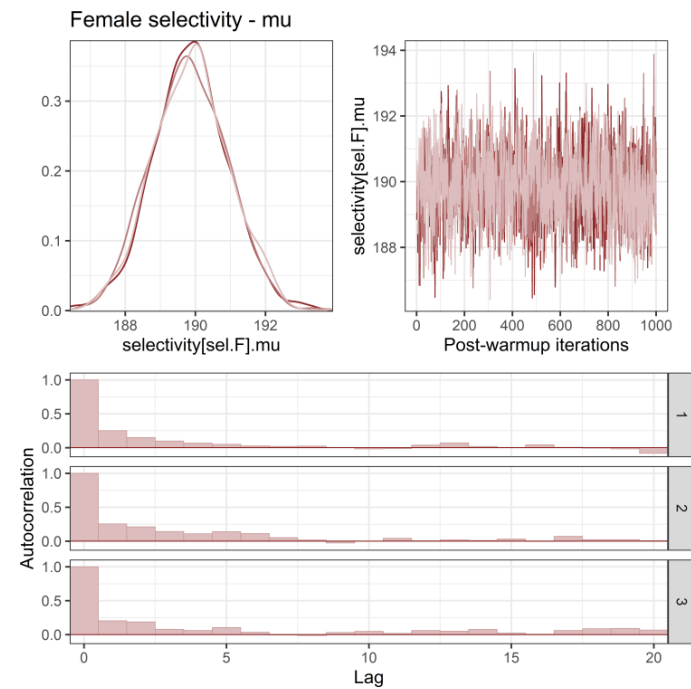


Figure 11 Diagnostic plots for μ of female selectivity of Antarctic toothfish in Subarea 48.4.

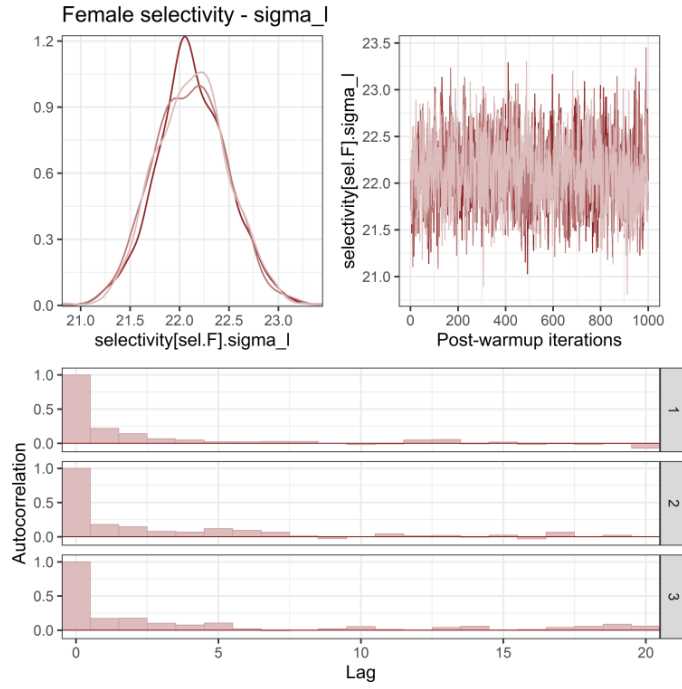


Figure 12 Diagnostic plots for σ_L of female selectivity of Antarctic toothfish in Subarea 48.4.

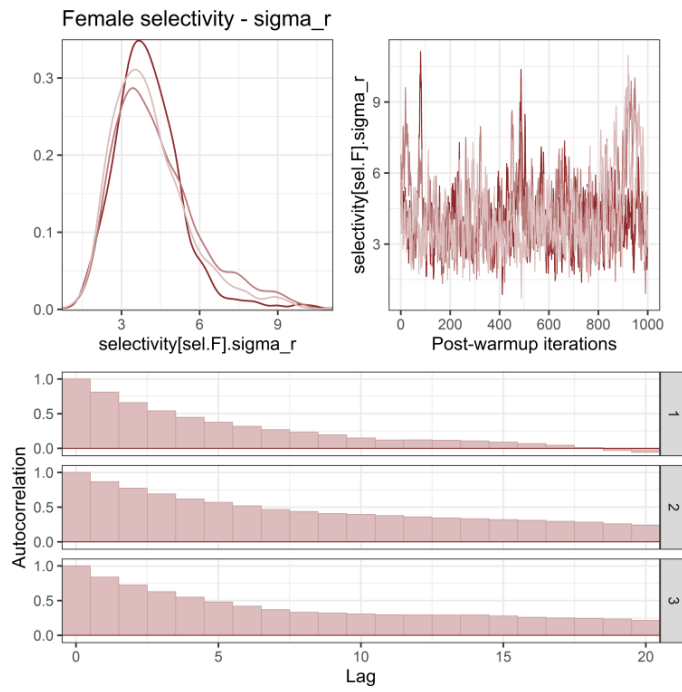


Figure 13 Diagnostic plots for σ_R of female selectivity of Antarctic toothfish in Subarea 48.4.

6.2.2 Male selectivity

Table 9 Diagnostic metrics for male selectivity parameters for Antarctic toothfish in Subarea 48.4. Includes the Gelman-Rubin diagnostic (R-hat), and bulk and tail effective sample size (ESS).

Parameter	R-hat	Bulk ESS	Tail ESS
μ	1.00	2936	2985
σ_L	1.00	2909	2940
σ_R	1.00	2853	2788
α	1.00	2226	2491

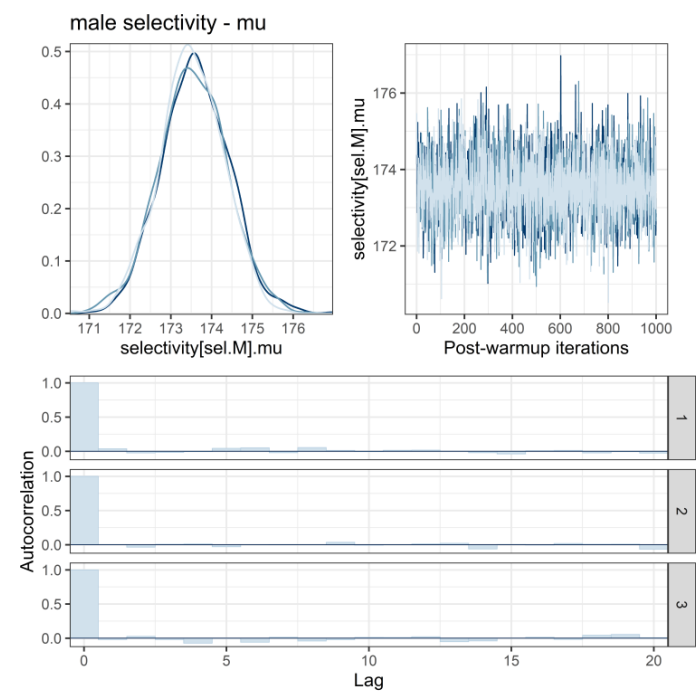


Figure 14 Diagnostic plots for μ of male selectivity of Antarctic toothfish in Subarea 48.4.

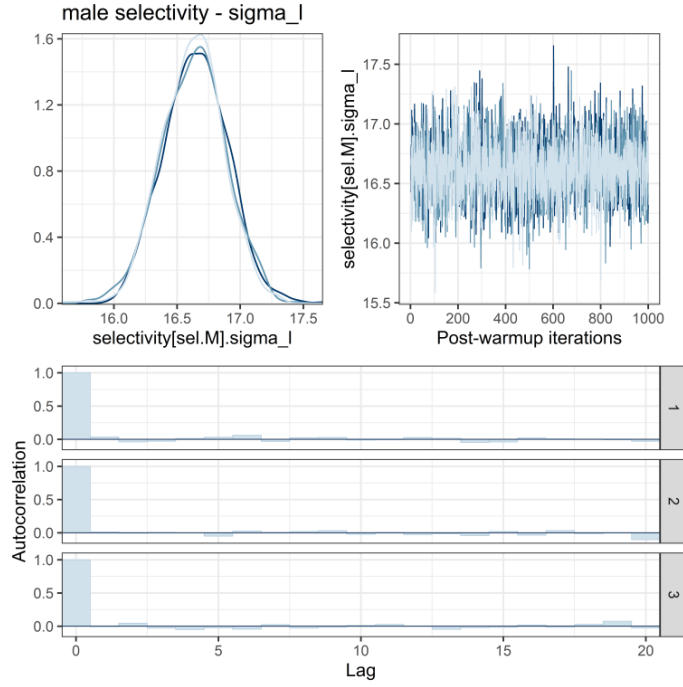


Figure 15 Diagnostic plots for σ_I of male selectivity of Antarctic toothfish in Subarea 48.4.

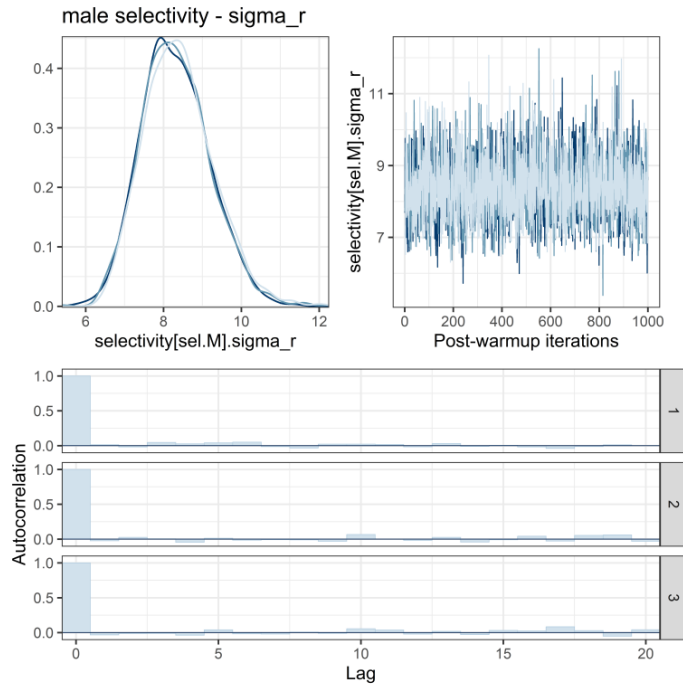


Figure 16 Diagnostic plots for σ_r of female selectivity of Antarctic toothfish in Subarea 48.4.

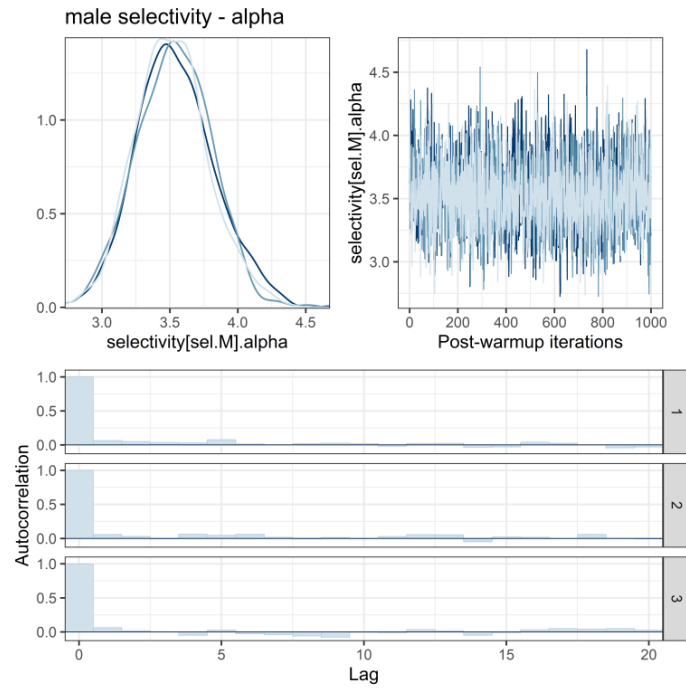


Figure 17 Diagnostic plots for α of male selectivity of Antarctic toothfish in Subarea 48.4.

6.2.3 Vulnerable biomass

Table 10 Diagnostic metrics for vulnerable biomass estimates for Antarctic toothfish in Subarea 48.4. Includes the Gelman-Rubin diagnostic (R-hat), and bulk and tail effective sample size (ESS).

Year	R-hat	Bulk ESS	Tail ESS
Initial	1.00	1372	2343
2009	1.00	1361	2324
2010	1.00	1341	2341
2011	1.00	1344	2389
2012	1.00	1340	2340
2013	1.00	1329	2420
2014	1.00	1326	2305
2015	1.00	1321	2305
2016	1.00	1320	2187
2017	1.00	1323	2217
2018	1.00	1318	2187
2019	1.00	1315	2333
2020	1.00	1311	2412
2021	1.00	1306	2385
2022	1.00	1307	2282
2023	1.00	1311	2282
2024	1.00	1307	2258
2025	1.00	1306	2258

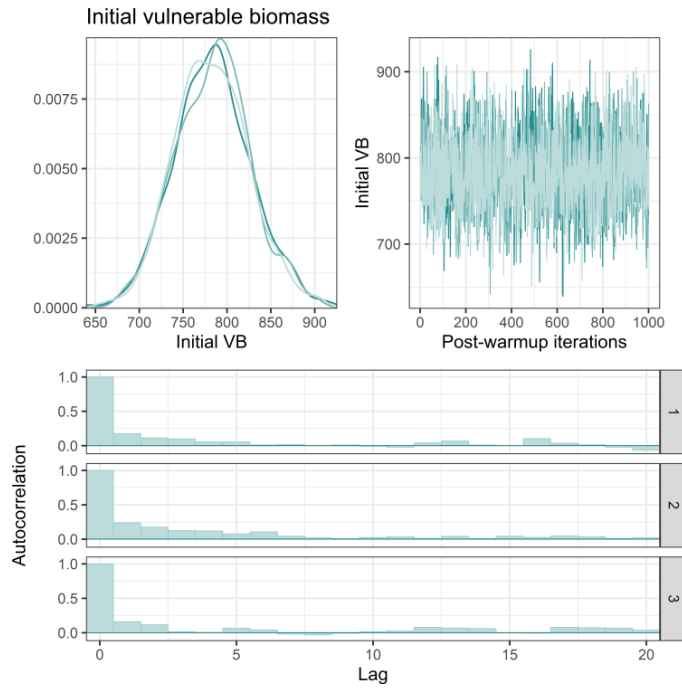


Figure 18 Diagnostic plots for initial vulnerable biomass of Antarctic toothfish in Subarea 48.4.

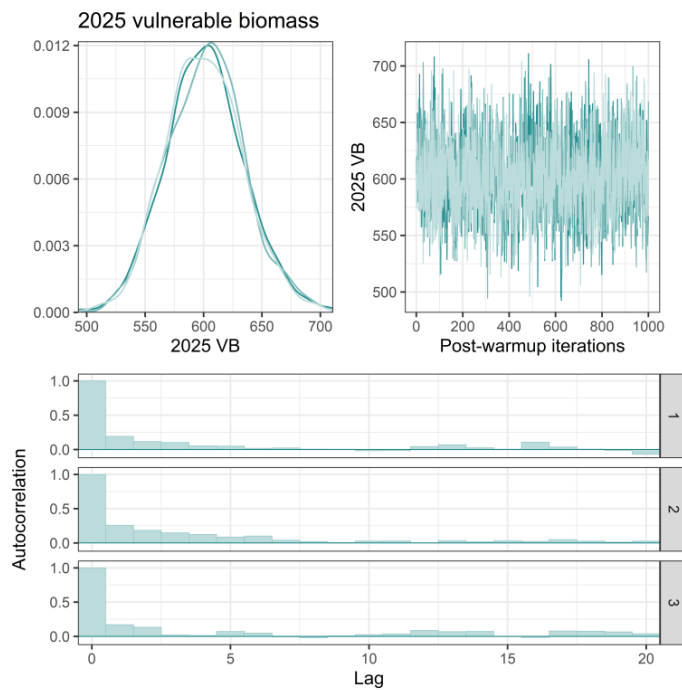


Figure 19 Diagnostic plot for vulnerable biomass of Antarctic toothfish in Subarea 48.4 in 2025. This is given as an example of yearly estimates of vulnerable biomass from the Casal2 model.

6.3 Casal2 input files

6.3.1 Population

```
#### Population definition ####

# Model definition
@model
  type length # essential for a length-based model
  start_year 2009
  final_year 2025
  projection_final_year 2060
  base_weight_units tonnes
  length_bins 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 10
0 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190
  length_plus true
  length_plus_group 195
  initialisation_phases init
  time_steps annual

# Categories
@categories
  format stock.sex
  names TOA.F TOA.M
  growth_increment growth.F growth.M

## Time steps

@initialisation_phase init # init for 100 years, check for convergence at
80 and 100
  type iterative
  years 100
  lambda 0.0001
  convergence_years 80 100

@time_step annual # single timestep containing all processes
  processes recruitment growth.F growth.M fishing

## Processes

@process recruitment
  type recruitment_beverton_holt
  categories TOA.F TOA.M
  proportions 0.52 0.48 # sex ratio from characterisation
  b0 7370 # max biomass estimation (2014)
  steepness 0.75
  ssb_offset 7 # recruitment age in model
  initial_mean_length 85 # age 7
  initial_length_cv 0.3 # lowest possible without causing convergence issu
es
  recruitment_multipliers 1*17
  ssb SSB
```

```

@process fishing
  type mortality_instantaneous
  categories TOA.F TOA.M
  m 0.13 # from TOA RSR stock annex
  relative_m_by_length one
  time_step_proportions 1.0
  biomass true

  table catches
  year  catch
  2009  26.176
  2010  56.210
  2011   3.155
  2012  21.818
  2013  36.909
  2014  23.889
  2015  27.640
  2016  27.775
  2017  19.388
  2018  31.928
  2019  33.056
  2020  43.894
  2021  43.131
  2022  32.074
  2023  25.949
  2024  42.036
  2025  40.591
  end_table

  table method
  method category selectivity u_max time_step penalty
  catch TOA.F sel.F 0.99 annual fishing_penalty
  catch TOA.M sel.M 0.99 annual fishing_penalty
  end_table

@process growth.F
  type growth
  categories TOA.F

@process growth.M
  type growth
  categories TOA.M

## Selectivities

@selectivity one
  type constant
  c 1.0

@selectivity maturity.F # from Parker & Mariott 2012 (WG-FSA)
  type logistic
  a50 135
  ato95 29

```

```

@selectivity maturity.M # from Parker & Mariott 2012 (WG-FSA)
  type logistic
  a50 109
  ato95 28

@selectivity sel.F
  type double_normal
  mu 145 # mean length in fishery
  sigma_l 10
  sigma_r 10
  alpha 1.0

@selectivity sel.M
  type double_normal
  mu 145 # mean length in fishery
  sigma_l 10
  sigma_r 10
  alpha 1.0

## Biological parameters

@growth_increment growth.F
  type exponential
  l_alpha 2.5 # first length bin
  l_beta 172.5 # last length bin
  g_alpha 14.40 # growth at start
  g_beta 0.84 # growth at end
  cv 1.0 # from RSR VBGF
  min_sigma 0.1
  distribution normal
  length_weight lw.F

@growth_increment growth.M
  type exponential
  l_alpha 2.5
  l_beta 162.5
  g_alpha 16.06
  g_beta 0.35
  cv 1.3
  min_sigma 0.1
  distribution normal
  length_weight lw.M

@length_weight lw.F # from assessment
  type basic
  a 1.995022e-05
  b 2.878312
  units kgs

@length_weight lw.M # from assessment
  type basic
  a 1.640175e-05
  b 2.907542

```

```

units kgs

## Derived quantities

@derived_quantity SSB
  type biomass
  time_step annual
  time_step_proportion 1.0
  time_step_proportion_method weighted_sum
  categories TOA.F TOA.M
  selectivities maturity.F maturity.M

@derived_quantity vulnerable_biomass
  type biomass
  time_step annual
  time_step_proportion 1.0
  time_step_proportion_method weighted_sum
  categories TOA.F TOA.M
  selectivities sel.F sel.M

```

6.3.2 Estimation

```

#### Estimation ####

@minimiser adolc # from base model (MSE am)
  type adolc
  tolerance 0.00001
  iterations 1000
  covariance true
  active true

# MCMC

@mcmc mcmc
  type random_walk
  start 0
  length 1100000
  keep 1000
  step_size 0.02
  adapt_stepsize_at 10000 20000 50000 100000
  proposal_distribution t
  adapt_stepsize_method ratio
  burn_in 100000

@estimate sel_mu.F
  type uniform
  parameter selectivity[sel.F].mu
  lower_bound 20
  upper_bound 200

@estimate sel_sigma_l.F
  type uniform
  parameter selectivity[sel.F].sigma_l
  lower_bound 0
  upper_bound 30

```

```

@estimate sel_sigma_r.F
  type uniform
  parameter selectivity[sel.F].sigma_r
  lower_bound 0
  upper_bound 30

@estimate sel_mu.M
  type uniform
  parameter selectivity[sel.M].mu
  lower_bound 20
  upper_bound 200

@estimate sel_sigma_l.M
  type uniform
  parameter selectivity[sel.M].sigma_l
  lower_bound 0
  upper_bound 30

@estimate sel_sigma_r.M
  type uniform
  parameter selectivity[sel.M].sigma_r
  lower_bound 0
  upper_bound 30

@estimate sel_alpha.M
  type uniform
  parameter selectivity[sel.M].alpha
  lower_bound 0
  upper_bound 5

@penalty fishing_penalty
  type process
  log_scale true
  multiplier 10000

@catchability catchability # fix to 1
  type nuisance
  lower_bound 1.0
  upper_bound 1.0

```

6.3.3 Observation

Observation

```
@observation length_comp
  type process_removals_by_length
  method_of_removal catch
  mortality_process fishing
  years 2009:2025
  categories TOA.F TOA.M
  length_bins 70 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
160 165 170 175 180 185 190
  likelihood multinomial
  time_step annual
  table obs
#length_bins    70  85  90  95  100 105 110 115 120 125 130 135 140 145 15
0 155 160 165 170 175 180 185 190 70  80  90  95  100 105 110 115 120 125
130 135 140 145 150 155 160 165 170 175 180 185 190
2009    0    0    0    0    0.001612903 0    0.003225806 0.008064516 0.00161290
3 0.003225806 0.009677419 0.041935484 0.046774194 0.04516129 0.077419355
0.087096774 0.080645161 0.046774194 0.033870968 0.024193548 0.009677419 0.
008064516 0    0    0    0    0    0    0.001612903 0.008064516 0.012903226
0.016129032 0.016129032 0.037096774 0.038709677 0.072580645 0.075806452 0.
085483871 0.048387097 0.037096774 0.014516129 0.001612903 0    0.003225806
0.001612903
2010    0    0    0.001191895 0    0    0.001191895 0.001191895 0.00476758 0.
005959476 0.008343266 0.019070322 0.025029797 0.046483909 0.069129917 0.07
8665077 0.087008343 0.076281287 0.0488677 0.028605483 0.007151371 0.0023
8379 0.00238379 0.00238379 0    0    0    0.001191895 0.00238379 0.001191
895 0.00238379 0.003575685 0.008343266 0.026221692 0.033373063 0.03814064
4 0.045292014 0.070321812 0.057210965 0.072705602 0.05601907 0.045292014
0.013110846 0.00476758 0.001191895 0    0.001191895
2011    0    0    0    0    0    0    0    0    0.014084507 0.028169014 0.0281
69014 0.014084507 0.070422535 0.056338028 0.056338028 0.098591549 0    0.04
2253521 0    0    0    0    0    0    0    0    0.014084507 0    0    0.
042253521 0.042253521 0.126760563 0.070422535 0.126760563 0.084507042 0.05
6338028 0    0.028169014 0    0    0
2012    0    0    0    0    0    0.004524887 0.018099548 0.013574661 0.0180
99548 0.018099548 0.045248869 0.036199095 0.027149321 0.058823529 0.049773
756 0.049773756 0.022624434 0.013574661 0.018099548 0    0    0    0
0    0    0.009049774 0    0.013574661 0.027149321 0.040723982 0.05882352
9 0.07239819 0.122171946 0.104072398 0.076923077 0.036199095 0.031674208
0.009049774 0    0.004524887 0    0
2013    0    0    0.002028398 0    0    0.002028398 0    0.004056795 0.00202839
8 0.004056795 0.006085193 0.026369168 0.036511156 0.054766734 0.079107505
0.081135903 0.073022312 0.056795132 0.024340771 0.020283976 0.002028398 0.
004056795 0    0    0.002028398 0.002028398 0.002028398 0    0.002028398
0    0.006085193 0.006085193 0.014198783 0.038539554 0.064908722 0.08519269
8 0.060851927 0.107505071 0.062880325 0.038539554 0.016227181 0.00811359
0.002028398 0.002028398 0
2014    0.004065041 0    0    0    0    0.004065041 0    0.004065041 0    0.
008130081 0.028455285 0.040650407 0.06504065 0.069105691 0.105691057 0.06
9105691 0.012195122 0.028455285 0.020325203 0.008130081 0    0    0    0
```

0.004065041 0 0.004065041 0 0 0.012195122 0.024390244 0.016260163 0.
 032520325 0.081300813 0.093495935 0.06504065 0.073170732 0.044715447 0.04
 8780488 0.020325203 0.012195122 0 0 0
 2015 0 0 0 0 0 0 0 0 0 0 0.034682081 0.02890173
 4 0.098265896 0.098265896 0.104046243 0.075144509 0.052023121 0.034682081
 0 0 0.005780347 0 0 0 0 0 0 0 0 0 0.01734104
 0.057803468 0.057803468 0.075144509 0.098265896 0.057803468 0.052023121 0.
 040462428 0 0.011560694 0 0 0
 2016 0 0 0 0 0 0 0 0.005025126 0.005025126 0.010050251 0.
 015075377 0.045226131 0.085427136 0.095477387 0.090452261 0.095477387 0.03
 0150754 0.045226131 0.015075377 0 0 0 0 0 0 0 0 0 0
 0.005025126 0.010050251 0.015075377 0.015075377 0.070351759 0.085427136 0.
 065326633 0.085427136 0.08040201 0.020100503 0 0.005025126 0.005025126
 0 0 0
 2017 0 0 0 0.004694836 0 0.004694836 0 0 0 0.004694836 0.
 023474178 0.028169014 0.046948357 0.093896714 0.0657277 0.126760563 0.07
 0422535 0.051643192 0.014084507 0.014084507 0.004694836 0 0 0 0 0
 0 0 0 0.004694836 0.004694836 0.009389671 0.028169014 0.04225352
 1 0.042253521 0.079812207 0.079812207 0.084507042 0.046948357 0.018779343
 0 0.004694836 0 0 0
 2018 0 0 0.001234568 0 0 0 0 0 0.002469136 0.004938272 0.
 014814815 0.025925926 0.058024691 0.064197531 0.066666667 0.067901235 0.05
 4320988 0.030864198 0.017283951 0.007407407 0.003703704 0.002469136 0 0
 0 0.001234568 0.001234568 0 0.002469136 0.004938272 0.007407407 0.0098
 76543 0.020987654 0.038271605 0.066666667 0.064197531 0.079012346 0.083950
 617 0.081481481 0.067901235 0.022222222 0.014814815 0.009876543 0 0.0012
 34568 0
 2019 0 0.001375516 0 0 0 0 0 0 0.008253095 0.01788170
 6 0.028885832 0.031636864 0.067400275 0.097661623 0.09215956 0.05914718
 0.048143054 0.030261348 0.006877579 0.005502063 0 0 0 0 0 0
 0.001375516 0.001375516 0 0.008253095 0.012379642 0.012379642 0.026134801
 0.035763411 0.078404402 0.070151307 0.088033012 0.07565337 0.045392022 0.
 027510316 0.015130674 0.005502063 0.001375516 0 0
 2020 0 0 0 0 0 0 0 0 0.007827789 0.01369863 0.01956947
 2 0.023483366 0.064579256 0.072407045 0.078277886 0.074363992 0.068493151
 0.023483366 0.017612524 0.007827789 0.003913894 0 0 0 0 0 0
 0 0 0.007827789 0.01369863 0.029354207 0.037181996 0.043052838 0.0724
 07045 0.072407045 0.078277886 0.076320939 0.031311155 0.037181996 0.013698
 63 0.007827789 0.003913894 0 0
 2021 0 0 0 0 0 0 0 0.003012048 0.006024096 0.009036145 0.
 018072289 0.030120482 0.048192771 0.087349398 0.084337349 0.054216867 0.04
 2168675 0.027108434 0.012048193 0.006024096 0.003012048 0 0 0 0 0
 0.003012048 0 0 0.012048193 0.006024096 0.006024096 0.027108434 0.0180
 72289 0.069277108 0.093373494 0.078313253 0.090361446 0.063253012 0.057228
 916 0.024096386 0.018072289 0.003012048 0 0 0
 2022 0 0 0 0 0 0 0.002364066 0 0.002364066 0.01891253 0.
 021276596 0.042553191 0.06855792 0.078014184 0.087470449 0.087470449 0.06
 1465721 0.033096927 0.011820331 0.007092199 0.004728132 0 0 0 0 0
 0 0.004728132 0 0.009456265 0.011820331 0.009456265 0.01891253 0.0425
 53191 0.044917258 0.06855792 0.070921986 0.096926714 0.035460993 0.037825
 059 0.011820331 0.004728132 0.002364066 0.002364066 0 0
 2023 0 0 0 0 0 0 0 0 0.008379888 0.011173184 0.0363
 12849 0.061452514 0.072625698 0.089385475 0.078212291 0.067039106 0.055865
 922 0.016759777 0.005586592 0.005586592 0 0.002793296 0.002793296 0 0

```

0 0 0 0 0.011173184 0.016759777 0.030726257 0.055865922 0.05865921
8 0.053072626 0.069832402 0.047486034 0.067039106 0.022346369 0.027932961
0.011173184 0.005586592 0.005586592 0.002793296 0
2024 0 0.002906977 0 0 0 0 0.002906977 0.005813953 0 0.
005813953 0.034883721 0.055232558 0.052325581 0.090116279 0.081395349 0.05
8139535 0.026162791 0.014534884 0.01744186 0 0.002906977 0 0 0.0029
06977 0 0 0 0.00872093 0.00872093 0.00872093 0.023255814 0.03
4883721 0.063953488 0.069767442 0.075581395 0.101744186 0.081395349 0.0377
90698 0.011627907 0.01744186 0.002906977 0 0 0
2025 0 0 0 0 0 0 0.003267974 0.003267974 0 0.009803922 0.
019607843 0.019607843 0.071895425 0.094771242 0.049019608 0.058823529 0.05
5555556 0.026143791 0.009803922 0.006535948 0 0 0 0 0 0 0
0 0 0.009803922 0.013071895 0.026143791 0.049019608 0.065359477 0.0588
23529 0.107843137 0.104575163 0.075163399 0.029411765 0.013071895 0.013071
895 0 0.003267974 0.003267974 0
end_table
table error_values # number of fish measured
2009 620
2010 839
2011 71
2012 221
2013 493
2014 246
2015 173
2016 199
2017 213
2018 810
2019 727
2020 511
2021 332
2022 423
2023 358
2024 344
2025 306
end_table

@observation chap_biomass # biomass from Chapman estimator
type biomass
time_step annual
categories TOA.F + TOA.M
catchability catchability
likelihood lognormal
selectivities sel.F sel.M
years 2010 2011 2012 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2
024 2025
table obs
2010 478 0.23 # CV from Chapman
2011 502 0.31
2012 1300 0.40
2014 3462 0.57
2015 655 0.24
2016 1257 0.24
2017 969 0.27
2018 2301 0.35

```

```

2019 1471 0.37
2020 1585 0.33
2021 744 0.20
2022 648 0.22
2023 1637 0.37
2024 679 0.21
2025 808 0.23
end_table

```

6.3.4 Report

```

#### Report ####

@report default
  type default
  selectivities true
  derived_quantities true
  observations true
  processes true
  catchabilities FALSE
  time_varying true
  parameter_transformations true

@report est
  type estimate_value

@report covariance_matrix
  type covariance_matrix

@report hessian_matrix
  type hessian_matrix

@report mcmc_samples
  type mcmc_sample

@report mcmc_objectives
  type mcmc_objective

@report partitions
  type Partition
  time_step annual

```

6.3.5 Projection

```

#### Projection ####

@project future_catch
  type constant
  parameter process[fishing].method_catch
  years 2026:2060
  values 23 #  $U_{VB} = 0.038$ 

@project future_recruitment
  type empirical_sampling # which method to use

```

```
parameter process[recruitment].recruitment_multipliers  
years 2026:2060  
multiplier 1.0  
start_year 2009  
final_year 2025
```

6.4 Effect of year on length-weight relationship

To test for changes in the length-weight relationship of Antarctic toothfish in Subarea 48.4 over time, we added season as a covariate to the standard length-weight model:

$$W = Sc + aL^b$$

Where S is season as a numeric value between 2009 and 2025, and c is the effect of season.

The results of the model are given in Table A1.

Parameter	Estimate ± SE	t-value	p-value
c	-6.084e-02 ± 1.476e-02	-4.122	<0.001
a	1.651e-05 ± 2.153e-06	7.669	<0.001
b	2.917 ± 2.544e-02	114.637	<0.001

Additional Resources

- Fishery Summary: [pdf](#), [html](#)
- Fishery Report: [pdf](#), [html](#)
- Species Description for Patagonian Toothfish: [pdf](#), [html](#)
- Species Description for Antarctic Toothfish: [pdf](#), [html](#)
- Stock Annex for Patagonian Toothfish: [pdf](#)
- [Fisheries Documents Browser](#)