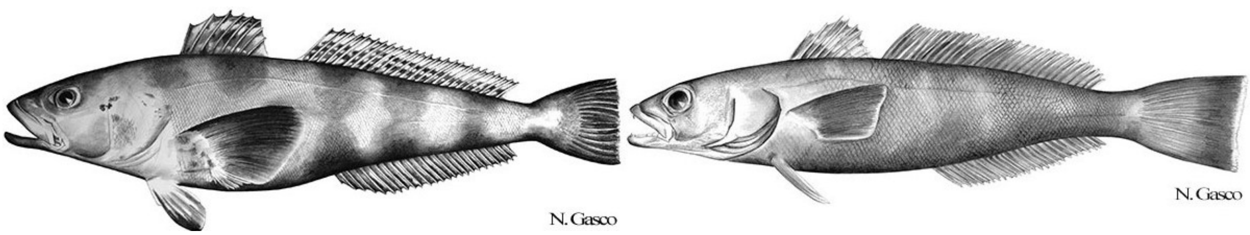
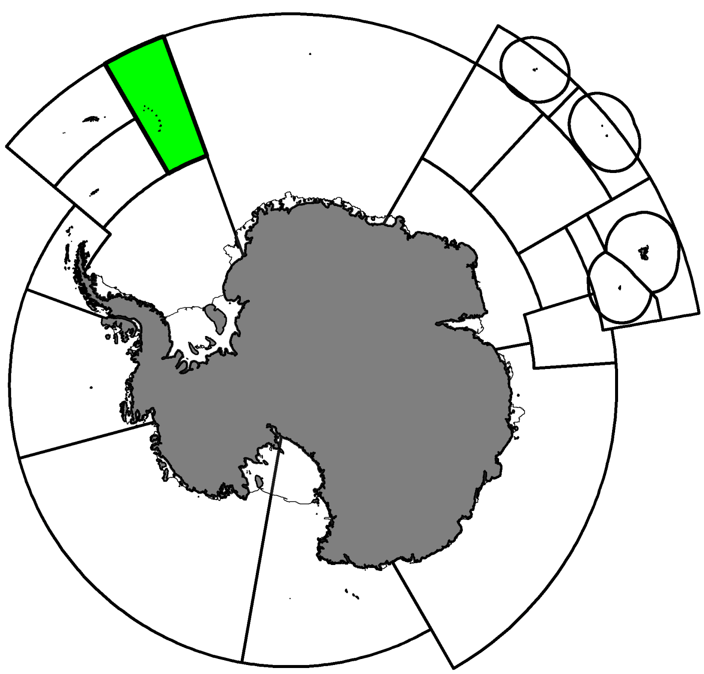
Stock Assessment Report 2024: *Dissostichus eleginoides* and *Dissostichus mawsoni* in Subarea 48.4

CCAMLR Secretariat

30 April 2025



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.

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Assessment of Patagonian Toothfish (Dissostichus eleginoides) in Subarea 48.4

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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 2021 and 2022 seasons[1]. Projections indicate that the stock was at 59.5% of B_0 in 2023 and that a yield of 19 tonnes in 2024 and 2025 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 Casal2 stock assessment replace the CASAL stock assessment as the basis for providing catch advice for this stock, and the migration to Casal2 be regarded as complete,
2. that the catch limit for *D. eleginoides* in Subarea 48.3 should be set at 19 tonnes for 2023/24 and 2024/25.

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 2021 and 2022 seasons. The history of the stock assessment is outlined in the Stock Annex (Readdy *et al.*, 2023). In 2023, after an initial run in CASAL with the inclusion of 2021 and 2022 data and minor corrections to historic data (see bullet points below), further developments towards the 2023 final assessment were carried out in Casal2 (Table 1.2), as recommended by CCAMLR (WG-SAM-2023, para 6.46). In addition to the change in software, the following changes have been implemented since the assessment presented at WG-FSA-2021 (Earl & Readdy, 2021):

Data revisions

- Revision of catch sample size in year 2014.
- Revision of the raised catch age compositions in years 2013, 2015 and 2016.
- Revision of the Tag Recaptures at length in years (release-recapture year) 2007-2009, 2009-2013.
- Revision of the estimated scanned lengths in years 2007 to 2017.
- Revision of the Tag Releases in years 2005 to 2014.

[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.

Casal2 implementation

- Update of length-weight parameters and tag loss rate.
- Update of the maturity vector used.

Table 1.1. 2023 assessment development.

Software model run	Objective	Model run
2021 assessment (Earl and Readdy, 2021)	Base model.	Run10
CASAL 2023 base case	Initial run adding additional years of data (2021 and 2022).	Run11
CASAL data corrections	Revision of historic input data.	Run12
Casal2 compatibility	Replicate the results from CASAL [Run12] in Casal2.	Run21
Casal2 biology	Updated length-weight parameters and maturity ogive. Minor update to tag loss rate following Marsh *et al*. (2022a).	Run22
Casal2 recruitment	Investigate the effect of moving to the simplex method of estimating recruitment strength and removing the "CASAL compatibility" option applied to the tag releases.	Run23

Historically catches fluctuated from 18.7 tonnes (2006) to 97.6 tonnes (2008), generally averaging around 40 tonnes, but have been lower since 2018 with catches of 15.9 tonnes in 2021 and 13.8 tonnes in 2022 (Table 1.1). Since 2016, catches have declined in line with the revised assessment and application of the CCAMLR Decision Rule targets. CPUE data for *D. eleginoides*, across all vessels and the whole of Subarea 48.4, fluctuate without an overall trend (Table 1.2). Fishing effort by season is shown in Annex 1.

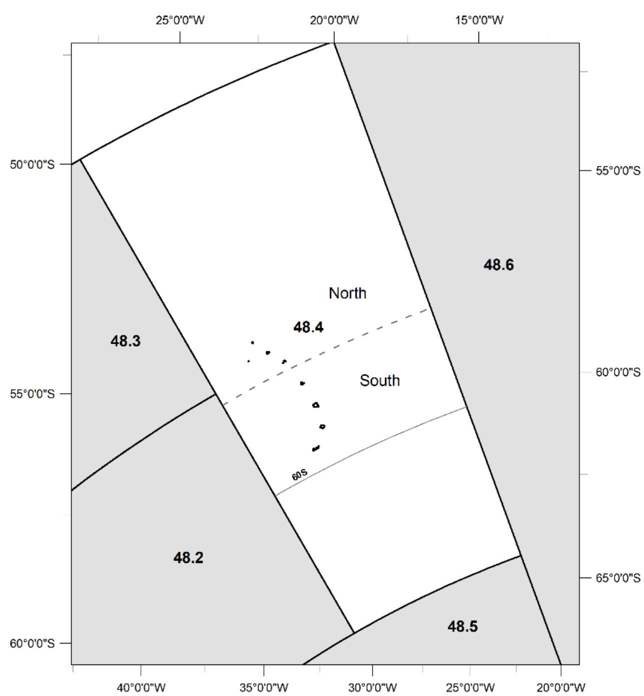

Figure 1.1. Map of Subarea 48.4. Dashed line at 57.33˚S indicates previous North and South rectangles, which since 2012 have been combined into a single assessment.

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 CASAL 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.

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	0.09
2010	39.77	0.15	57.47	0.08
2011	35.81	0.09	38.65	0.08
2012	44.10	0.10	55.41	0.10
2013	61.94	0.18	72.35	0.13
2014	41.67	0.30	43.84	0.21
2015	40.89	0.18	41.70	0.15
2016	40.42	0.13	41.60	0.10
2017	25.79	0.09	27.91	0.07
2018	14.00	0.09	16.66	0.07
2019	14.53	0.08	17.11	0.06
2020	14.92	0.07	18.64	0.06
2021	14.97	0.05	15.90	0.04
2022	12.71	0.10	13.81	0.07
2023	4.24	0.05	4.91	0.05

2. Input data

Input data are included in this assessment up to the end of the 2022 season. The catch for 2023 is available and used in the assessment and set at 4.91 tonnes.

The following additional data sources are used in the updated assessment (See Readdy and Earl (2023) Figure 2):

- **Catch tonnage:** Catch tonnage for the 2022 and 2023 seasons were added.
- **Scanned length distribution:** Data for the 2021 and 2022 seasons were added.
- **Tag release data:** Data for the 2020 and 2021 seasons were added.
- **Tag recapture data:** Data for the 2021 and 2022 seasons were added.
- **Otolith aging data from a sample of the catch:** Data for the 2021 and 2022 seasons were added.

All data were taken from the CCAMLR data extraction dated 27/07/2023.

3. Length and age distributions

The length composition of the catch is determined from observer sampling of the catch and is raised to the reported vessel catch. The length distribution of caught fish for the period 2005 to 2022 (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.

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 provide data for the age-length-key (ALK) used in the assessment to estimate the growth parameters of a von Bertalanffy growth model. The number of otoliths read for construction of the ALK is shown in Table 3.1 with the sample size for age determination varying over time.

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

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 and is also included in the assessment as age-length pairs. There is good overlap between the length sampled for otolith collection and the length distribution of the catch, with an overlap statistic of 92% and 83% for 2021 and 2022, respectively (Figure 3.2). Consecutive age compositions (Figure 3.3) show a similar pattern 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. These age-length pairs are included in the model to provide the necessary information to transform the length-based observations of tag releases and recaptures to ages.

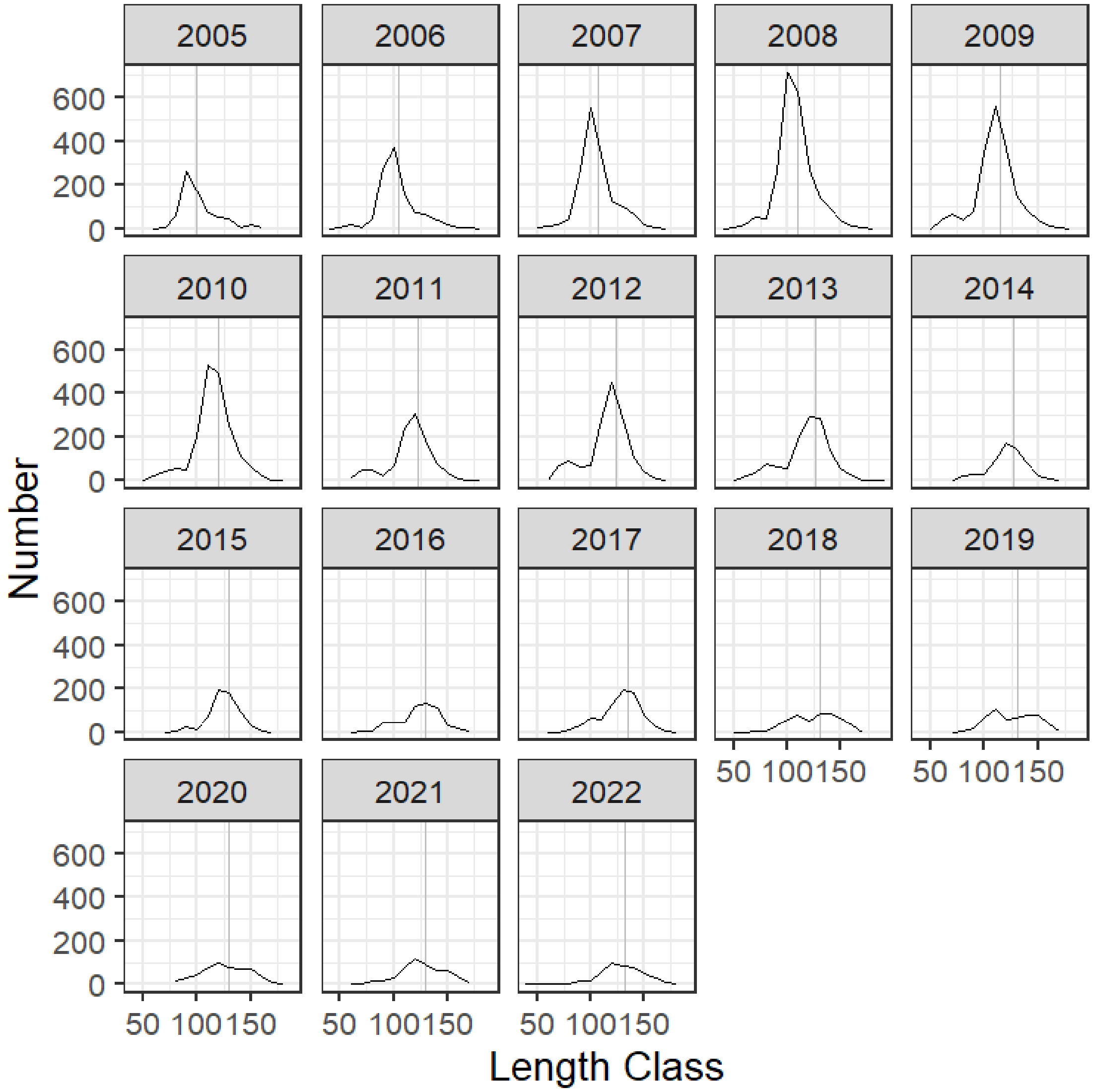

Figure 3.1. Catch length frequency by 10cm length bin from 2005 - 2022. Grey lines represent the median length for each year.

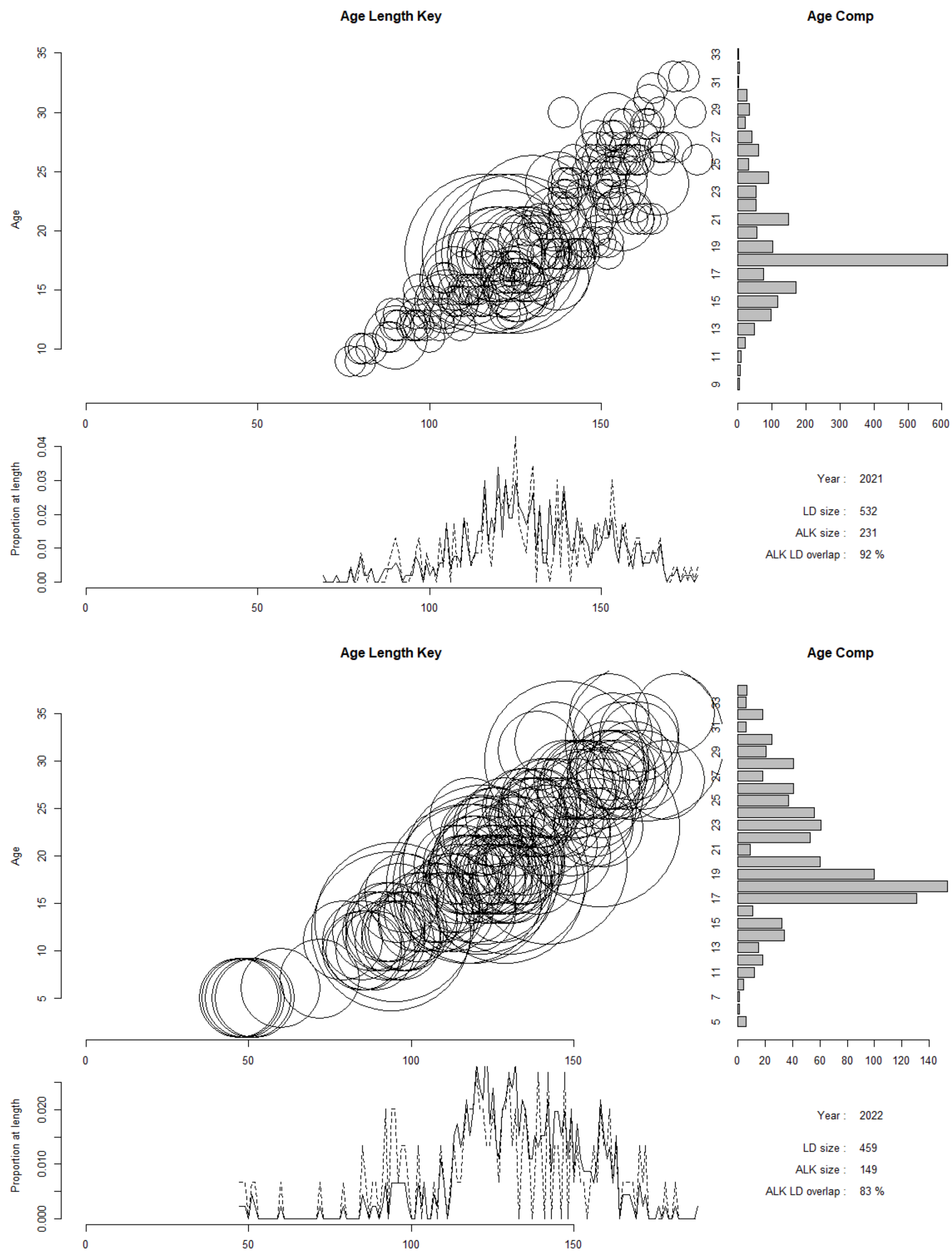

Figure 3.2. 2021 and 2022 ALKs. Lower panel of each plot shows the length distribution of the fishery (solid) and aged samples (dotted). The upper left panel shows the age and length of aged fish, with size of circles indicating the number of samples. The right panel shows the derived age composition.

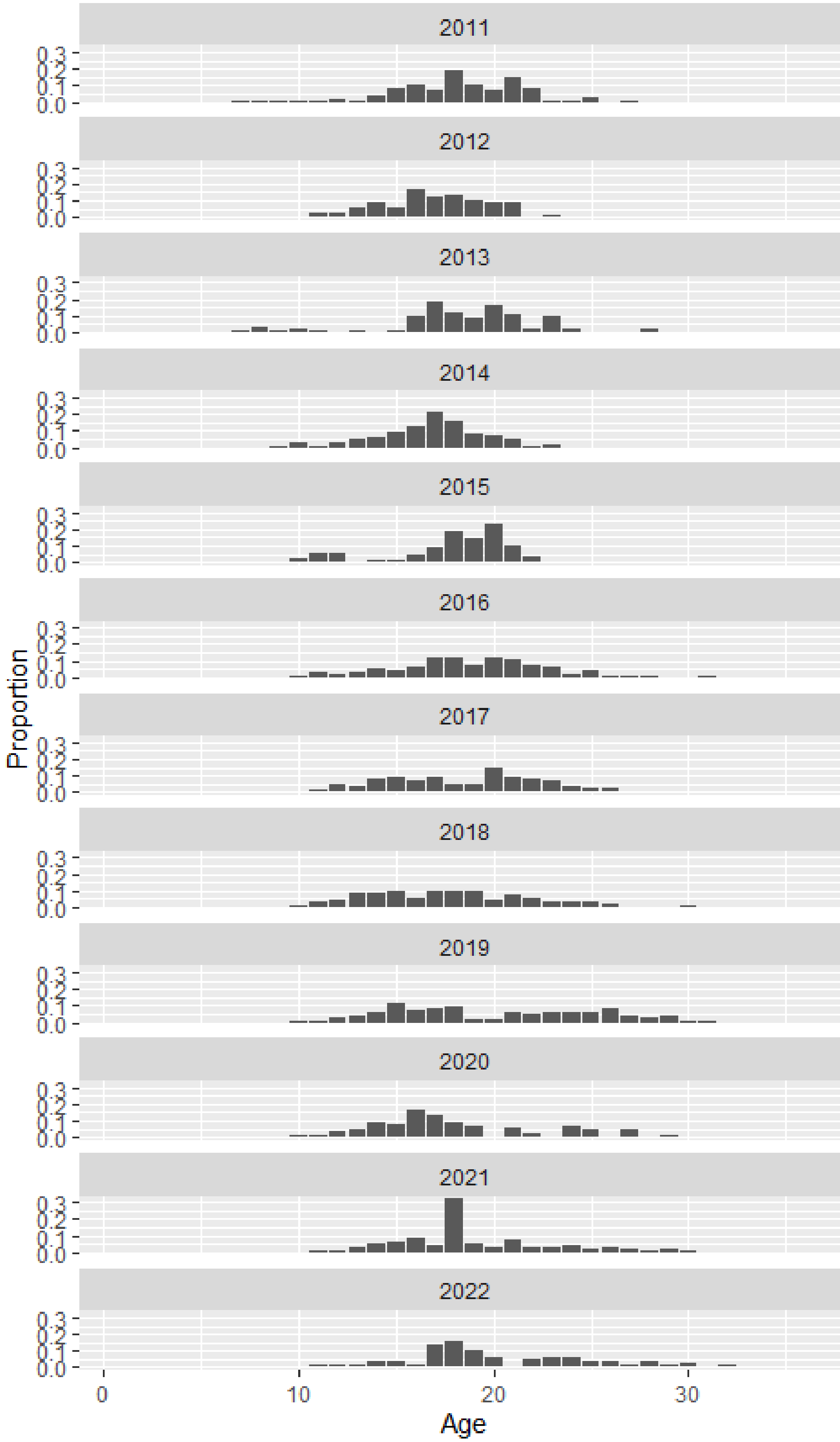

Figure 3.3. Raised age composition of otolith samples from the catch by year 2011-2022.

4. Tagging data

Between 2005 and 2023, a total of 4,257 *D. eleginoides* were tagged and released in Subarea 48.4 (Table 3). To date, a total of 562 were recaptured in 48.4 (Table 4.1) having been released in 48.4. This region 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 178 *D. eleginoides* were released in 48.4 but recaptured in 48.3; all are currently excluded from the assessment.

The 55 fish that have been recaptured in 48.4 in 2021 and 2022 had been released across a range of years.

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

			Recapture year																
		Releases	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total recapture
Release year	2005	42	0	2	2	0	1	0	0	0	1	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	25
	2007	291	0	13	12	1	4	5	4	2	1	0	0	2	2	0	0	0	46
	2008	504	0	0	8	11	8	11	10	4	3	7	6	2	3	2	1	0	76
	2009	551	0	0	3	16	12	12	9	3	5	3	4	0	1	4	1	0	73
	2010	419	0	0	0	2	13	2	12	4	1	4	3	2	2	3	0	1	49
	2011	220	0	0	0	0	0	0	2	3	0	4	2	1	1	1	0	1	15
	2012	303	0	0	0	0	0	0	7	3	2	2	3	5	3	1	0	1	27
	2013	468	0	0	0	0	0	0	0	23	19	15	7	1	4	3	2	4	78
	2014	223	0	0	0	0	0	0	0	0	20	12	9	1	2	2	1	2	49
	2015	226	0	0	0	0	0	0	0	0	0	11	12	7	4	1	5	2	42
	2016	224	0	0	0	0	0	0	0	0	0	0	5	1	4	3	9	5	27
	2017	159	0	0	0	0	0	0	0	0	0	0	1	1	1	2	5	1	11
	2018	87	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0	6
	2019	91	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	7
	2020	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3
	2021	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5
	2022	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	4257	2	23	30	32	39	32	46	42	52	60	53	23	28	28	32	23	545

5. Biological Parameters

The biological parameters used in the assessment are provided in the Stock Annex (Readdy *et al*. 2023). Table 5.1 provides the detail of the updated fixed parameters included in this year's assessment, details of all parameters and settings used in the assessment are provided in the Stock Annex (Readdy *et al*., 2023).

Table 5.1. Update of fixed parameters used in the integrated assessment of 48.4 Patagonian toothfish.

Component	Parameter	Old value	New value
Maturity ogive	*Age*		
	1-5	0	
	6	0.06	
	7	0.14	0
	8	0.22	0.465
	9	0.30	0.524
	10	0.38	0.582
	11	0.46	0.638
	12	0.54	0.691
	13	0.62	0.739
	14	0.658	0.782
	15	0.70	0.82
	16	0.742	0.852
	17	0.784	0.879
	18	0.826	0.902
	19	0.868	0.921
	20	0.91	0.937
	21	0.952	0.949
	22	0.994	0.96
	23	1	0.968
	24		0.974
	25		0.98
	26		0.984
	27		0.987
	28		0.99
	29		0.992
	30		0.994
	31		0.995
	32		0.996
	33		0.997
	34		0.998
	35		0.998
	36		0.998
	37		0.999
	38		0.999
	39		0.999
	40		0.999
	Age		
	41+		1
Tag loss rate		0.006377	0.0061
Length to weight (cm to t)	*a*	$4.15e^{-09}$	$3.44e^{-09}$
	b	3.194	3.237

Maturity

With the absence of available information to estimate maturation parameters specific to Subarea 48.4, proportions at age estimated for Subarea 48.3 are used, based on the analysis presented in Marsh *et al*. (2022b). Table 5.1 and Figure 5.1 show the comparison between the old and new ogives used in the assessment.

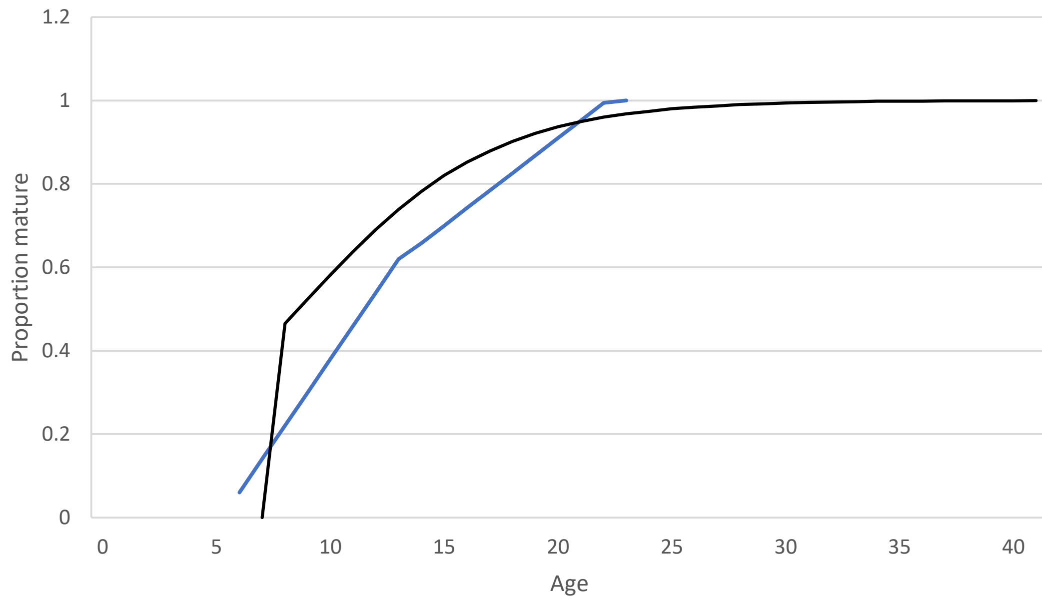

Figure 5.1. Maturity at age ogive used in the 2021 assessments, "Old" values (blue) and 2023 final assessment "New" values (black) using the methods presented in Marsh et al. (2022b).

Tag loss rate

As with previous years the Subarea 48.3 tag loss rate was used owing to few tag recaptures from Subarea 48.4. With the absence of specific estimates for Subarea 48.4 the tag loss rate used in the last assessment has been replaced with the updated estimate for Subarea 48.3 and is estimated as a single tag loss rate that best approximates the double tag loss rate as $0.0061y^{-1}$ (Marsh *et al*., 2022a; Readdy *et al*. 2023).

Length-weight

Length-weight function parameters used in the integrated assessment have been periodically updated to include the most recent available data, with the 2017 assessment (Earl, 2017) being the last time it was updated. As an additional seven years of data are available and given the negligible trends in the length-weight relationship over time (Marsh *et al*., 2023) all data were used, with the exclusion of two outliers, to update the length-weight parameters used for this year's assessment (Table 5.1).

Figure 5.2 shows the comparison between the length-weight functions used in the 2021 and 2023 final assessments with the underlying data. With the inclusion of the additional seven years of data it indicates that larger fish, on average, are slightly heavier than previously estimated.

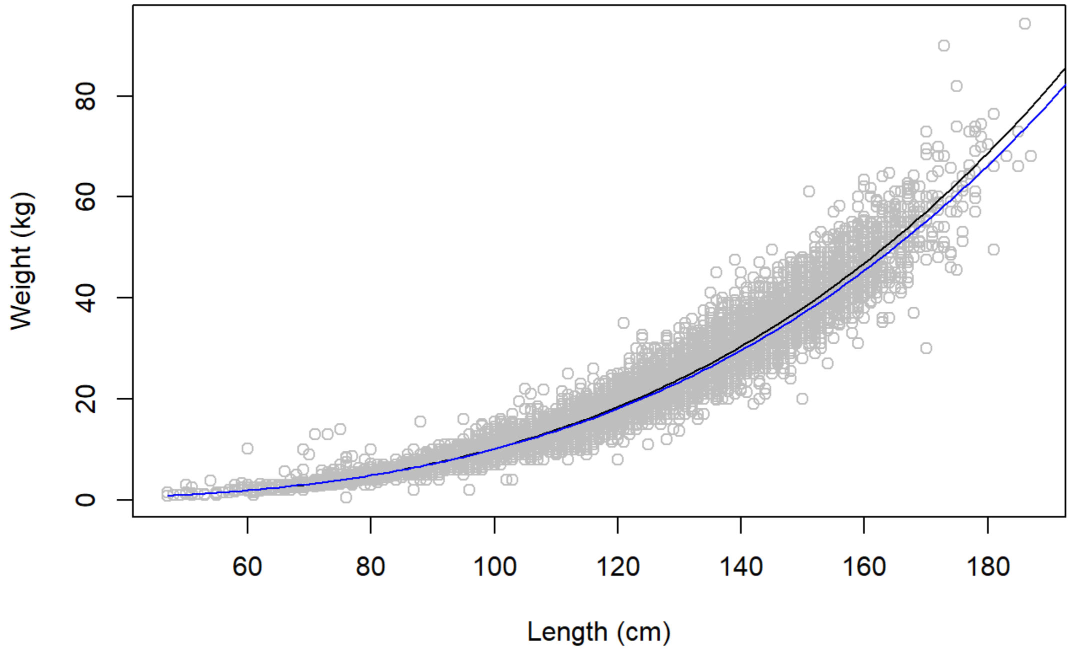

Figure 5.2. Length-weight data overlaid with "Old" parameter values (blue) and "New" parameter values (black) using the length-weight function described in the Stock Annex (Readdy et al. 2023).

6. CASAL model structure

The stock assessment is described in Readdy *et al*. (2023). As in the previous assessment, the population model is a combined-sex, single-area model with an annual cycle comprising five timesteps (Readdy and Earl, (2023) Table 1). 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 (previously included in period two within the CASAL model) 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 2023, 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 two-area model development, exploring the linkage between Subareas 48.3 and 48.4.

7. Data weighting

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

- Tag dispersion constant across all years.
- Catch age distribution effective sample size given by the number of otoliths aged in each year.

Subsequently runs were performed to scale the weightings applied to each data source:

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

The results of these steps are shown in detail for Run23 in Table 7.1, and summarised for model runs for the bridging analyses in Table 8.1.

Table 7.1 Data weighting steps in the 2023 Run23 assessment.

	Initial weighting	Update priors step 1	Weighting step 2	Weighting step 3
ESS* per otolith 2011 -2022	1	1	0.159	0.159
Tag dispersion	2.070249	2.070249	2.070249	1.974

8. Bridging analysis

Methods

The CCAMLR accepted 2021 assessment was used as the base case for progressing the model configuration and is described in Earl and Readdy (2021) and Readdy *et al*. (2022), the latter describing the additional step needed to address the convergence issues. Models were implemented in either CASAL version v2.30 v2.30-2012-03-21 00:22:59 UTC (rev.4648) or Casal2 v22.10-2022-10-09 22:54:45 UTC (rev. e3805a5), details of which can be found in Table 1.2. All models include a full run to estimate the maximum posterior density (Readdy *et al*. 2023, Table 5.3) and includes the reweighting of data in a four-step process, with the exception of the 2021 assessment model which does not use the initial step to update initial priors for the L_{inf} and k parameters. Firstly, the model is run to obtain suitable priors for L_{inf} and k of the growth function and were updated 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 was re-run and the outputs were used for the calculation of effective sample size using the Francis data weighting method (TA1.8 from Francis (2011) implemented in Francis (2015)). The value computed (Table 8.1) was applied to the sample size of the catch at age composition where the input files were again updated and re-run. Using the outputs of the third run the tag dispersion parameter was updated using the methods described by Francis (2015) and a final run was executed.

Likelihood profiling on B_0, MCMC runs and forecasts were only computed for Run11 and Run23 (final model) owing to time limitations. The final model configuration is described in the Stock Annex

(Readdy *et al.*, 2023) and full diagnostics of the final model are presented in the diagnostics paper (Readdy and Earl, 2023).

Results

The parameter estimates at each step of the model fitting, where effective sample size is rescaled and the tag dispersion parameter updated, for all model runs are presented in Table 8.1. These show that the parameters estimated for all models were similar at each of the steps.

With the addition of two additional years of data, Run11, derived quantities for SSB showed a perception change with lower overall SSB (figure 8.1) and a harvest rate estimated for 2021 showing a declining trend. With the inclusion of the corrected data, Run12, overall SSB increased slightly but remained below the SSB estimated in the 2021 assessment, diagnostics and fits to the data were similar across Run10, Run11 and Run12.

The same data and parameter settings used in the CASAL assessment framework for Run12 was used in Casal2 Run21. However, an additional timestep was included in Casal2 specific to tag loss to explicitly put this process after the processes that happened during the second "fishing" timestep. This ensured that the processes in both models gave the estimates for all derived quantities and the same data contributions to the objective function using the initial starting values before minimisation occurred and estimation of the free parameters.

Figure 8.2 presents the derived quantities after obtaining the MPDs for Run12 and Run21. It shows a minor difference in recruitment, but some differences to the perception of the SSB with an overall decrease and a slightly stronger decline in Run12, more noticeable for relative SSB. Figures 8.3 – 8.8 provide additional diagnostics and indicate that there was little to no differences between either model. The difference between CASAL and Casal2 MPD estimates of B_0 and B2023/B_0 was 1.5%. What is noteworthy was the time that the Casal2 model and final model MCMCs took to run, less than half that of the CASAL model and MCMCs.

As noted in section 5, revisions to length-weight and tag loss rate parameters and the maturity ogive were made available and Run21, the Casal2 base model, was updated to include the new values. With the inclusion of the new length-weight parameters and tag loss rate, the resulting derived quantities showed very little difference to that estimated by the Run21 model (Figure 8.9). However, when including the updated maturity vector an overall increase was observed for SSB, with minor variations seen in relative SSB, recruitment and harvest rate across the model runs. Diagnostics showed similar fits to those presented for Run12 and Run21 (Figures 8.3 to 8.8).

The final run, Run23, included the use of the simplex method for recruitment recommended by CCAMLR (WG-SAM-2023, para 6.37), which provides an alternative method of parameterising recruitment strength compared to the Haist parameterisation used previously. The MPD derived quantities (Figure 8.10) shows very similar results to that estimated for Run22 with some variation for the estimated recruitment in the years where age data are not available (2017 to 2023).

There is strong consistency between the models where data up to 2023 is included, as well as strong consistency between all models when comparing the diagnostic fits to the age compositions and tag data. Furthermore, the likelihood profiles, MCMC trace and distribution of B_0 (Figures 8.11 and 8.12) for the 2021 assessment (Run10) and the final model (Run23), support the consistency between the models.

The additional flexibility of the Casal2 model will enable improved parameterisation and further the exploration of the reweighting of the age-length pairs, which contribute the most to the objective function and heavily influence the estimation of B_0.

Table 8.1 Key parameter values estimated at each step of the process for the six models.

		Francis weighting	B_0	k	L_{inf}	Age of 50% selected	Selectivity range (years)	B_{2021}	B_{2021} (% B_0)	B_{2023} (% B_0)
	Initial value		1000	0.092	153	8	4			
2021	Base run		690.628	0.054015	201.958	15.3277	5.30559			
[Run10]	sample size rescaled	0.153	953.868	0.05404	202.18	13.6184	4.82404			
	tag dispersion updated	2.064	954.81	0.05404	202.18	13.6144	4.82208	615.941	0.65	
Run11	Pre-run		651.534	0.051786	206.056	15.2838	5.33746			
	Base run		657.226	0.051417	206.889	15.2526	5.31555			
	sample size rescaled	0.165	861.727	0.051269	207.491	13.9583	5.05859			
	tag dispersion updated	2.121	855.055	0.05126	207.514	13.9894	5.07223	553.034	0.65	0.61
Run12	Pre-run		614.796	0.051878	205.913	15.5104	5.46333			
	Base run		620.017	0.051785	206.148	15.5223	5.47095			
	sample size rescaled	0.159	806.889	0.051469	207.073	14.0673	5.12133			
	tag dispersion updated	1.930	824.846	0.051507	206.976	13.9662	5.07708	516.909	0.63	0.59
Run21	Pre-run		625.955	0.0513	207.397	15.4328	5.41431			
	Base run		617.046	0.051859	206.022	15.6042	5.4531			
	sample size rescaled	0.156	783.32	0.051733	206.393	14.2526	5.31101			
	tag dispersion updated	1.895	837.343	0.052067	205.673	13.8977	5.0937	536.04	0.64	0.60
Run22	Pre-run		686.92	0.05134	207.271	15.3117	5.33805			
	Base run		670.921	0.051906	205.921	15.4487	5.41876			
	sample size rescaled	0.159	864.664	0.051774	206.291	14.1488	5.25318			
	tag dispersion updated	1.927	886.692	0.051808	206.21	14.0405	5.20182	556.135	0.63	0.58
Final model	Pre-run		693.724	0.05231	204.998	15.3574	5.29185			
[Run23]	Base run		688.057	0.051669	206.488	15.4659	5.34529			
	sample size rescaled	0.159	889.708	0.052004	205.783	14.1835	5.14094			
	tag dispersion updated	1.974	914.093	0.052023	205.756	14.0351	5.0715	583.416	0.64	0.59

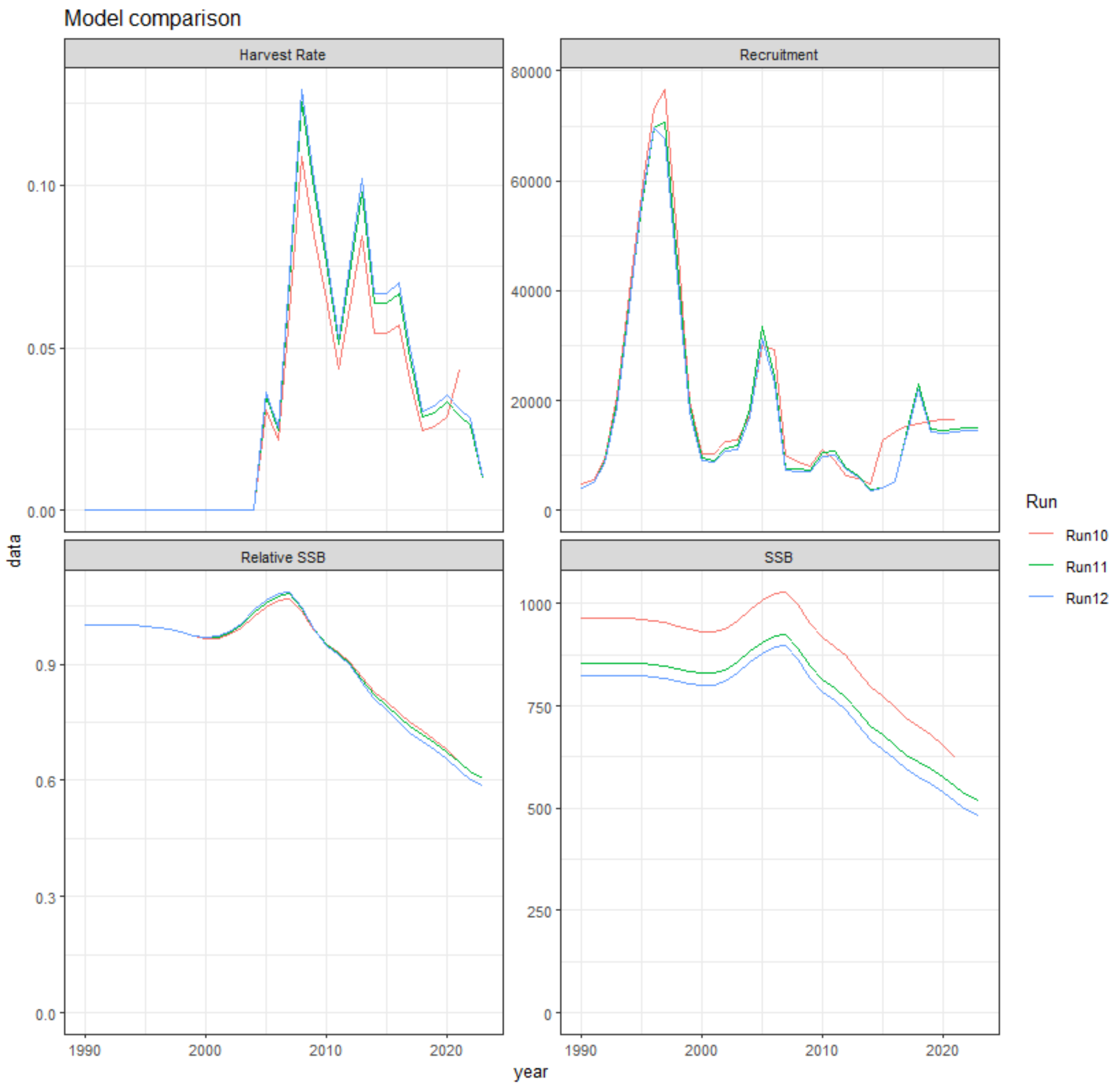

Figure 8.1. MPD derived quantities for the CASAL models: Run10 (red), Run 11 (green) and Run12 (blue).

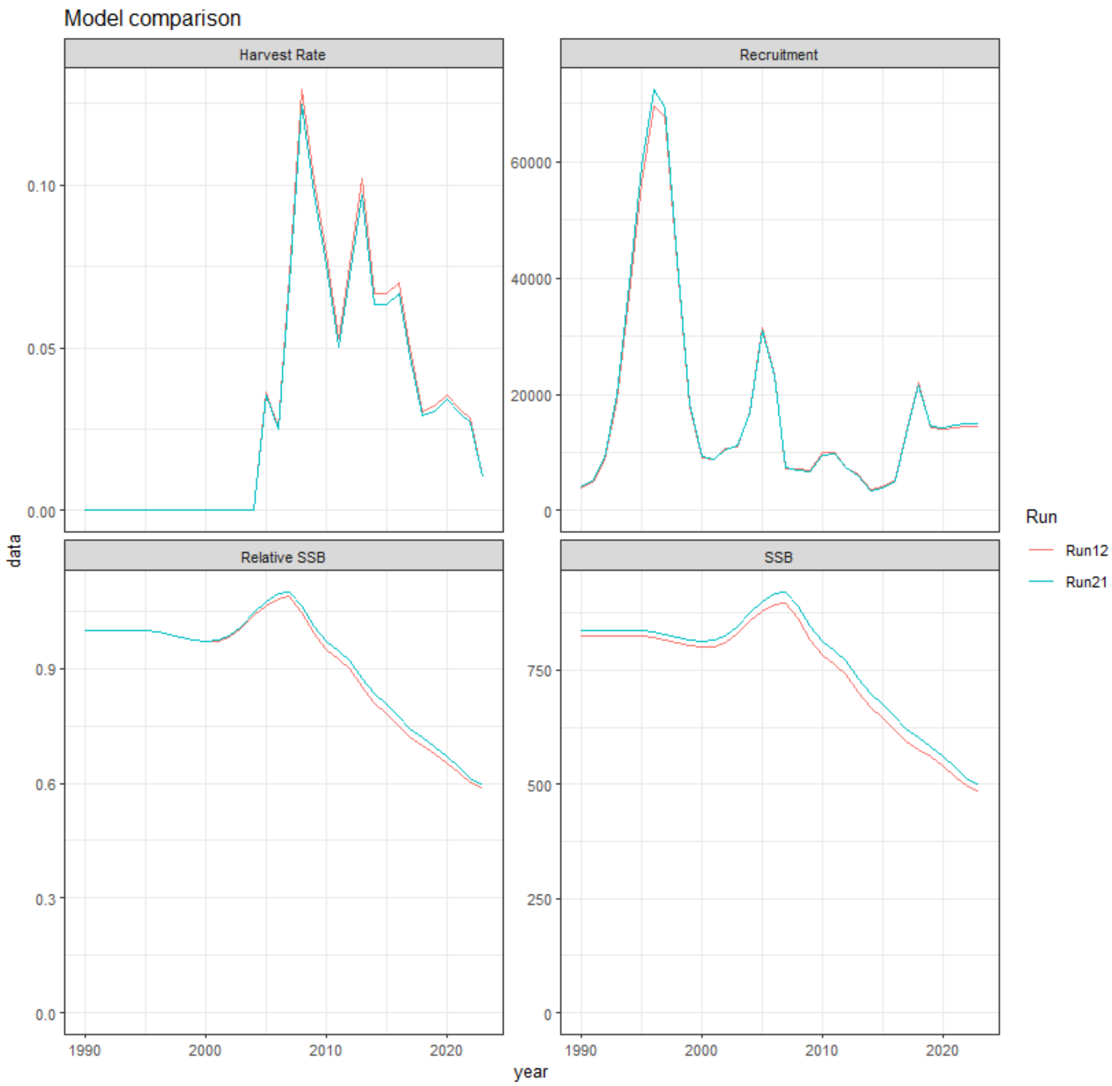

Figure 8.2. MPD derived quantities for the CASAL models: Run12 (red) and Run21 (blue).

Figure 8.3. Contribution of the data sources to the objective function Run12.

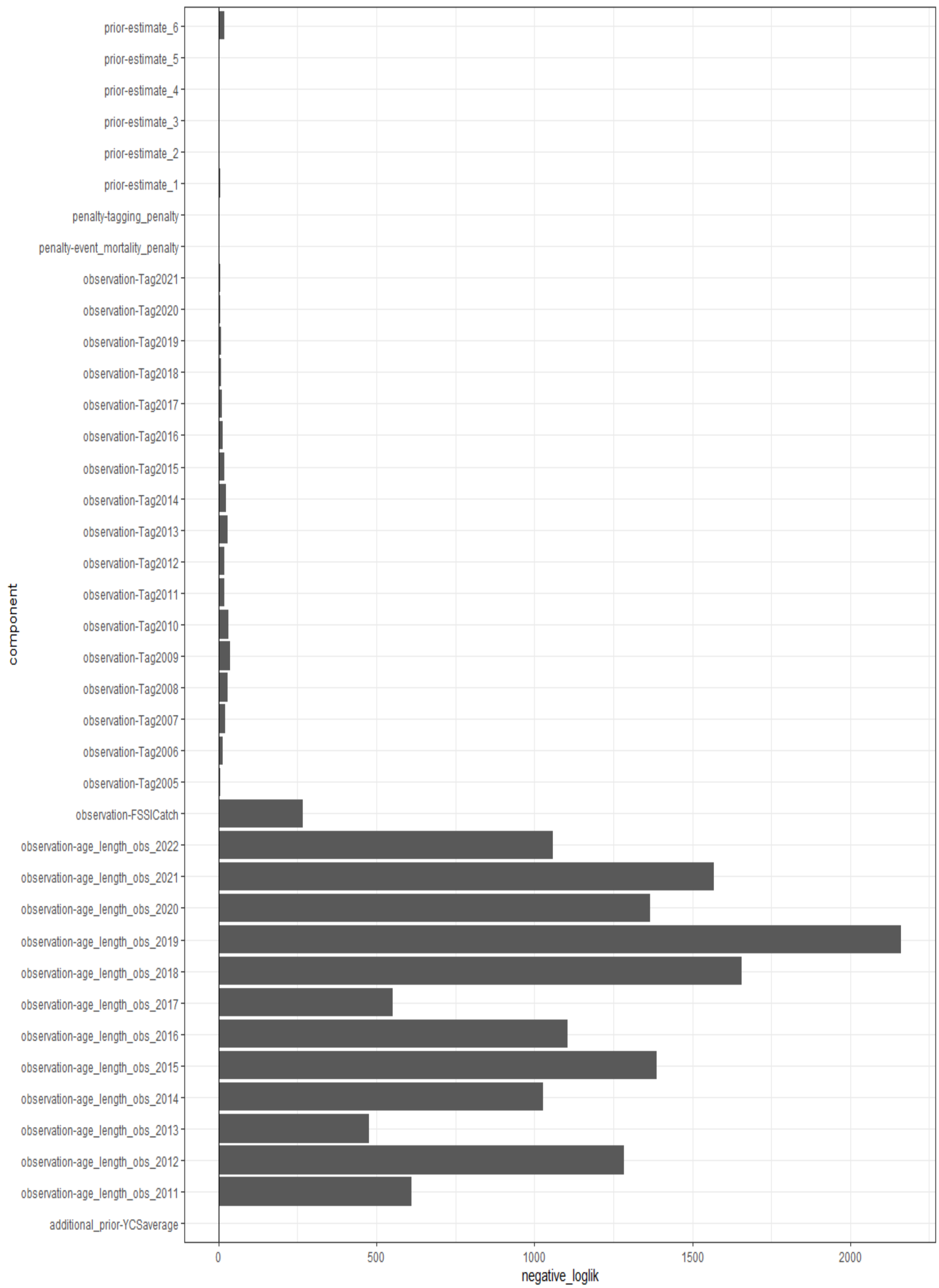

Figure 8.4. Contribution of the data sources to the objective function Run21.

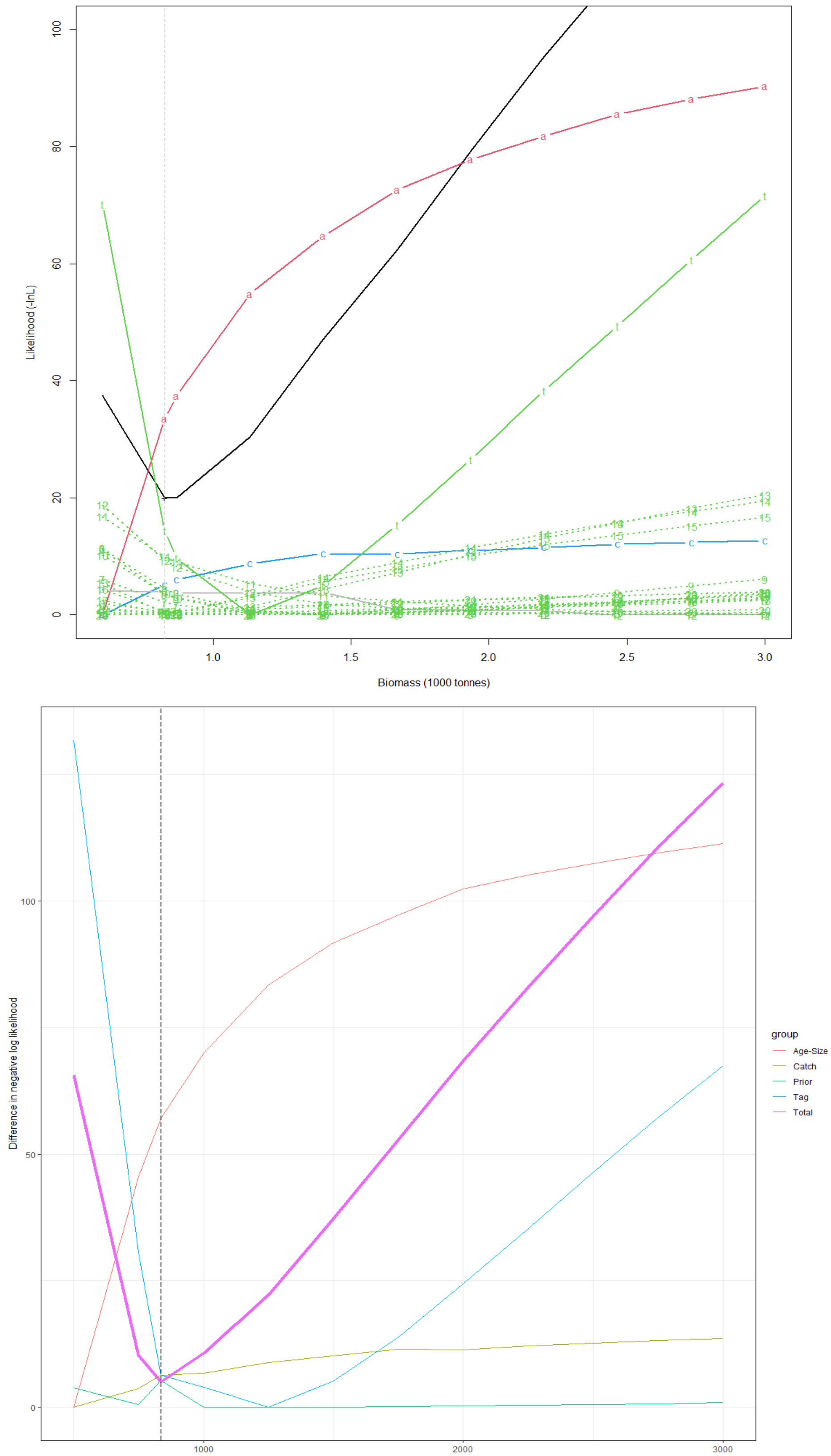

Figure 8.5. Likelihood profiles for B_0. Top Run12; bottom Run21. In the top plot, green – Tag (dashed shows the components by release cohort), blue is catch, red is age-size and black is Total.

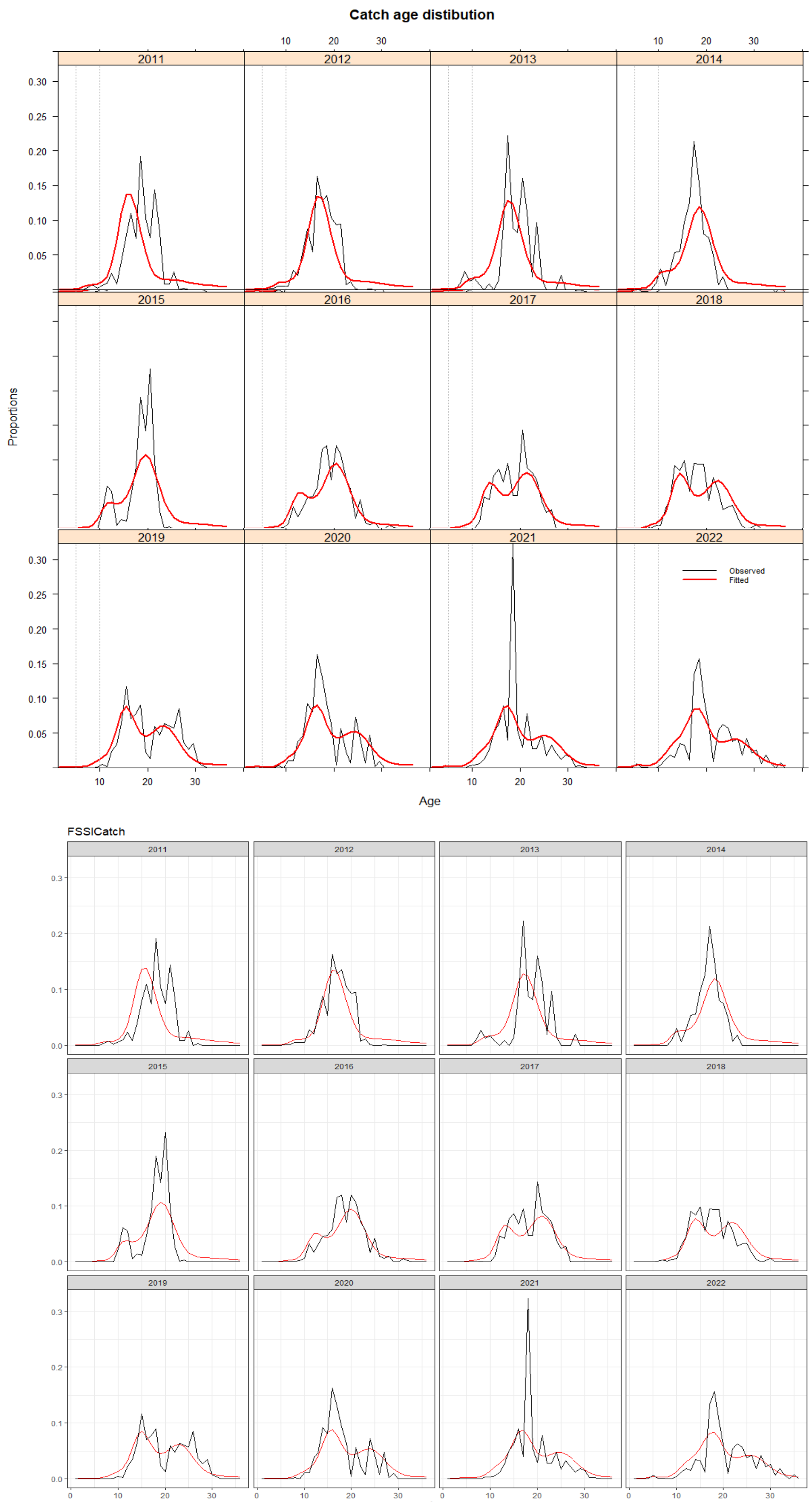

Figure 8.6. MPD fits to catch at age composition data. Top Run12; bottom Run21.

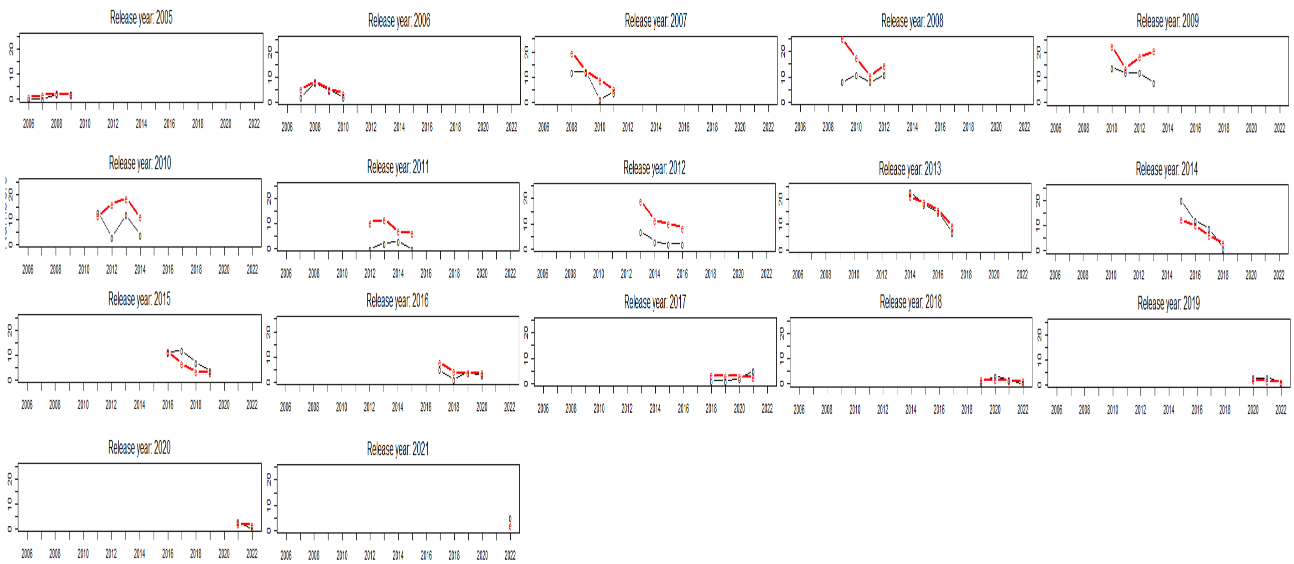

Figure 8.7. MPD fits to the number of tags recovered in each tag cohort for Run12.

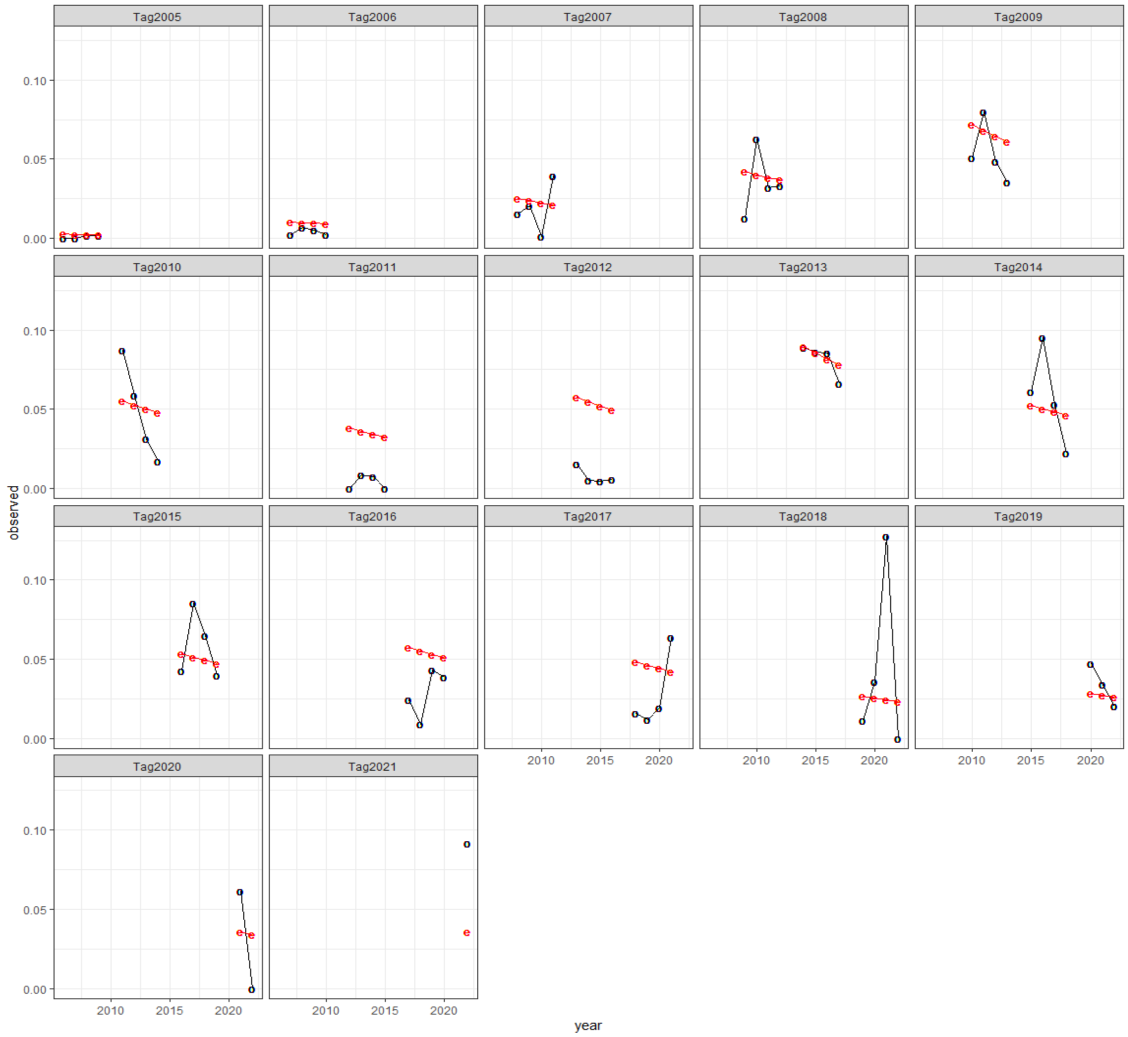

Figure 8.8. MPD fits to the number of tags recovered in each tag cohort for Run21.

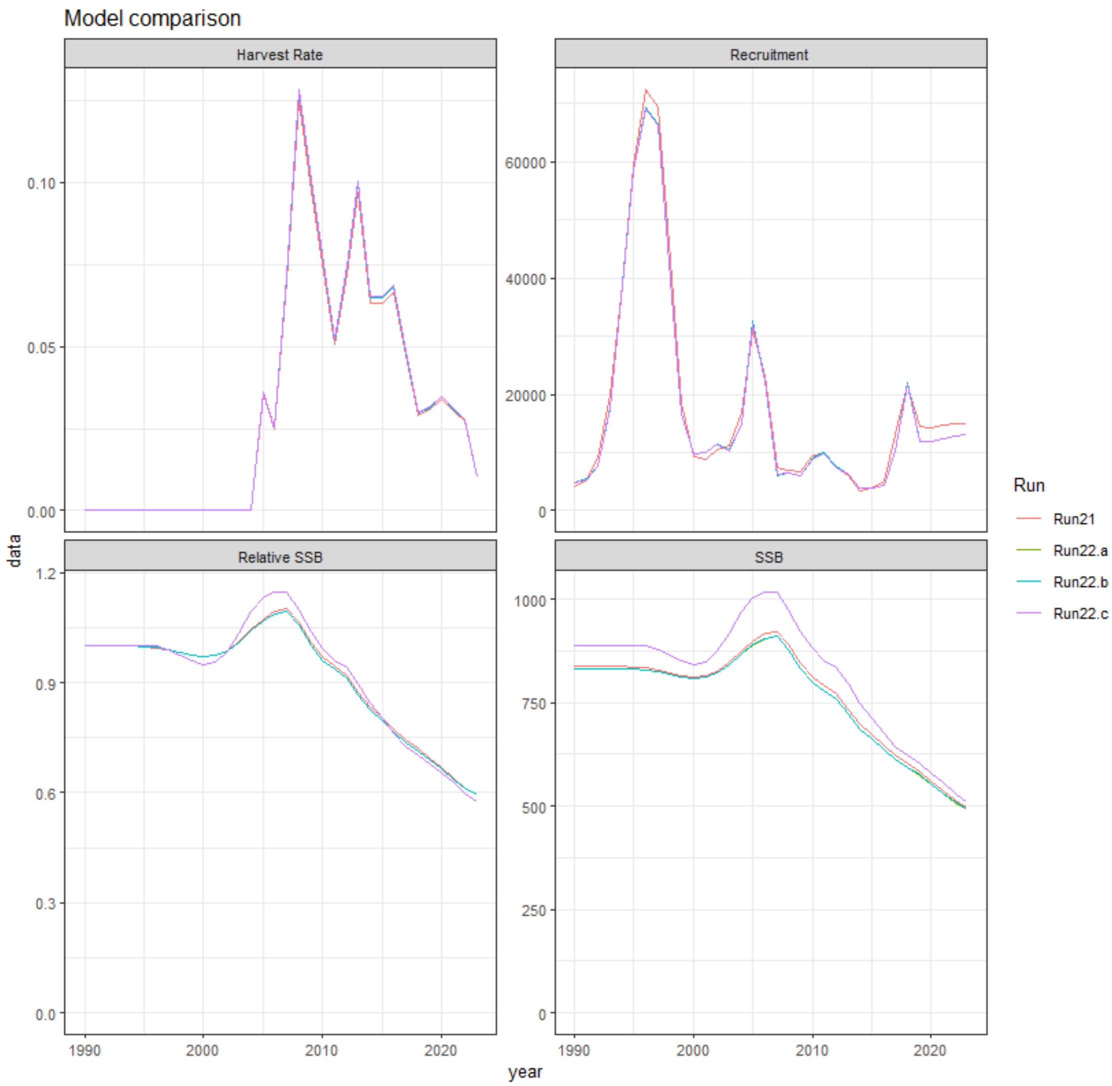

Figure 8.9. MPD derived quantities for runs Run21 (Red) and Run22 (with a stepwise inclusion of updates to length-weight parameters (a), tag loss rate (b) and maturity vector (c)).

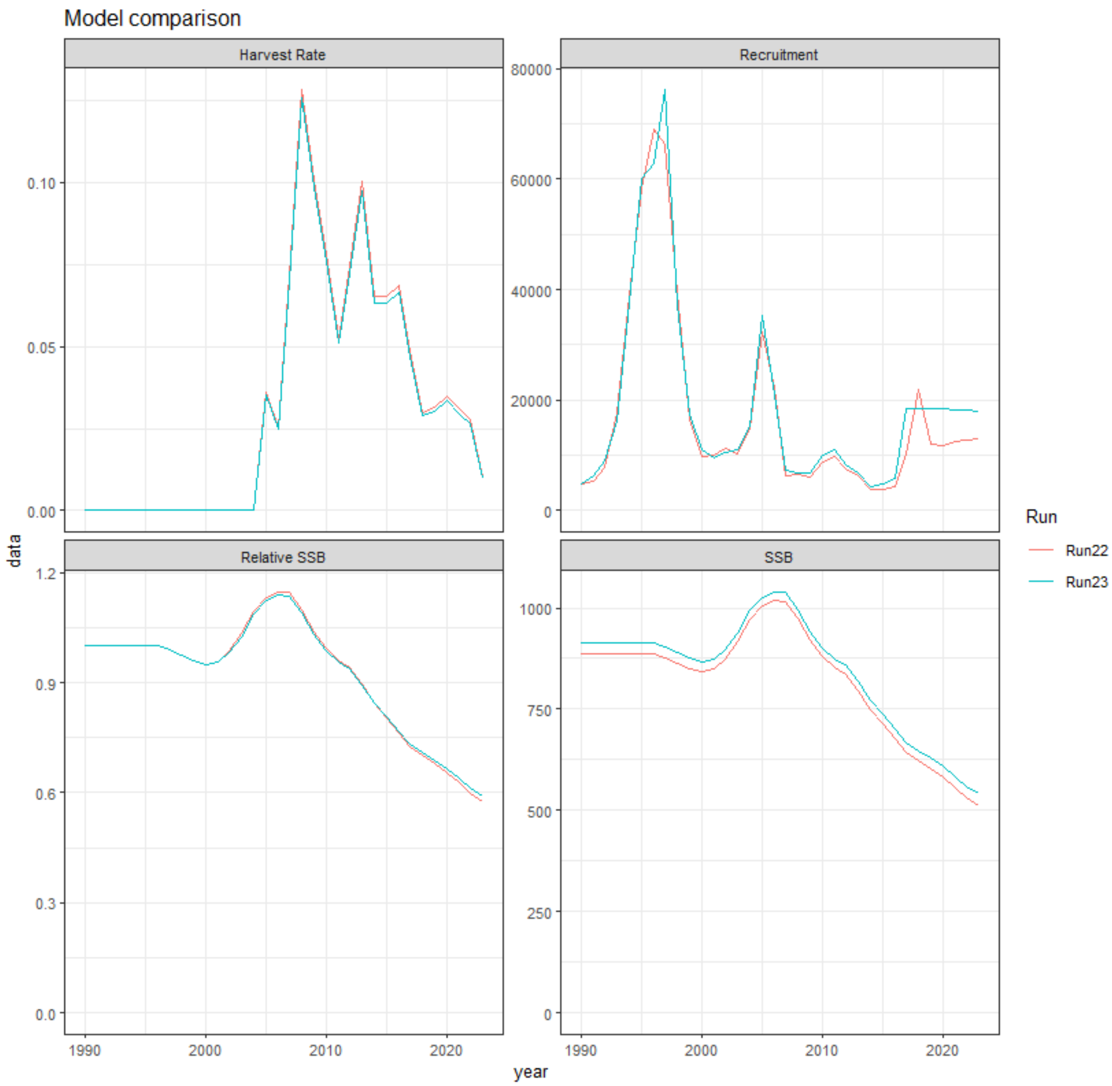

Figure 8.10. MPD derived quantities for runs Run22 (red) and Run23 (blue).

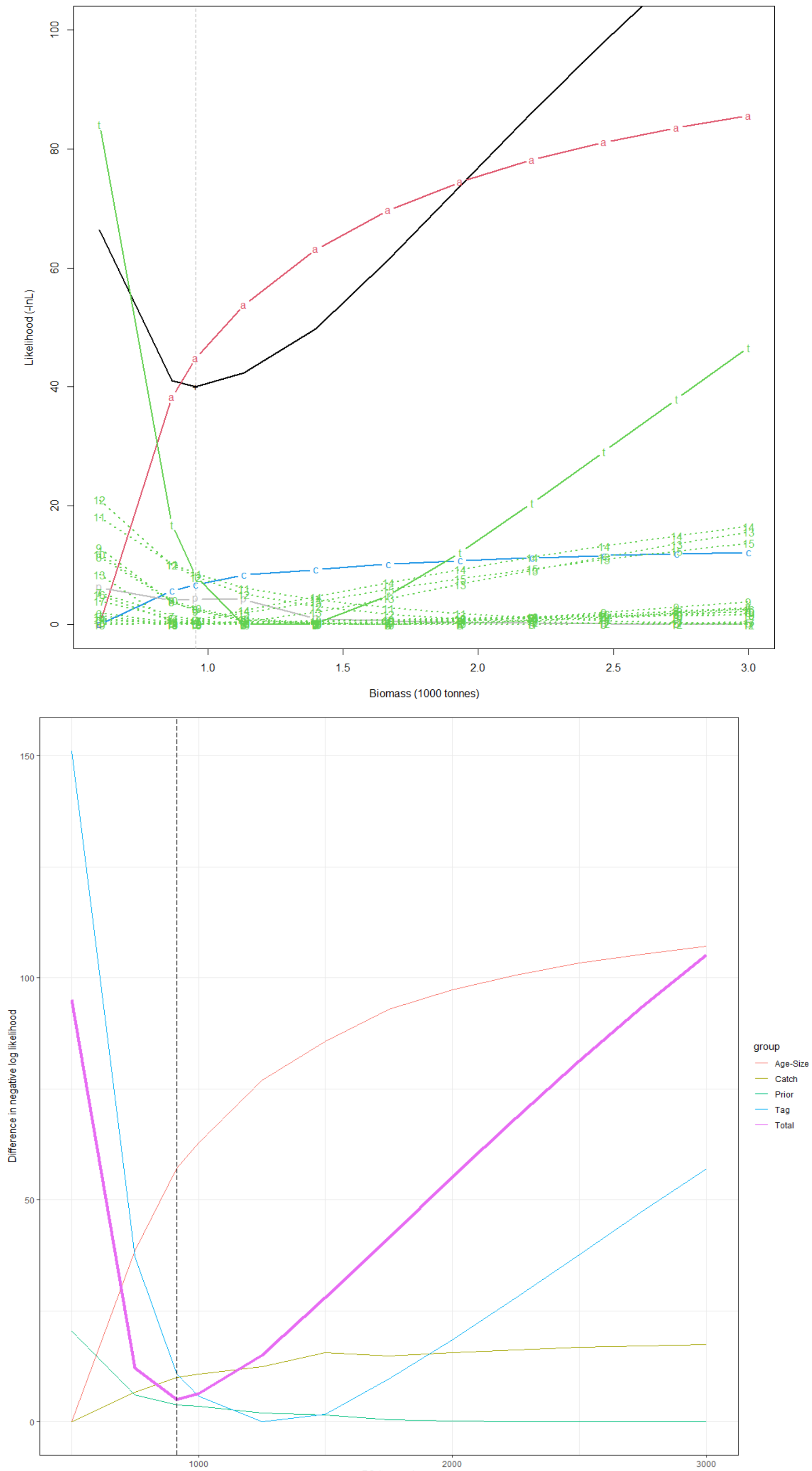

Figure 8.11. MPD likelihood profiles for B_0: Run10 (top) and Run23 (bottom).

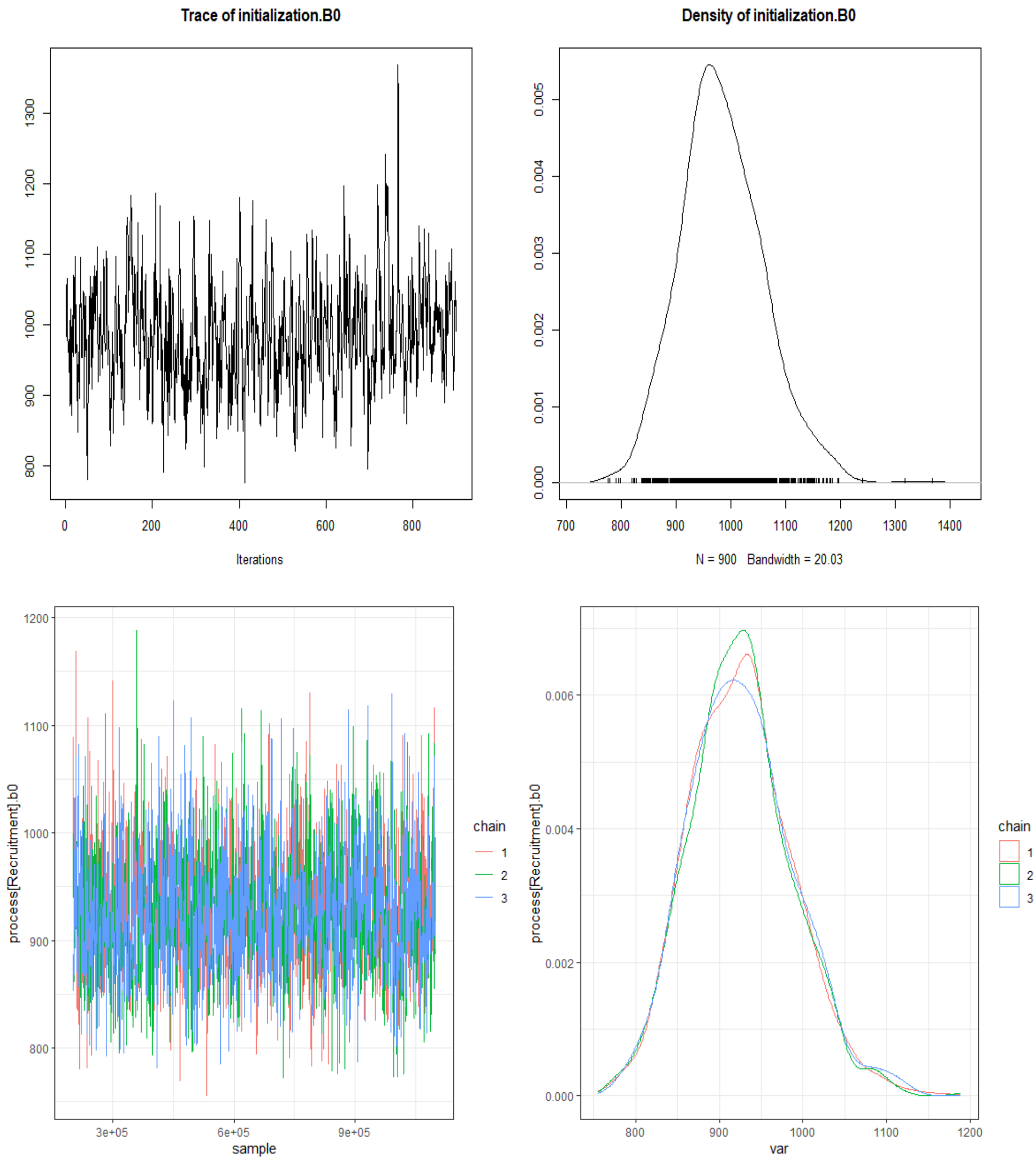

Figure 8.12. MCMC trace for B_0 (left) and distribution (right) for Run10 (top) and Run23 (bottom).

10. Final model outputs

Maximum Posterior Density (MPD) fits

The 2023 model, including the additional step to update growth parameters before the re-weighting process, ran without issue.

The individual contributions to the overall objective function (Figure 9.1) show that the 2018 and 2019 size at age data 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 9.2 – Figure 9.6 and Figures 3 - 10 in Readdy and Earl (2023)), show that the fit to the age compositions is variable, matching particularly well in 2012, 2016, 2017, 2019 and 2022 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, 2012 and 2016. The length distribution of the recaptures fits the model in most cases with a slightly higher estimated size than is observed.

A von Bertalanffy curve using values from the model MPD files was plotted against the raw age-length data (Readdy and Earl (2023), Figure 8) and showed that the curve fitted the data. As with previous assessments, the parameter t0 was set to zero; it was not possible to estimate t0 reliably because of the absence of data from fish smaller than 50cm and 6 years old.

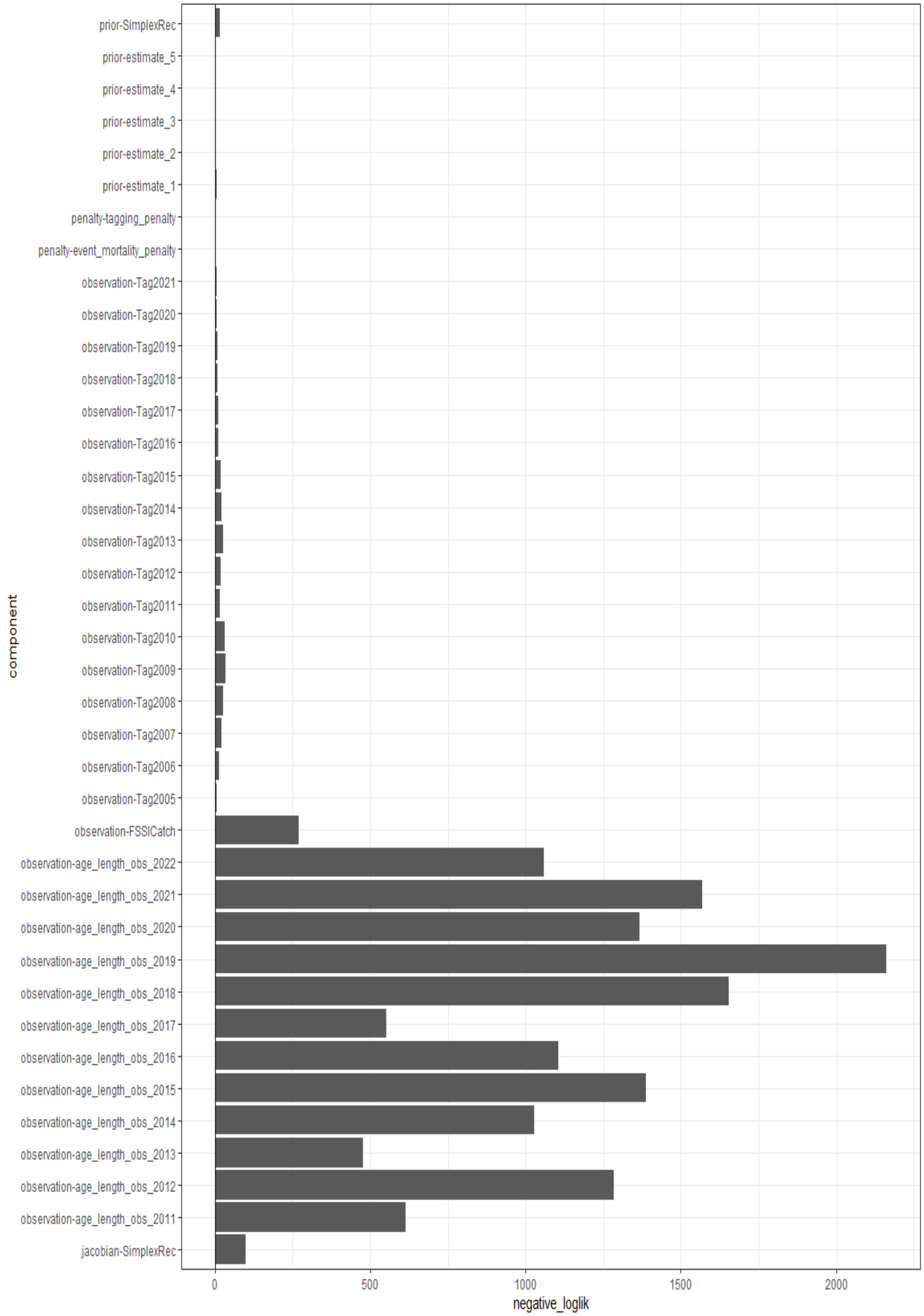

Figure 9.1. Likelihood components of the MPD fit.

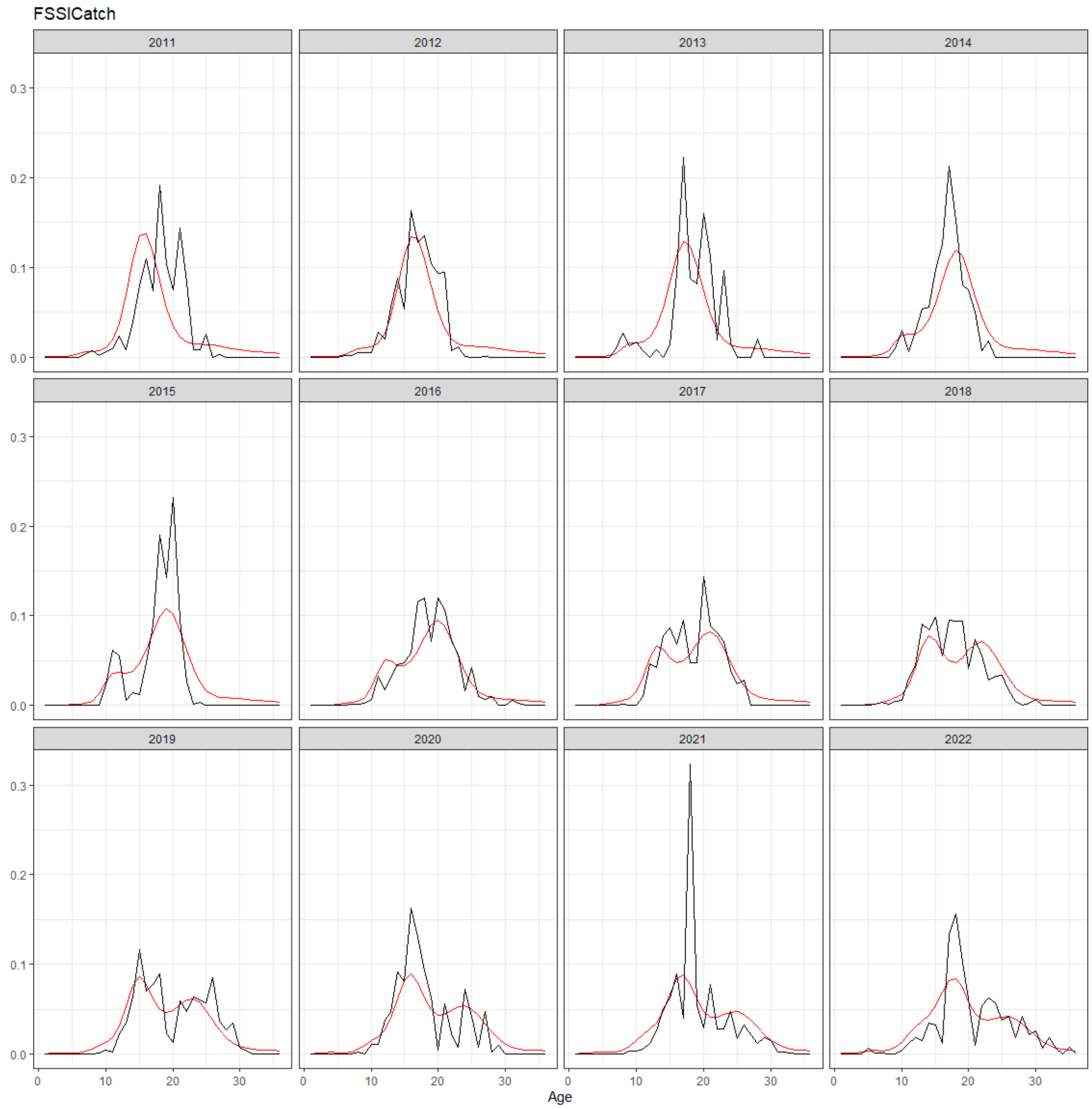

Figure 9.2. Fit to catch age composition data.

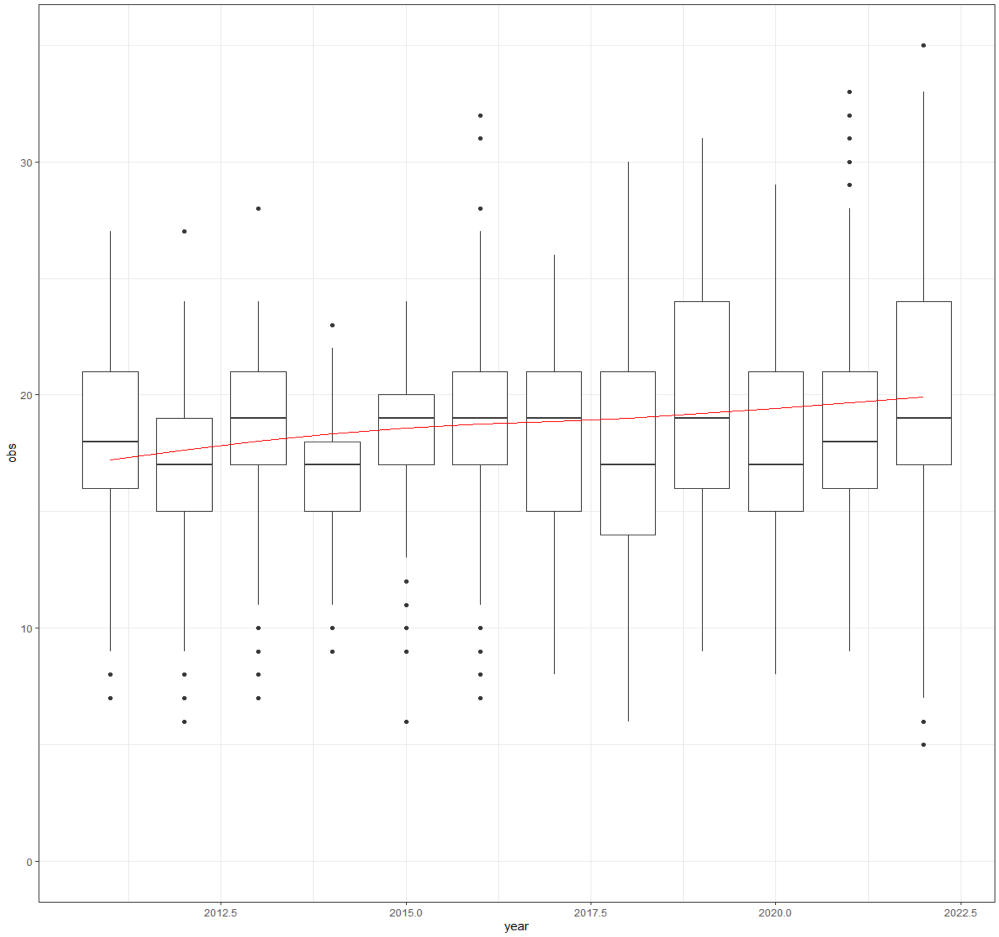

Figure 9.3. Median age in the catch estimated by the model (red line) and observed (white boxes).

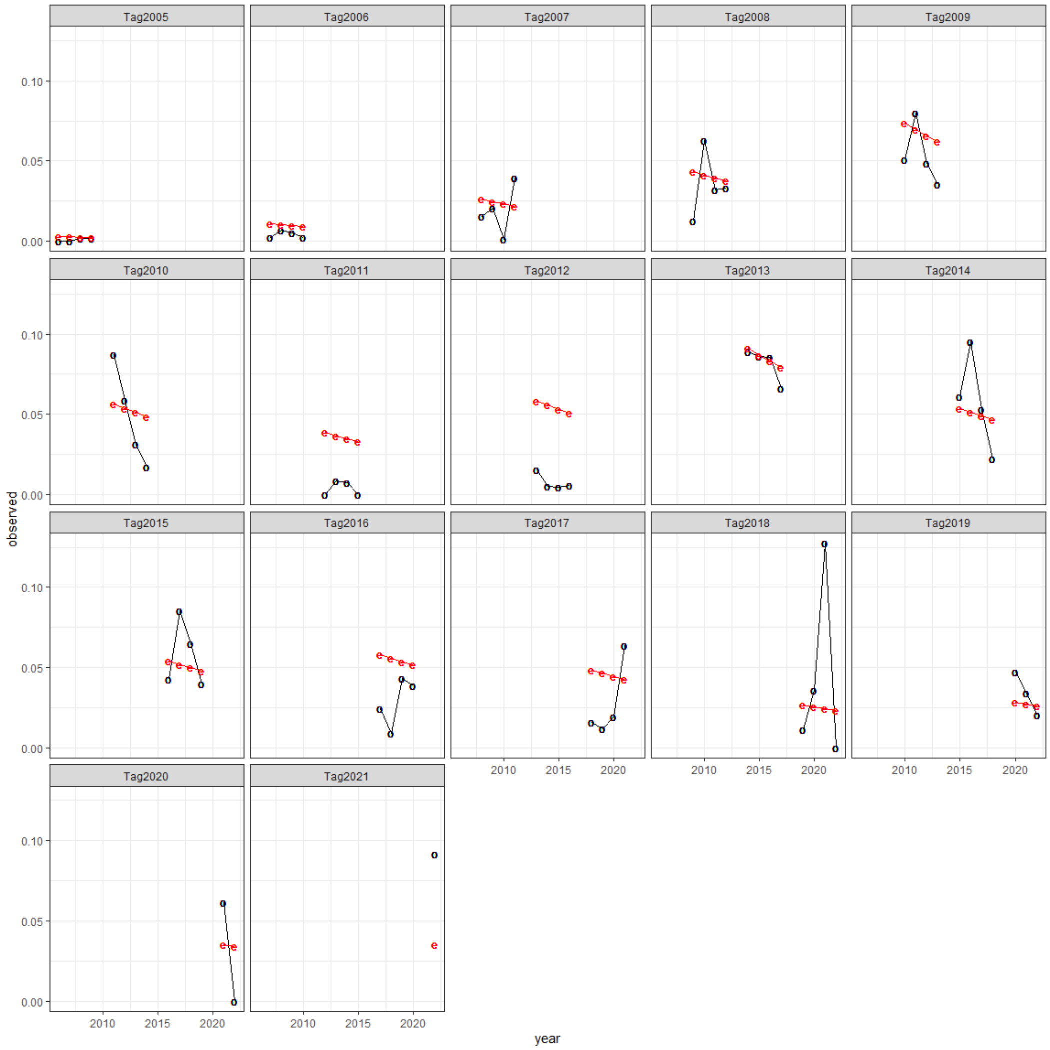

Figure 9.4. Fits to the number of tags recovered in each tag cohort.

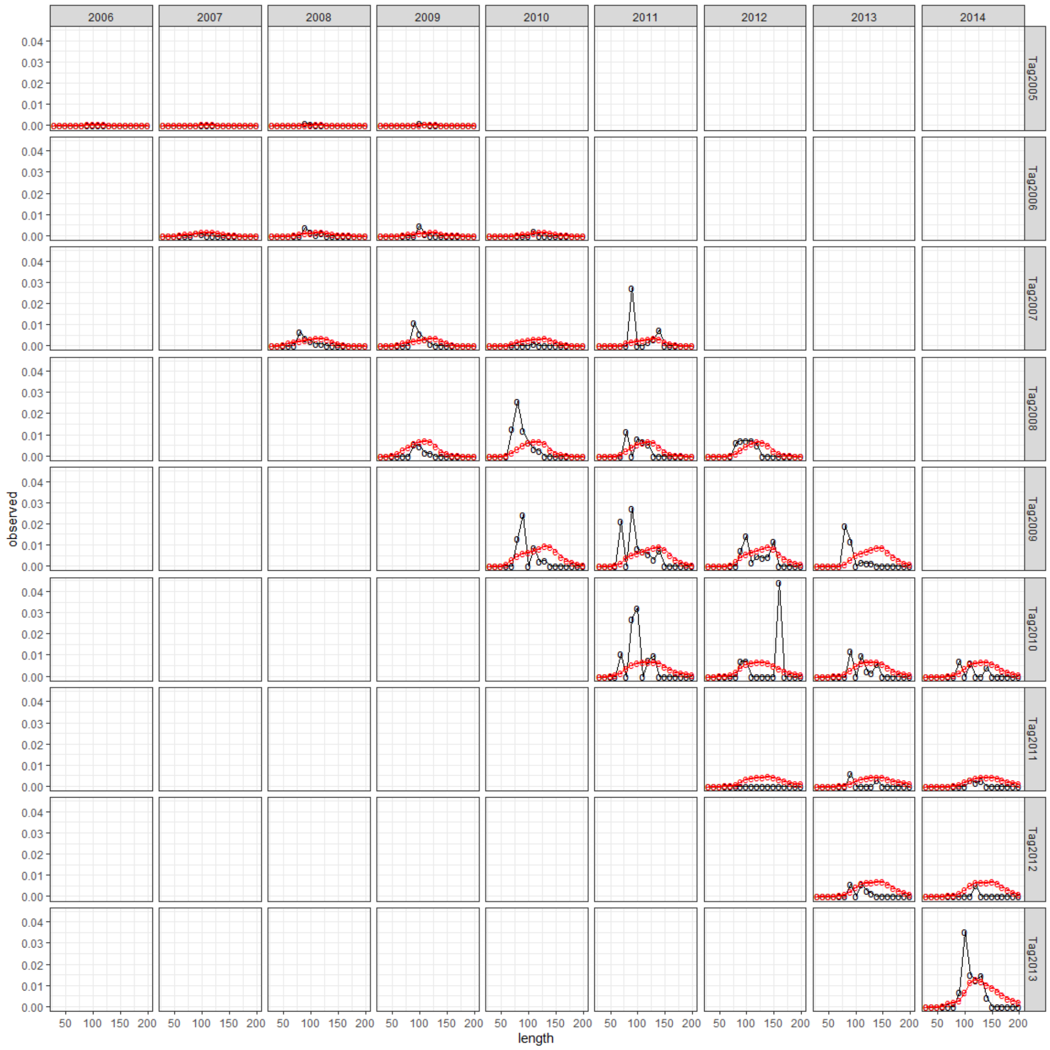

Figure 9.5. Fits to tagging data by length (releases up to 2013).

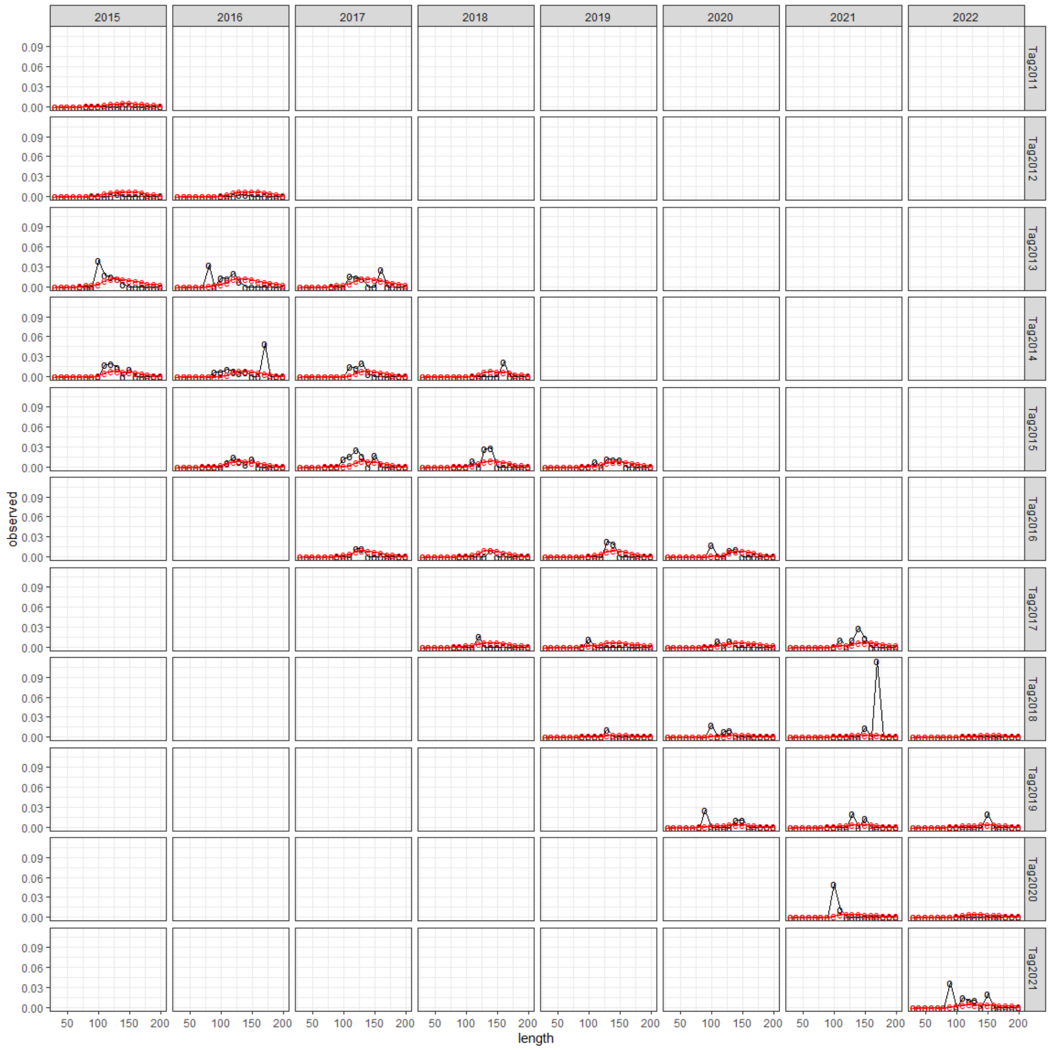

Figure 9.6. Fits to tagging data by length (releases since 2011).

11. Output quantities

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

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

	Assessment year			
	2017	**2019**	**2021**	**2023**
B_0 (tonnes)	965	1004	955	914
k	0.058	0.055	0.054	0.052
L_{inf} (cm)	194	200	202	206
Age of 50% selectivity (years)	14.1	13.7	13.6	14.0
Selectivity range (years)	5.6	5.2	4.8	5.1

The MPD assessment outputs (Figure 10.1) show a stable spawning stock biomass across the years 1990 – 2000, after which the SSB increased following the recruitment of the strong year classes from the early 1990s. After this initial increase the SSB declined steadily as recruitment reverted to lower values. The current spawning biomass was estimated to be at 59% of B_0 in 2023. The difference in perceived SSB status between the current model and the 2021 model run is small. 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 5 - 6%. The 2023 harvest rate has been revised down substantially, following the replacement of the assumed catch (the catch limit at the time) with the actual catch realised. Following the strong 1993 – 1998 year classes, recruitment was estimated to be very low except for a small peak in 2005. Recruitment is estimated to have decreased over the past few years, although the recent estimates will have a high uncertainly associated with them.

Table 10.2. B_0 and SSB output quantities across assessment years.

Assessment year	**B_0**	**SSB_y in last year**	**SSB_y/B_0**
2013	1,311	1,070	0.82
2015	1,434	1,133	0.79
2017	965	645	0.67
2019	1,004	674	0.67
2021	955	616	0.65
2023	914	541	0.59

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.

Retrospective analysis

The historic retrospective, Figure 10.1, comparing the 2021 assessment and the final assessment, shows that with the addition two more years of data, data and parameter updates and the move to the Casal2 integrated assessment framework the perception of the stock has remained similar with only minor differences.

Analytical retrospective analysis of the final assessment with a five-year peel, Figure 10.2, was carried out where for each peel a year of data is removed, and the model re-run through the four steps to obtain the MPD as described in Section 8. This analysis shows some perception shifts in SSB, but there is no observed bias and trend in the revisions of 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 data more is known about the strength of this year class.

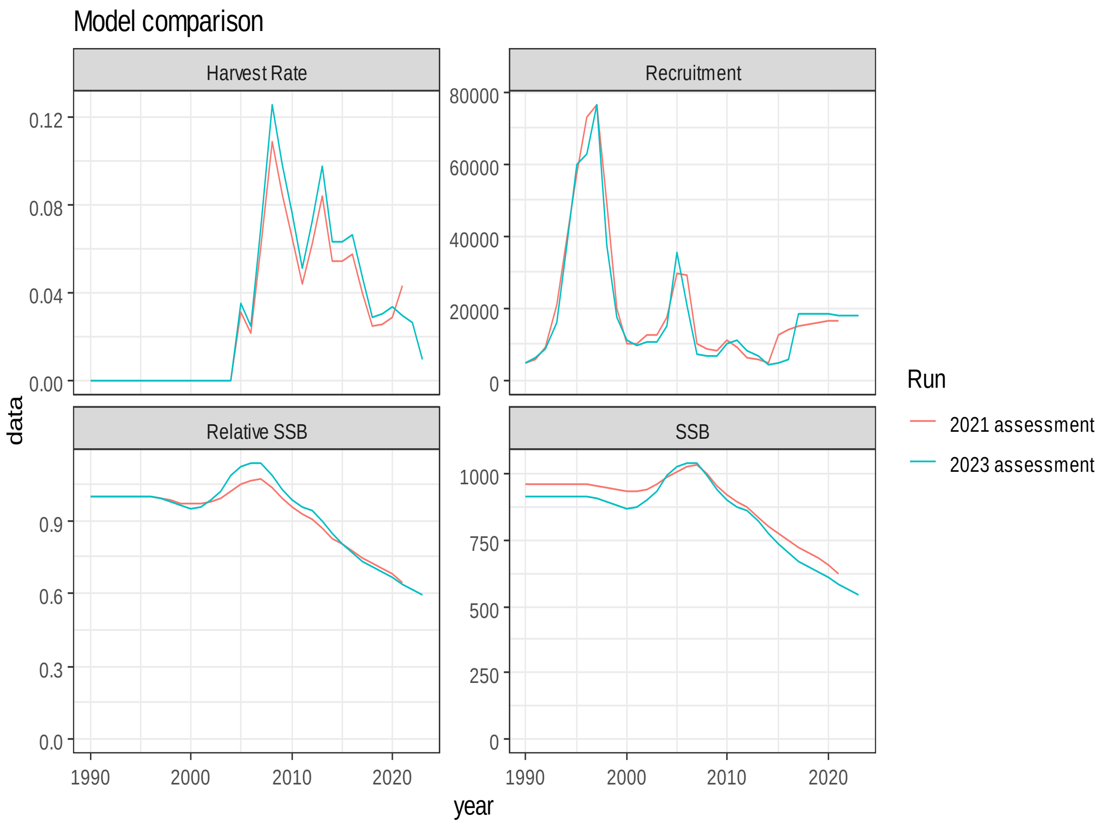

Figure 10.1. Output quantities of MPD estimates of vulnerable biomass, year class strength, harvest rate and spawning biomass of D. eleginoides in Subarea 48.4 compared to the previous (2021) assessment.

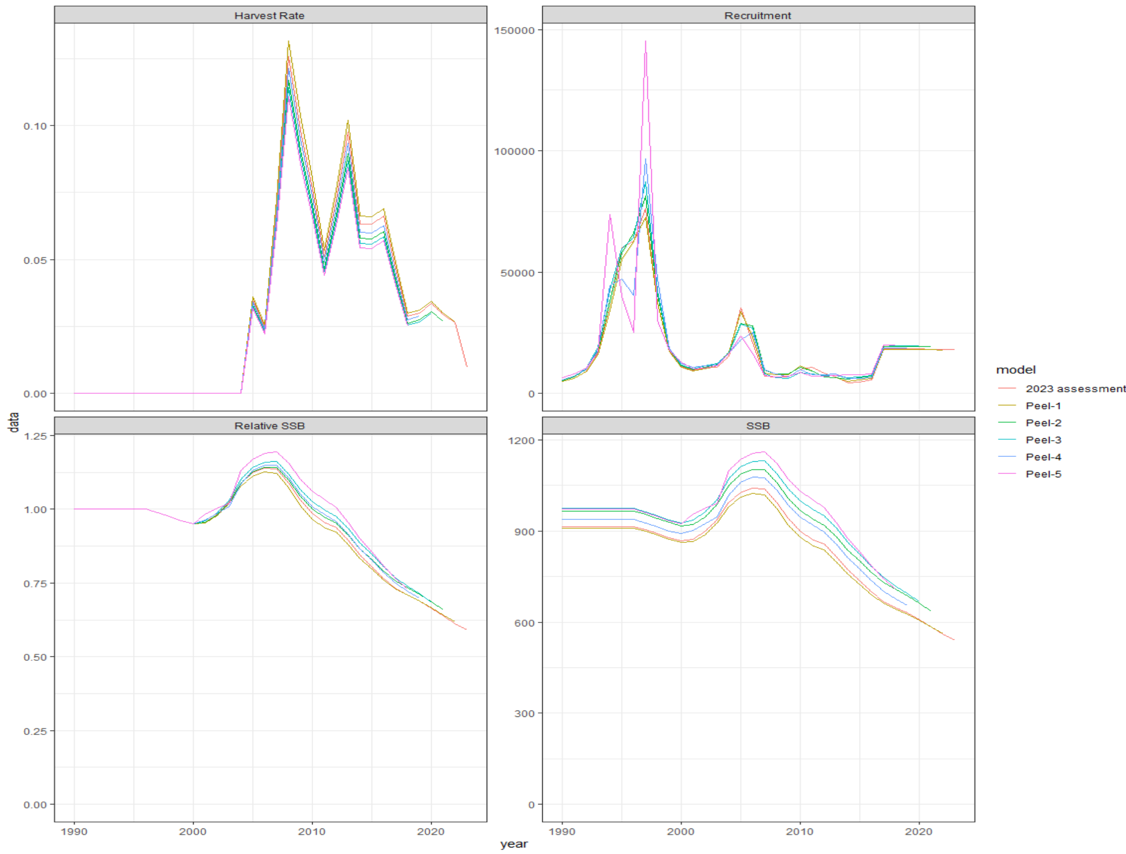

Figure 10.2. MPD analytical retrospective analysis of harvest rate, recruitment, relative spawning biomass and spawning biomass.

12. Likelihood profiles

Likelihood profiles for B_0 (Figure 11.1) 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 14 - 16 in Readdy and Earl, 2023) 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.

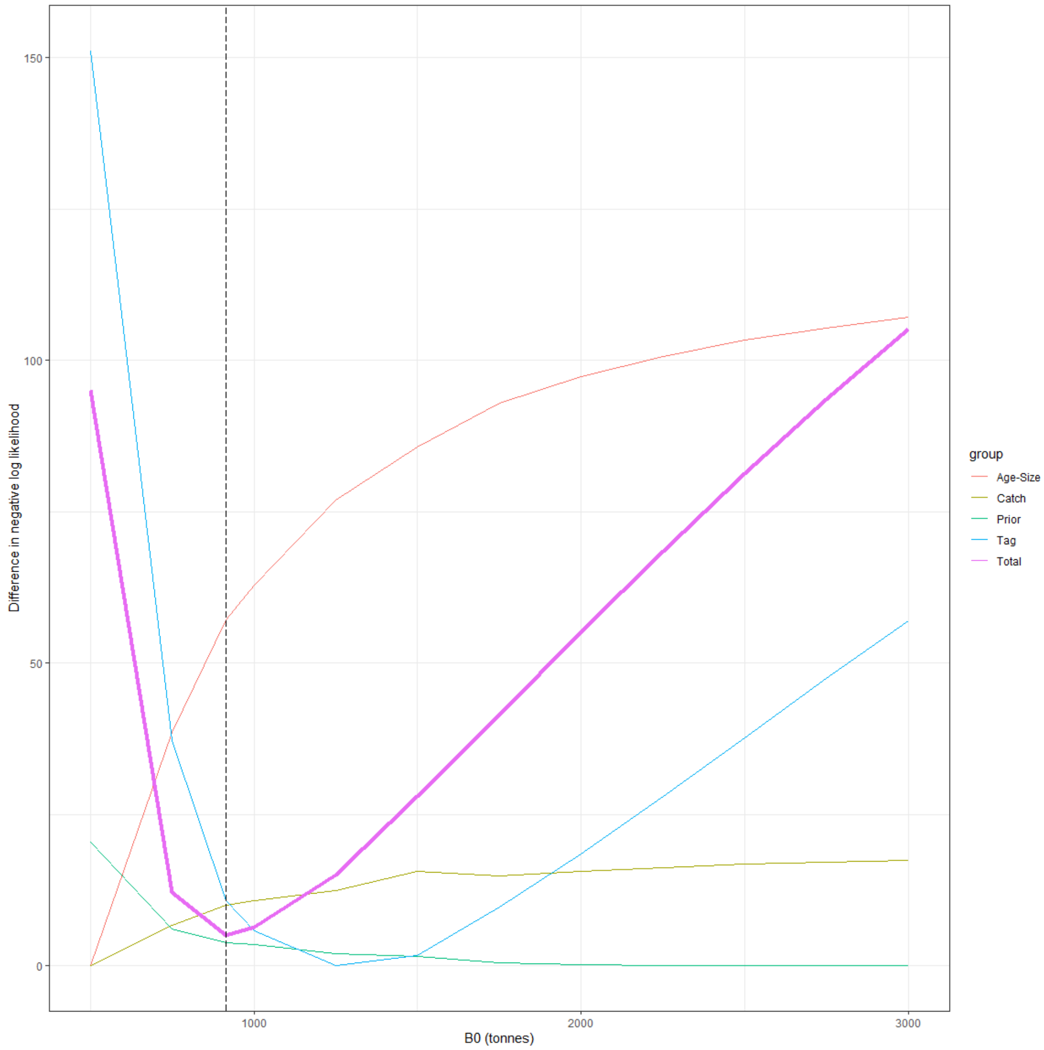

Figure 11.1. Likelihood profiles for B_0.

13. MCMC results and diagnostics

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 was tested using the coda (output analysis and diagnostics for MCMC) package in R (Figure 12.1, 12.2 and Readdy and Earl, 2023). Geweke convergence tests indicated successful convergence for some of the estimated parameters, though not all. Heidelberger and Welch tests indicated sufficient chain length and stationarity in 19 out of the 38 estimated parameters (where some were the YCS parameters). A test of auto-correlation showed significant autocorrelation in some samples, particularly recruitment estimates (Figure 12.1 and MCMC diagnostics in Readdy and Earl, 2023). In general, MCMC analyses performed adequately, but still showed susceptibility to poor convergence, which was probably due to the model's reliance on a relatively small quantity of data.

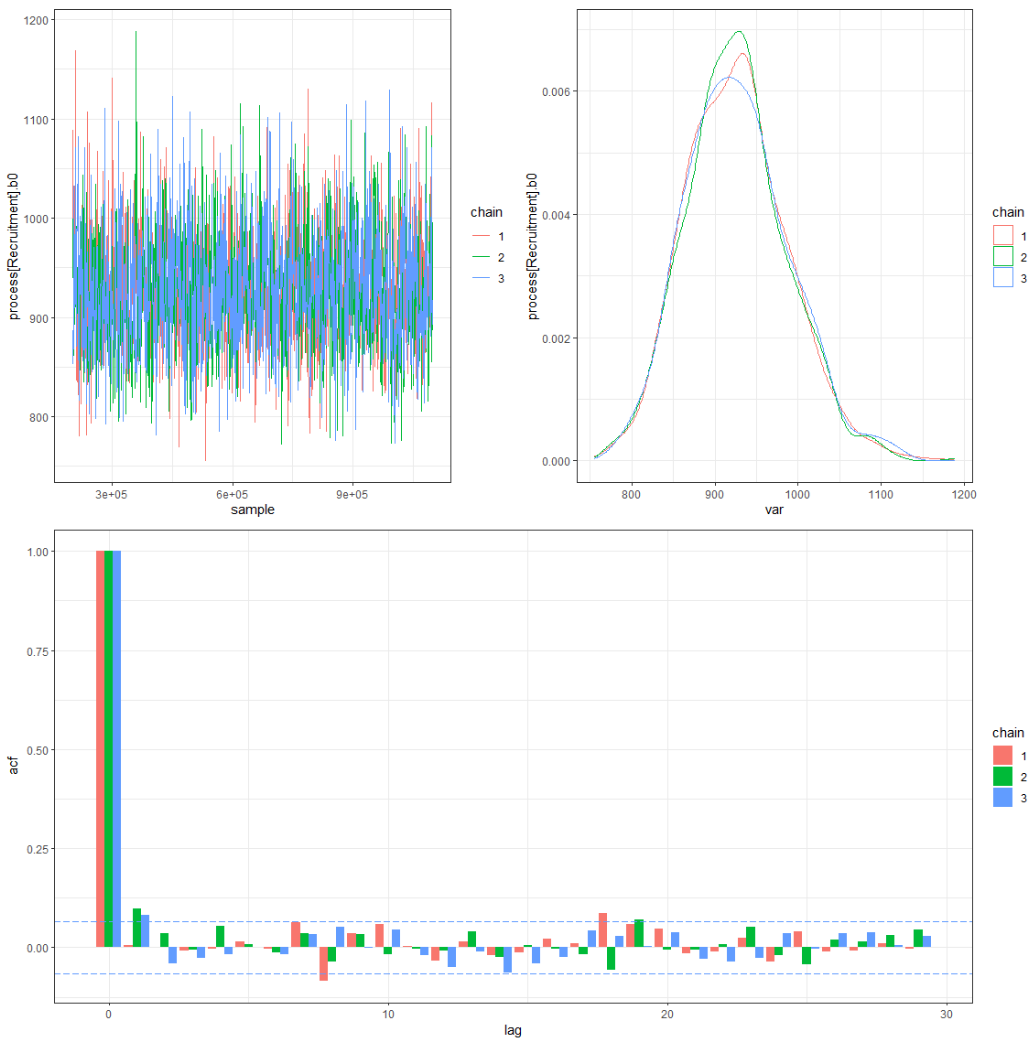

Figure 12.1. Three MCMC traces for B_0 (top left), distribution (top right) and autocorrelation diagnostic (bottom) after trimming and removal of burn-in period.

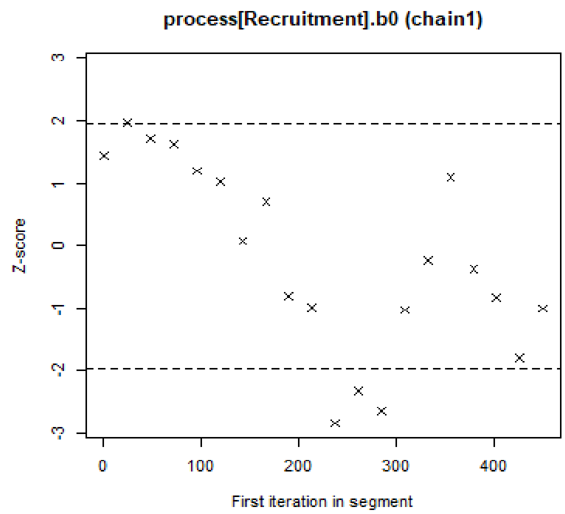

Figure 12.2. Geweke diagnostic plot for B_0.

14. Projections

Figures 13.1 – 13.2 show the estimation of the derived parameters recruitment, SSB and SSB status in the assessment and projection period. The recruitment continues to show a single large recruitment event around 1997, with low recruitment since with the exception of a lower peak around 2005. As a result of this high recruitment, stock size is estimated to have peaked in 2006 - 2007.

A constant catch projection was run for a 35-year period based on the MCMC samples 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 from the stock recruit curve. Recruitment strengths were randomly drawn from a lognormal distribution with standard deviation estimated from historic recruitment. Projections with a constant TAC of 19 tonnes are shown in Figures 13.1 – 13.3 and 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 0.4% of the simulations fall below 20% of B_0 during the 35-year period, under the assumption that recruitment follows a lognormal distribution with parameters estimated by the model. Following the procedure agreed by SC-CCAMLR-38 (paragraph 3.70), this implies that the TAC of 19 tonnes would be consistent with the CCAMLR Decision Rules.

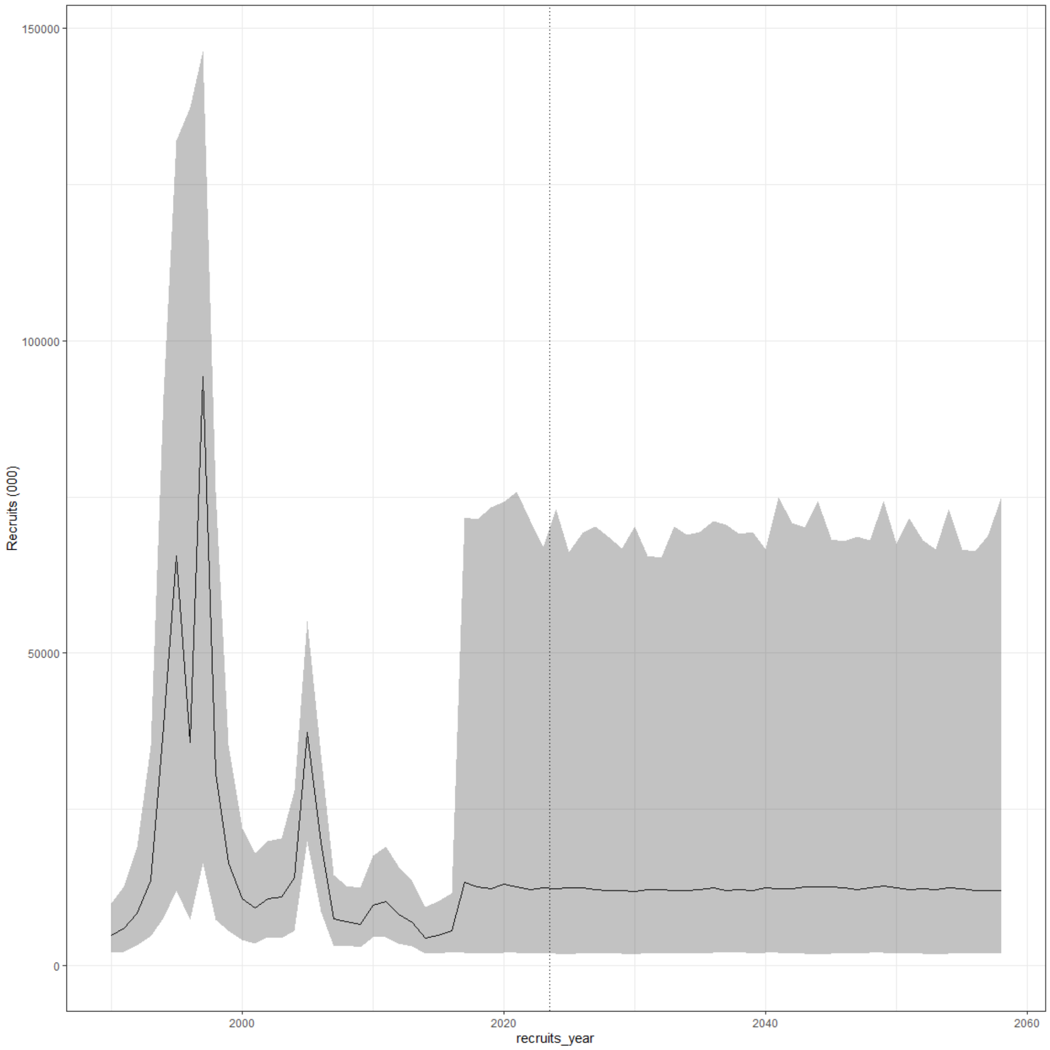

Figure 13.1. MCMC recruitment uncertainty and projection until 2058 based on a constant catch of 19 tonnes. Projections assume recruitment with a lognormal distribution from 2017 onwards.

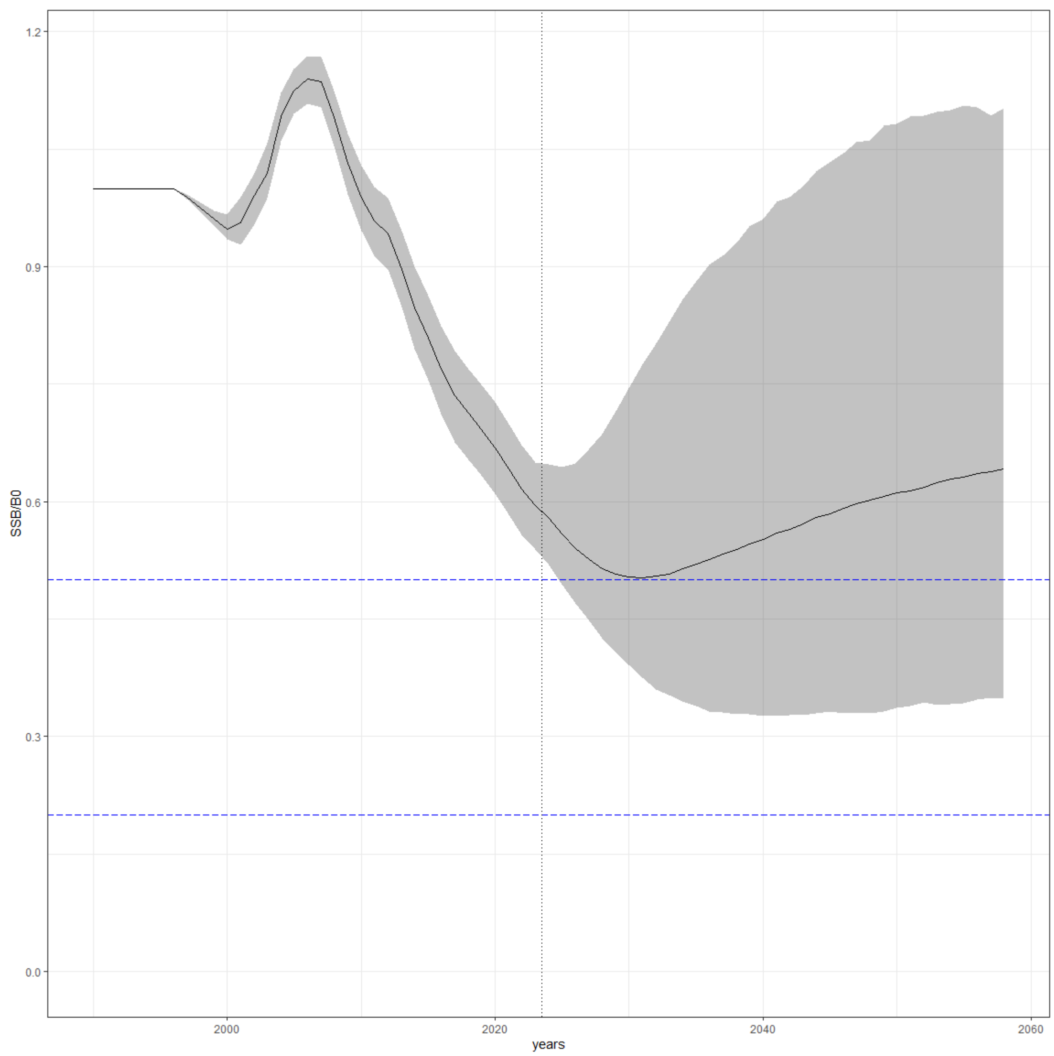

Figure 13.2. SSB status relative to B_0, MCMC projection until 2058 based on a constant catch of 19 tonnes.

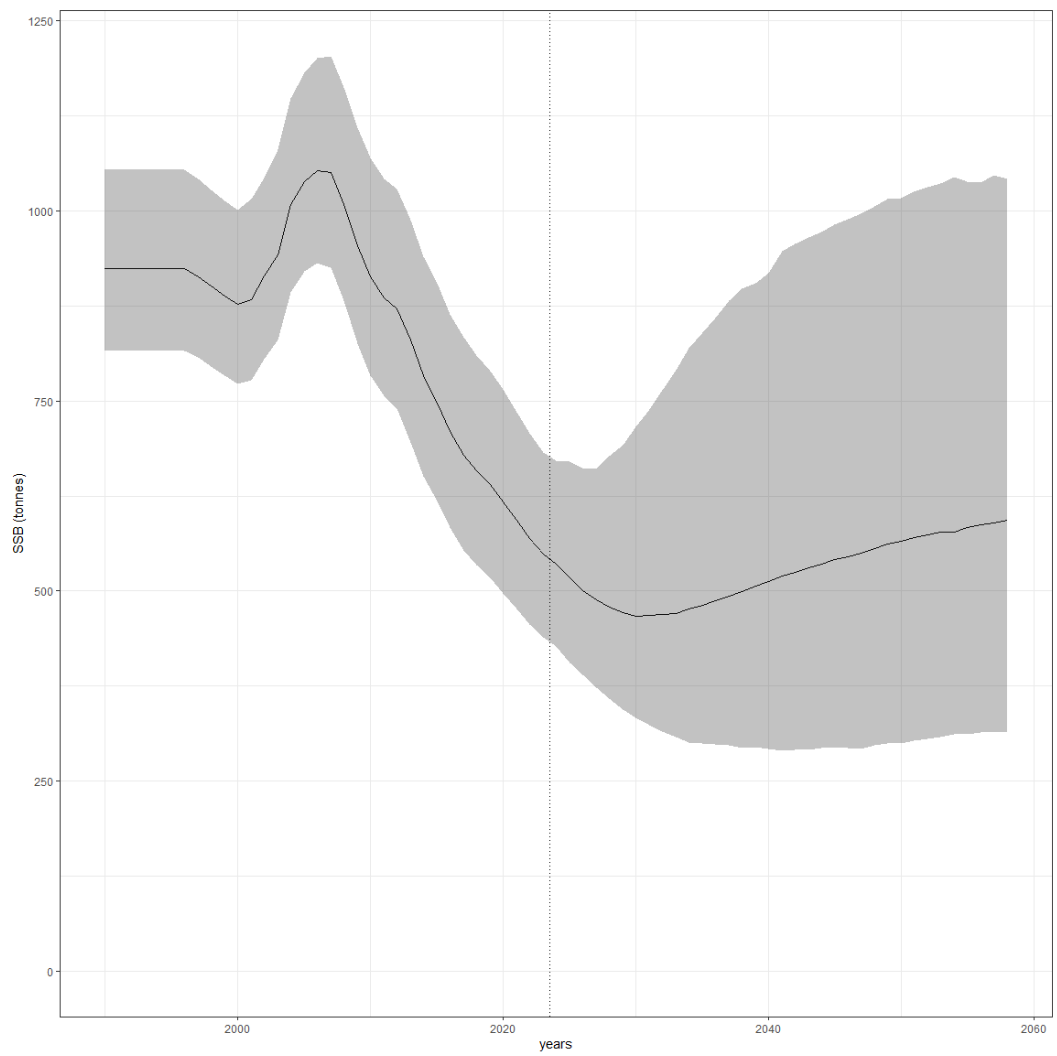

Figure 13.3. SSB, MCMC projection until 2058 based on a constant catch of 19 tonnes.

15. Summary

The model estimates of stock size continue to fluctuate slightly between assessments due to the influence of the additional data as highlighted in the bridging analysis and the historical and analytical retrospective analyses (Figures 10.1 and 10.2). Despite this, the estimates of recruitment, stock status and diagnostics remain consistent across all models. Therefore, future advice should be based on developing the Casal2 model which offers the advantages in speed and flexibility for future model development.

The results of the final assessment show that a TAC of 19 tonnes is consistent with the CCAMLR Decision Rule. This would be expected to achieve an SSB of 64% of B_0 after the 35-year period, with a low probability of falling below 20% of B_0.

16. References

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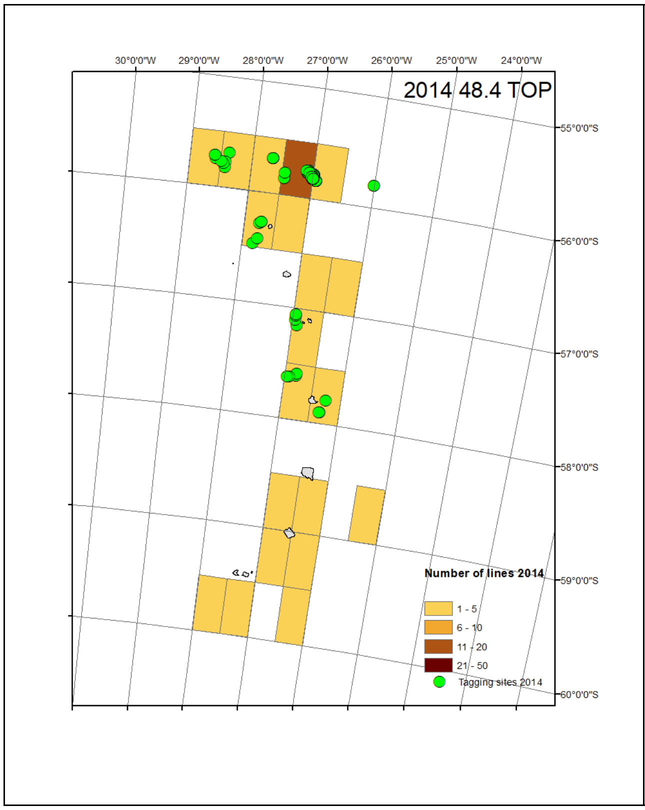
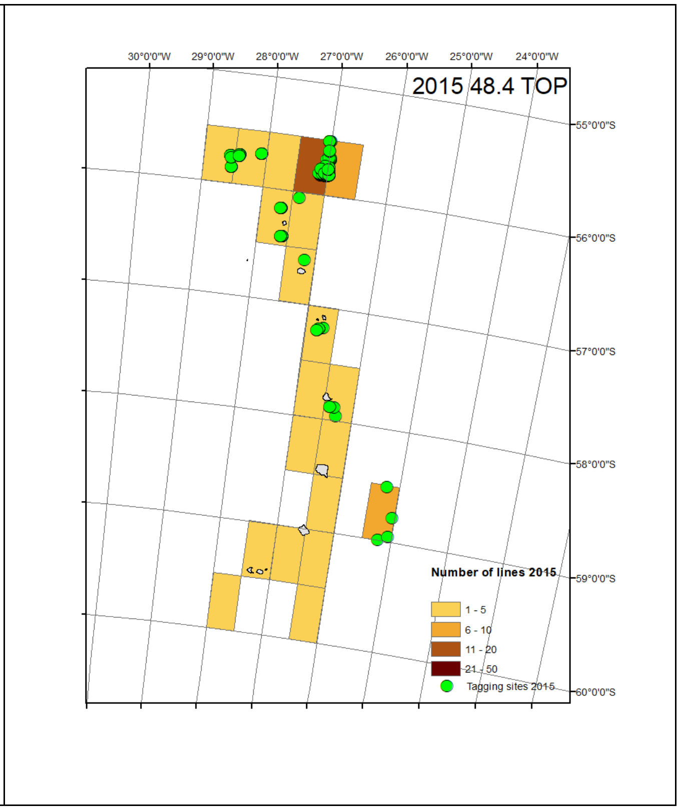
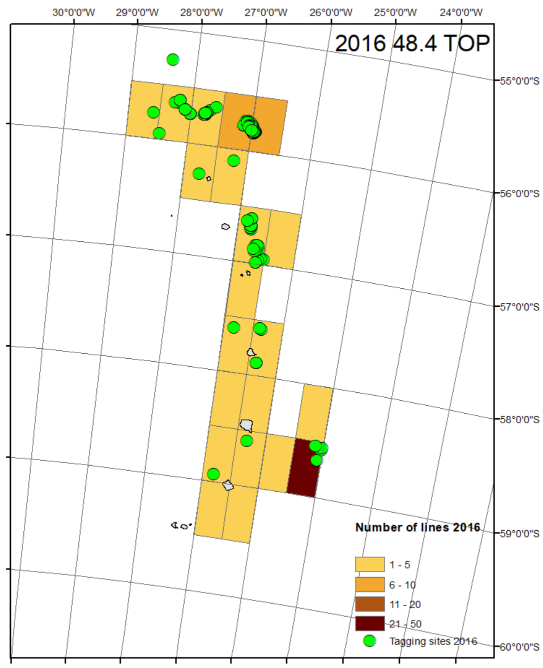
Annex 1: Plots of fishing effort for Patagonian toothfish in Subarea 48.4.



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30°0'0"W
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26°0'0"W
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24°0'0"W
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56°0'0"S
57°0'0"S
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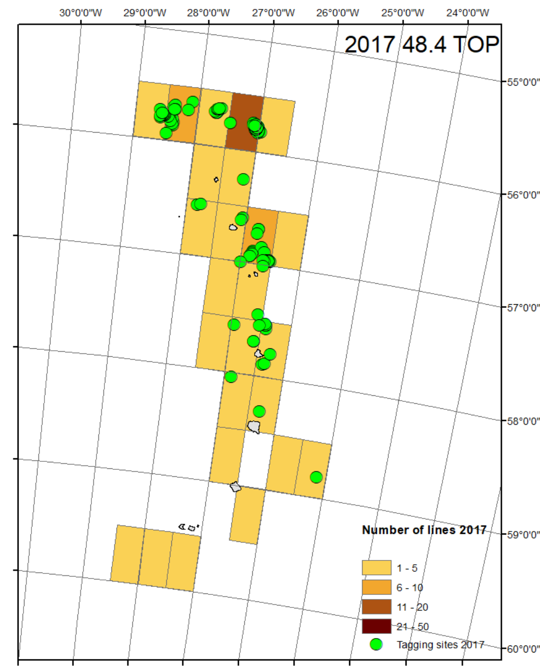
6 - 10
11 - 20
21 - 50
Tagging sites 2016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57°0'0"S
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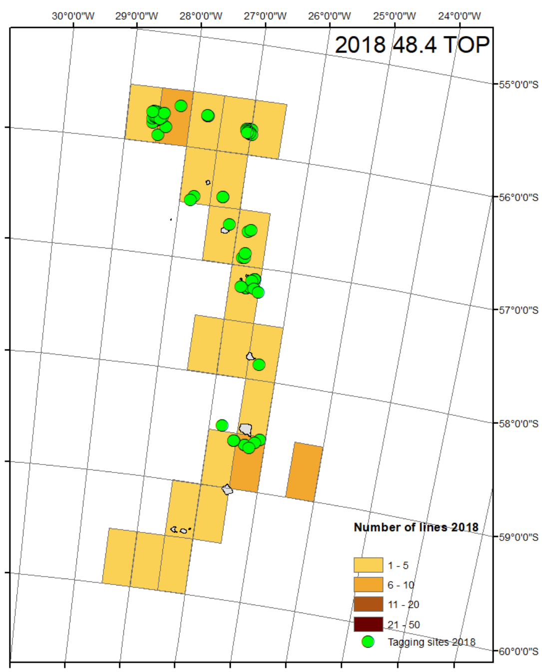
11 - 20
21 - 50
Tagging sites 2017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Number of lines 2018
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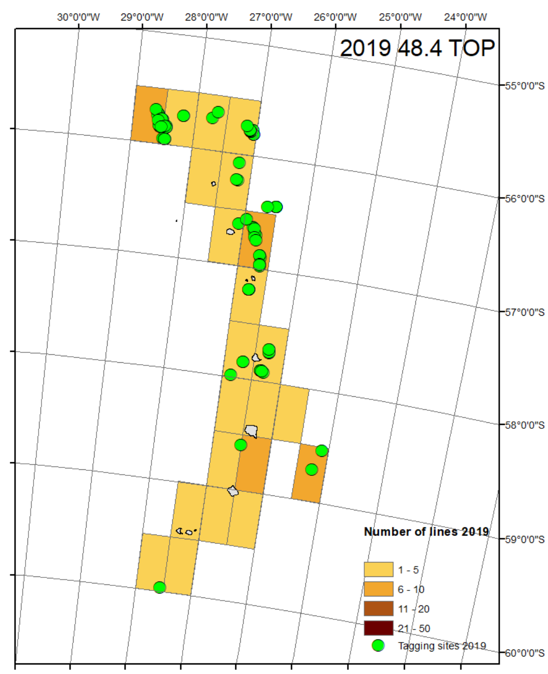
11 - 20
21 - 50
Tagging sites 2018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Number of lines 2019
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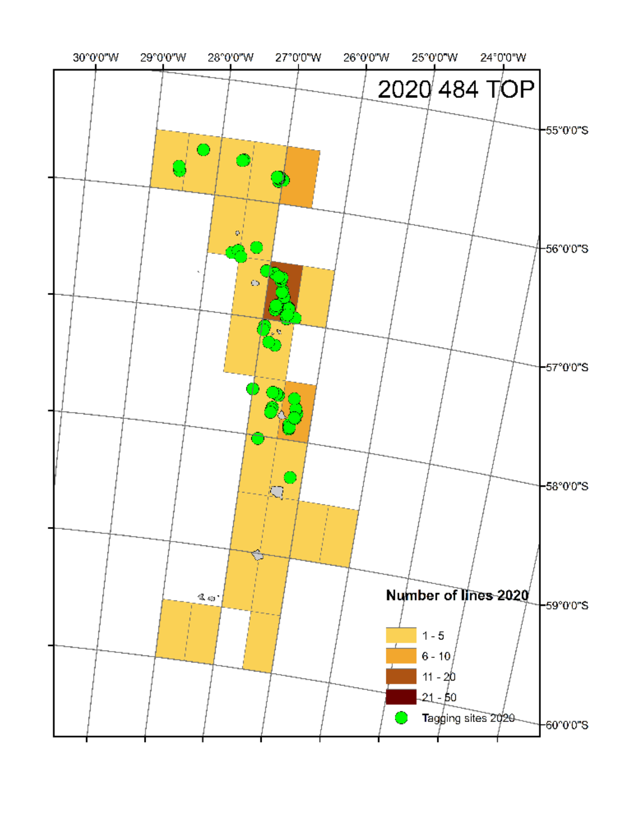
6 - 10
11 - 20
21 - 50
Tagging sites 2019


2020 484 TOP
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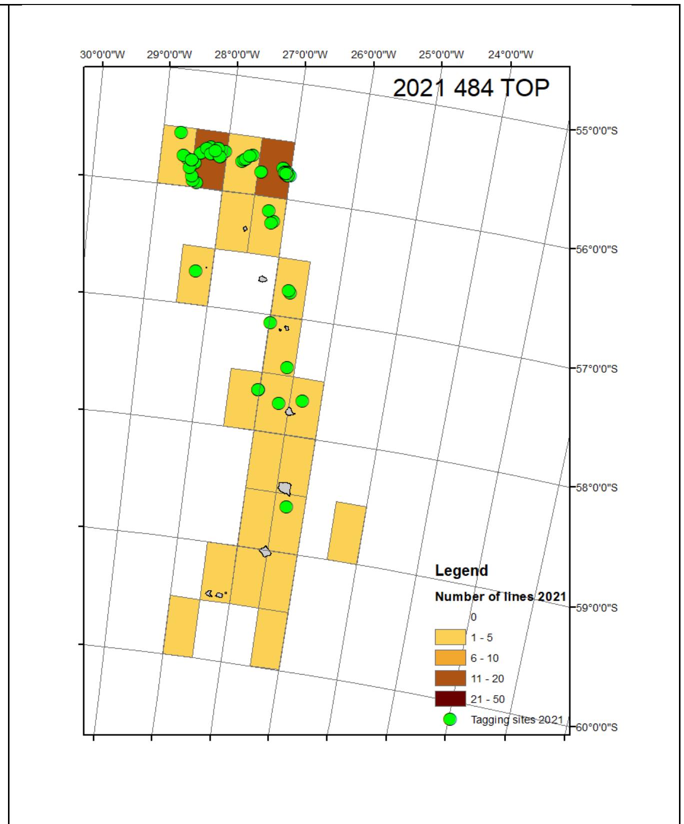
11 - 20
21 - 50
Tagging sites 2020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Legend
Number of lines 2021
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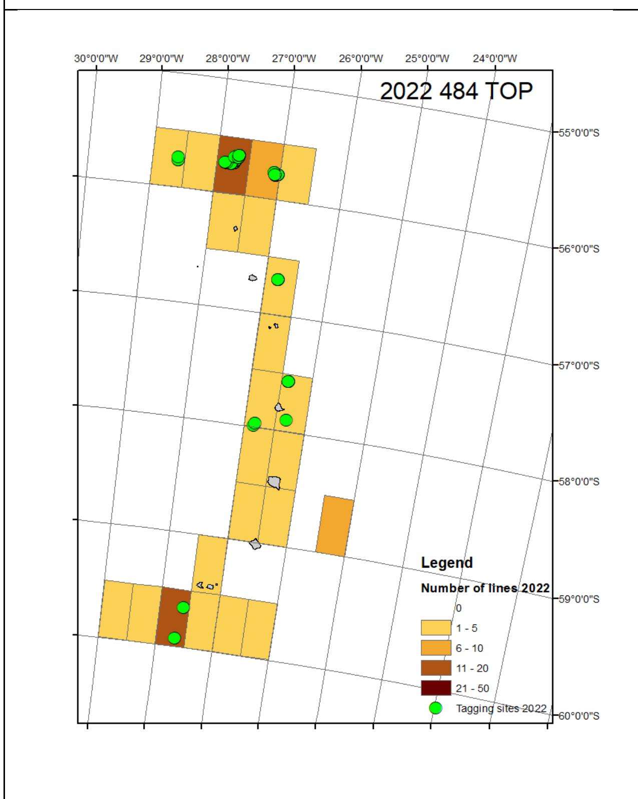
6 - 10
11 - 20
21 - 50
Tagging sites 2021


2022 484 TOP
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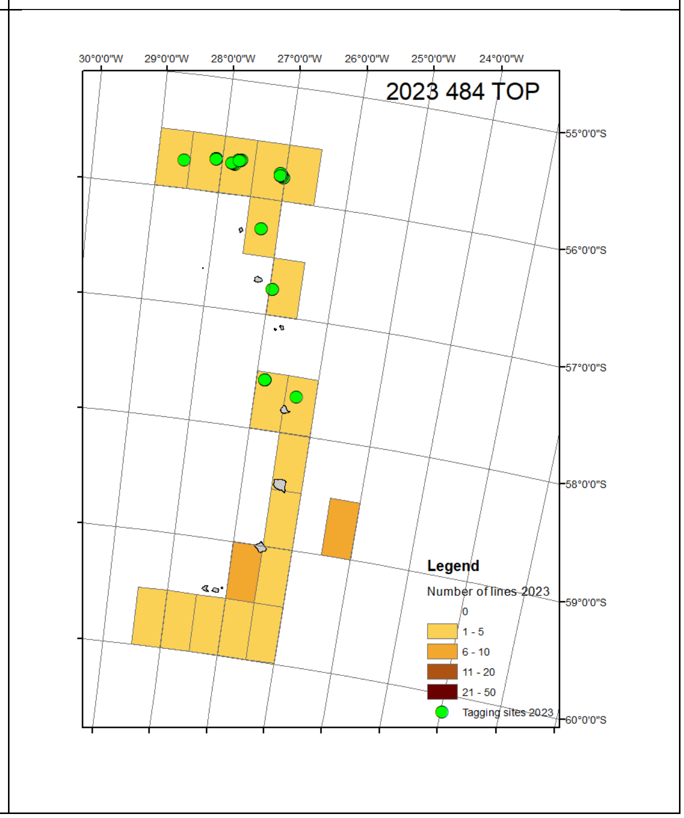
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Preliminary tag-recapture based population assessment of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4 - 2024/25 fishing season

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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 968 tonnes since 2020. Applying the CCAMLR agreed precautionary assumption of setting harvest rates based on a 5-year average biomass, and harvest rate of $\gamma = 0.038$, results in a 2025[1] catch limit of 37 tonnes.

Historically, a precautionary approach has been applied in treating the 48.4 Antarctic toothfish as a separate stock. Based on the biological characteristics of the catches in Subarea 48.4, and the surrounding regions, the Antarctic toothfish around the south of Subarea 48.4 are now hypothesised as being part of a much larger stock that extends south into Subareas 48.2, 48.6 and possibly 48.5. The current method of assessment, based on tag returns, consequently, is considered to provide an estimate of the local biomass. There is initial evidence indicating a northward shift of the boundary between Antarctic and Patagonian toothfish species in Subarea 48.4. Further observations and analyses are required to monitor any changes in stock area due to climate change and / or stock dynamics, and ensure any changes are integrated into the fisheries management of this area.

1. Introduction

In Subarea 48.4 (Figure 1), exploitation of Patagonian toothfish (*D. eleginoides*) began in 2005, and in 2009 for Antarctic toothfish (*D. mawsoni*), with a pilot tagging program initiated in 2005. Between 2009 and 2021, the fishery has been carried out by two vessels, and more recently by one vessel, with annual combined Antarctic toothfish catches ranging 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

[1] The seasons are labelled, henceforth, according to calendar year in which the season finishes e.g. the 2025 season refers to the season from 1 December 2024 to 30 November 2025.

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 with the southern area comprising mainly Antarctic toothfish (Appendix 2: Figures A.1 and A.2). 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 and length based Casal2 assessment model (Readdy and Earl, 2023), whereas Antarctic toothfish stock status is estimated annually, using a mark-recapture approach.

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	kg	kg/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

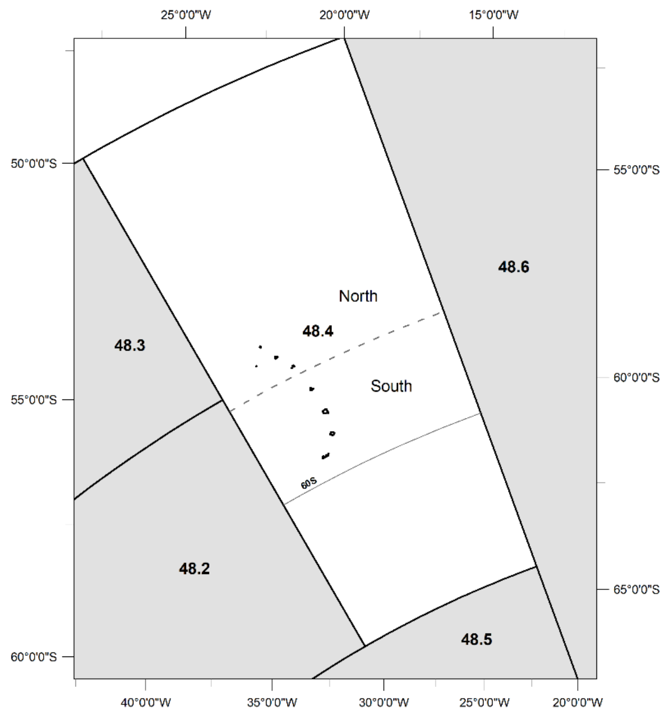

Figure 1. Map of area 48.4. Dashed line at 57.33˚S indicates previous North and South rectangles, which since 2012 have been combined into species-specific assessments for Antarctic and Patagonian toothfish.

1.1. Historic overview of key changes to the assessment

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 and CCAMLR agreed to use this from 2015 (CCAMLR, 2015). This has been applied in all successive years, with a minor correction introduced in 2015 (Walker *et al*., 2015).

Data from the Ross Sea and Subarea 48.6 on the biology of Antarctic toothfish suggests that on seamounts, tags may not be available beyond 3 years (Parker and 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 3 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 3 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 3-year limitation on tags at liberty in the Chapman biomass estimation in Subarea 48.4. 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. Numbers in bold indicate the tags used in the assessment. (Note: only tags released and recaptured in Subarea 48.4 are included in the assessment).

Release year	Number of releases	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total recaptures
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					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**	8
2023	150																**9**	9
2024	215																4	4
Totals	3,156	2	22	7	4		3	15	22	12	12	8	8	33	20	5	23	196

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

Year	Key changes	Estimated stock status (tonnes)
Until 2012	Combined assessment with 48.4 TOP, spatially segregated into N and S	1,368 (2012)
2013	Petersen tag-based assessment, Subarea-wide, TOA only	640
2014	As 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) and limiting 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 5-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

2. Data and approach used for the assessment

Primary data were checked for consistency with Antarctic toothfish taken as being identified to species at recapture and not at release, as some fish were identified as Antarctic toothfish at release and Patagonian at recapture and *vice–versa*.

A total of 3,156 Antarctic toothfish have been tagged in the northern and southern parts of Subarea 48.4 during 2009-2024, of which 196 have been recaptured (Table 2), with a long-term average tag return rate of approximately 6 %. Releases and recaptures south of 60°00’S, which were part of research surveys (Söffker *et al.,* 2021), are excluded.

In 2024, 23 tagged fish were recaptured in Subarea 48.4, all of which had been released in 48.4 during the period 2021-2024 (Table 2). 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 2015-2024, is shown in Appendix 1.

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 have shown higher recaptures following the year of release, with a large number of the recaptures, in each of the years, occurring in a single cluster around the seamounts.

Following the recommendation of WG-FSA-2014 (CCAMLR, 2014) the Antarctic toothfish stock in CCAMLR area 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). Numbers for tag releases and tag recaptures are presented in Table 2. 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, 146 tags recaptured between 2009 and 2024 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 2024 season.

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

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

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
$\overline{w}$ = Mean weight in tonnes of Antarctic toothfish caught between the 2009-2024 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:

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

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 2006-2024 (Figure 2) as:

$$W = 0.00001164\, L^{2.980628}$$

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 0.0377 tonnes. Figure 3 shows Antarctic toothfish length distribution by year (2009-2024).

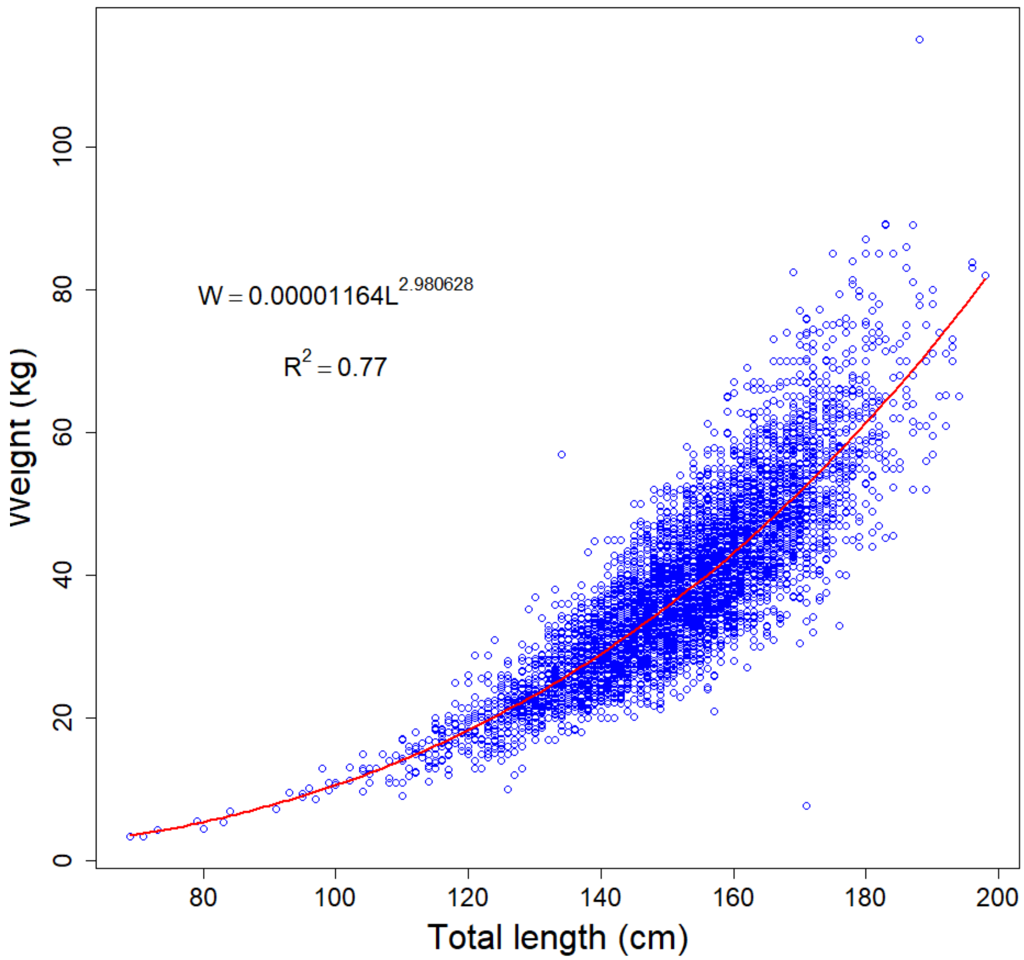

Figure 2. Length – weight relationship for the Antarctic toothfish caught in Subarea 48.4 between 2009 to 2024.

Table 4. Mean weight of the individual Antarctic toothfish in catches.

Year	Mean weight (kg)
2009	39.9
2010	39.8
2011	38.7
2012	35.6
2013	39.4
2014	39.3
2015	40.2
2016	37.5
2017	38.6
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2019	39.2
2020	37.9
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2022	36.8
2023	38.0
2024	37.7

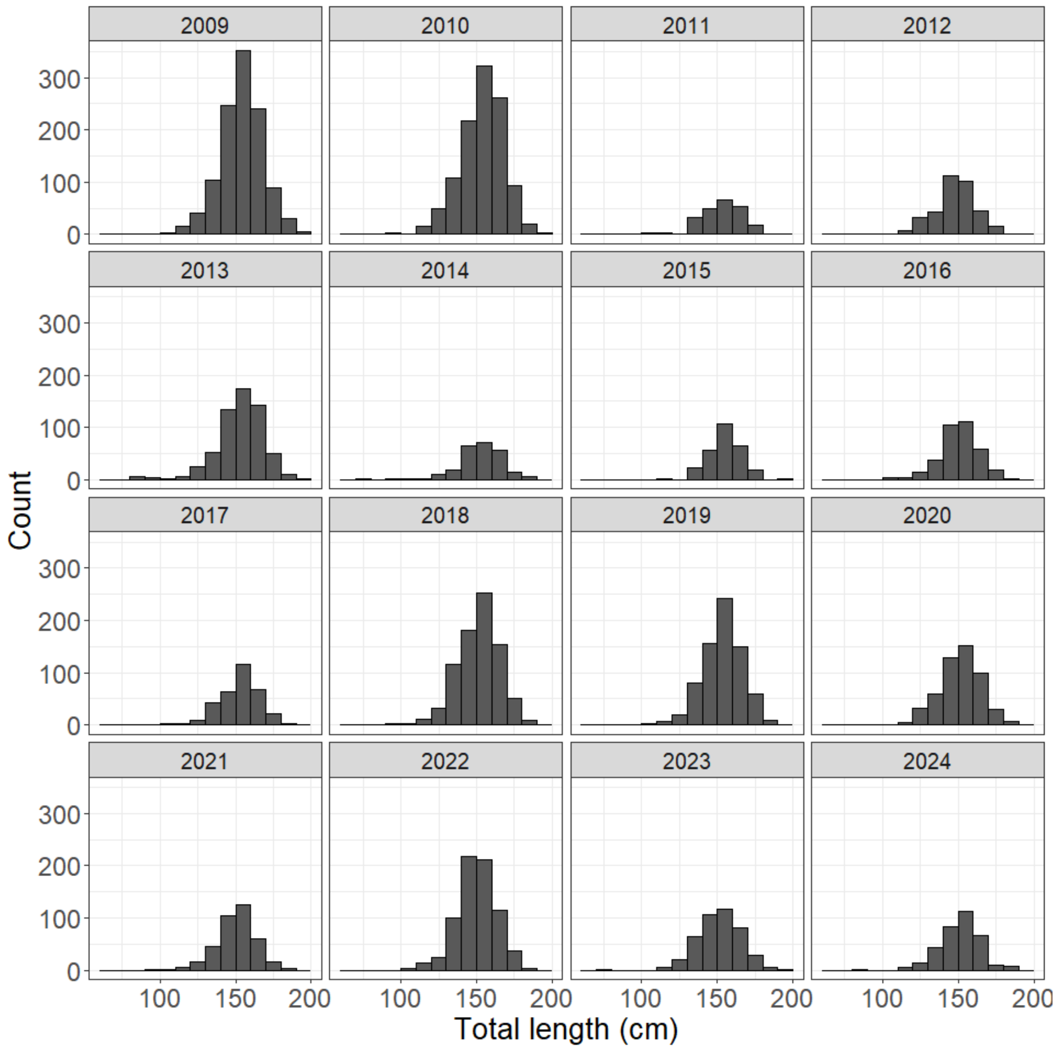

Figure 3. Raw length distribution by year (2009-2024), of Antarctic toothfish in Subarea 48.4.

3. Results

The estimated stock biomass remains variable (Table 5). The geometric mean of the estimates by Chapman method (years with zero recaptures excluded and considering only the first three years after tag release) was 968 tonnes using the 5-year average biomass. Applying the agreed harvest rate of γ = 0.038 to the 5-year average results in a catch limit of 37 tonnes.

Figure 4 shows the annual biomass estimates and the associated variance, where the red horizontal line represents the 5-year biomass estimate at 968 tonnes and the grey dashed line representing 1,067 tonnes using the 15-year average biomass over the full timeseries. The current method of assessment, based on tag returns, is considered to provide an estimate of the local biomass for the area.

Table 5. Biomass estimates by year of tag recapture from the stock assessment of the Antarctic toothfish in Subarea 48.4 using Chapman method and restricting tag availability to 3 years.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Biomass (tonnes)	478	502	1300	-	3462	655	1257	969	2301	1471	1585	744	648	1637	679
Confidence intervals (tonnes)	213	320	1029	-	3908	312	604	517	1581	1076	1020	300	274	1201	280

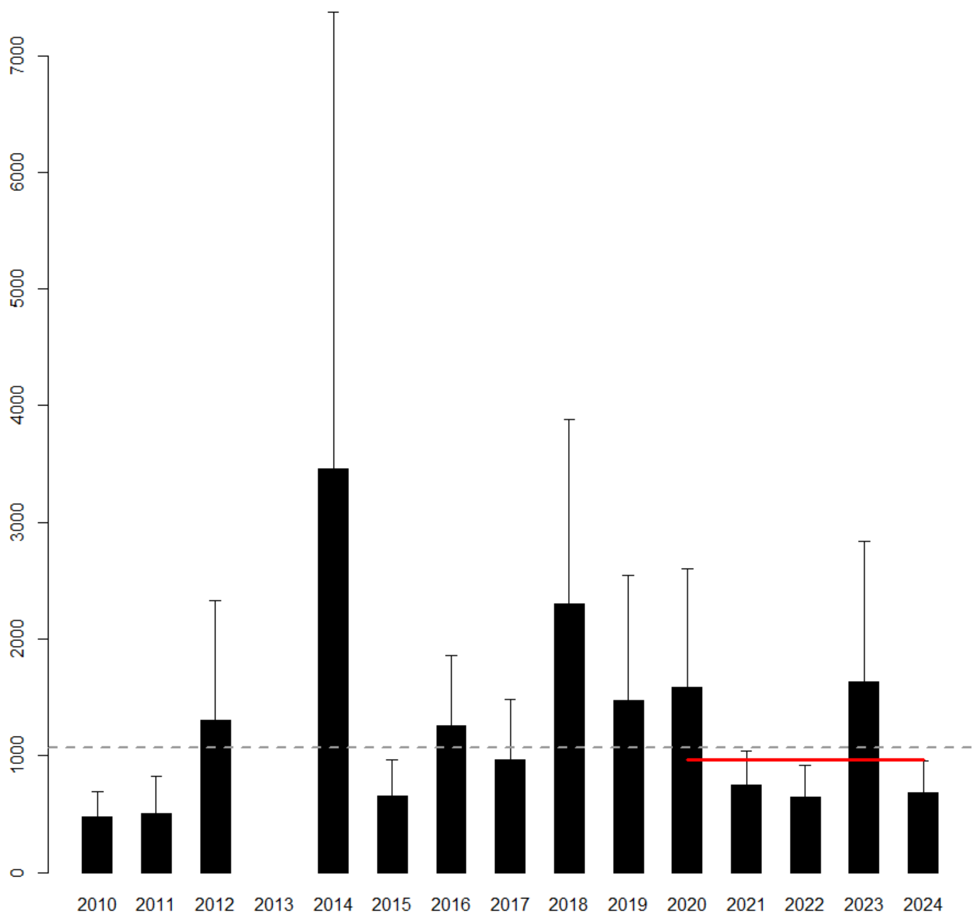

Figure 4. Stock assessment of the Antarctic toothfish in Subarea 48.4 using the method agreed by WG-FSA-14. The solid red line shows the 5-year average biomass at 968 tonnes, between 2020 and 2024, and the dashed grey line shows the historic average estimate of biomass at 1,067 tonnes.

4. Stock identity

Historically, a precautionary approach has been applied in treating the Subarea 48.4 Antarctic toothfish as a separate stock. Based on the biological characteristics (mostly large adults) of the catches 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. Eight 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 2024 (Figure 5). All fish were large adults at recapture, with length ranging from 123-158 cm, and their maturity was recorded as developing or developed, supporting the hypothesis proposed by Söffker *et al*. (2018).

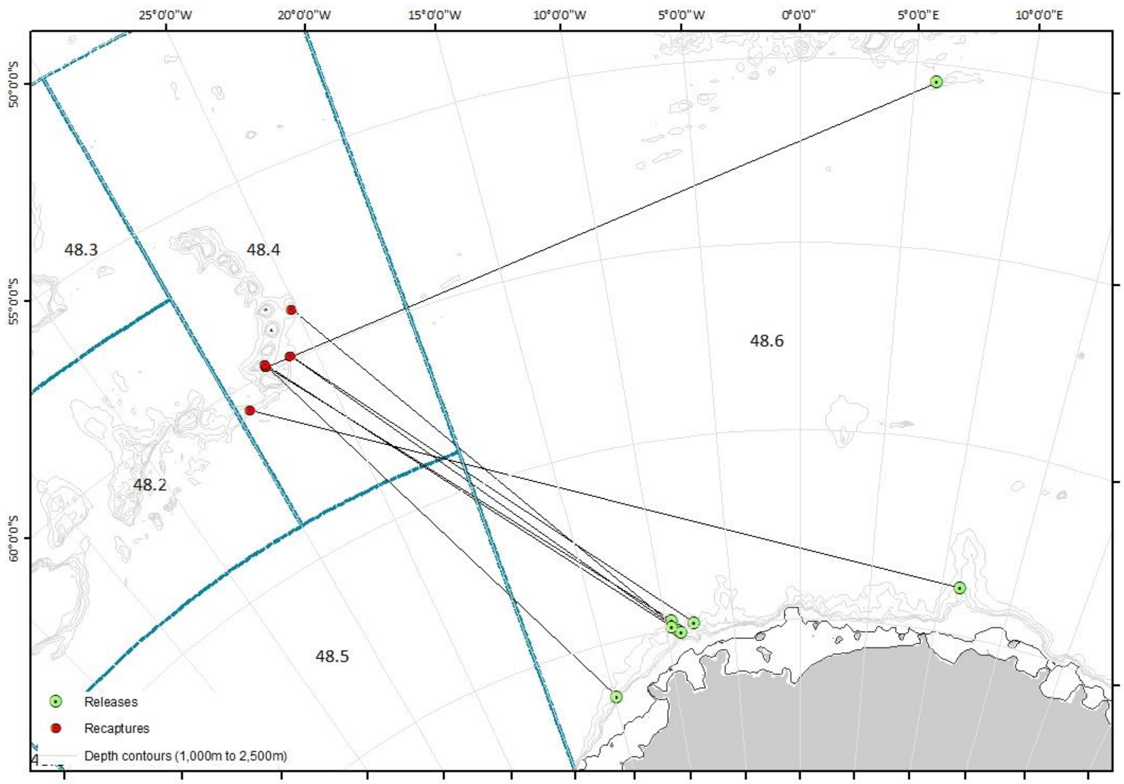

Figure 5. Map showing tagged Antarctic toothfish released outside of Subarea 48.4 and recaptured in 48.4.

5. Stock range

The fishery in Subarea 48.4 operates at the boundary of the range of Patagonian and Antarctic toothfish, with the species composition potentially dependent on the relative stock dynamics and environmental factors, such as water temperature (Söffker *et al.,* 2022). As an indicator of species range, the probability of catching Antarctic toothfish (rather than Patagonian toothfish) was estimated as a function of a two-way interaction of haul latitude and year in a binomial regression. Results suggested that the latitude at which predominance in the catch transitions from Antarctic to Patagonian toothfish had moved northwards over time (Appendix 2, Figure A1), consistent with findings in Söffker et al (2022). To explore whether this relationship could be due to an expansion in

Antarctic toothfish range, or reduction in Patagonian toothfish range, a hurdle lognormal model was fitted to the species' CPUE data with a three-way interaction of haul latitude, species, and year trend. At the latitudes around 57-58°S, Antarctic toothfish catch rates appear to be increasing, whereas Patagonian toothfish catch rates are decreasing (Appendix 2, Figures A2-3).

6. Conclusions

Application of the previously applied harvest rate for the stock (γ = 0.038, based on Patagonian toothfish in Subarea 48.3) results in a yield in 2024 of 37 tonnes using the 5-year average biomass of 968 tonnes. The 2024 biomass estimate is 679 tonnes.

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 were recaptured in each of the last nine years, and so the average over the more recent time period is considered more robust.

There is some initial evidence of a northward shift of the boundary between toothfish species, and further monitoring and analysis is required to ensure any changes in stock area, due to climate change or stock dynamics, are included in the management of this area.

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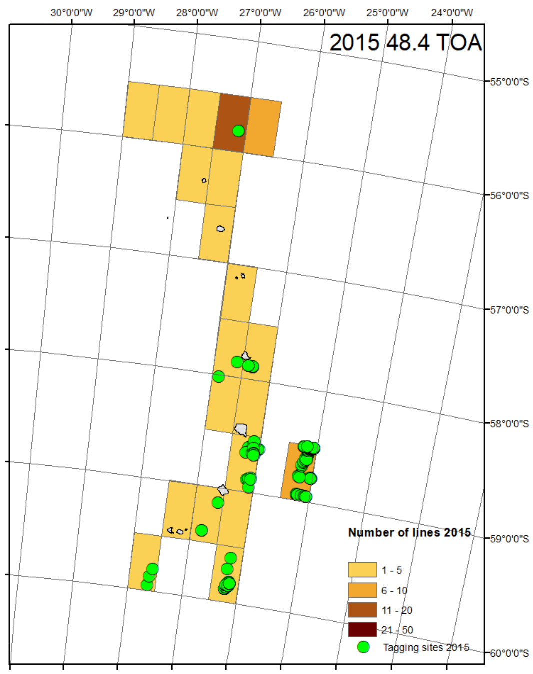
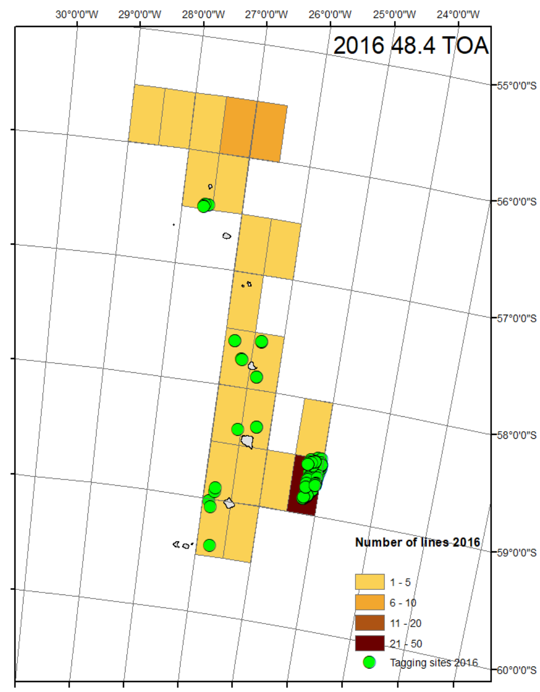
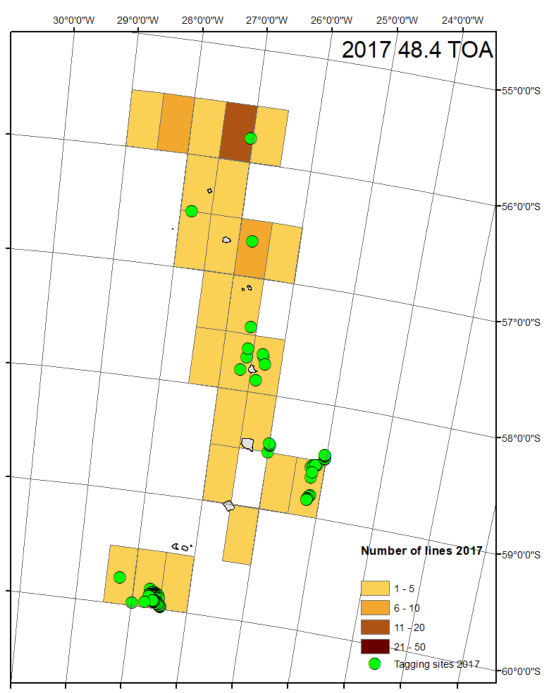
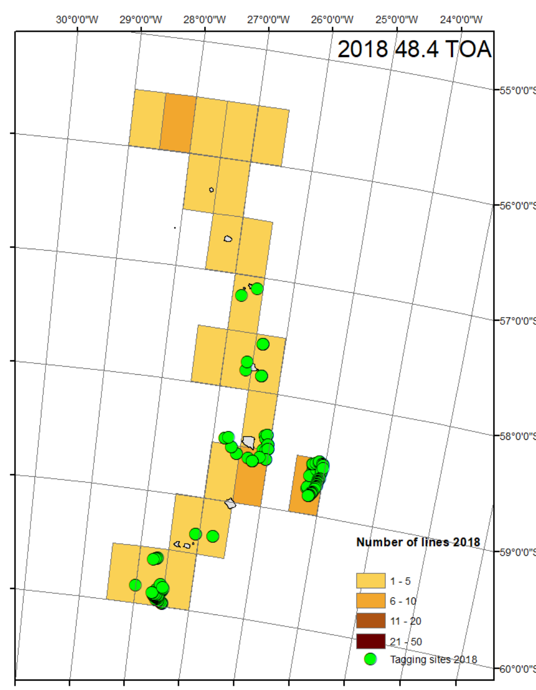
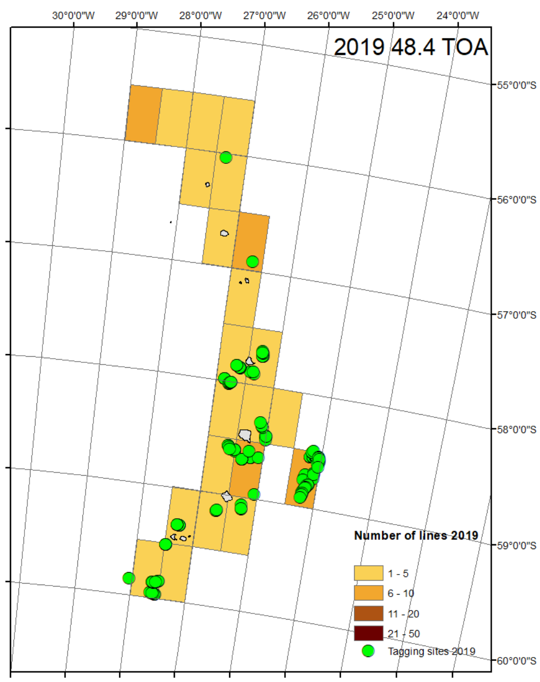
Appendix 1: Fishing Effort Plots







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11 - 20
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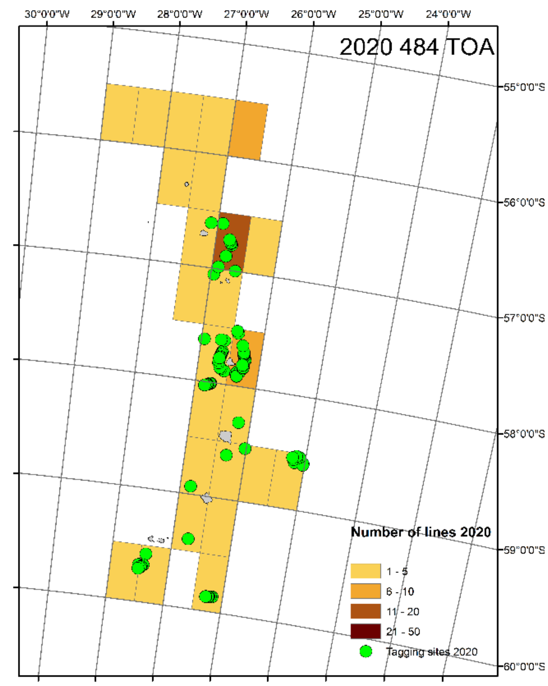
Tagging sites 2019


2020 484 TOA
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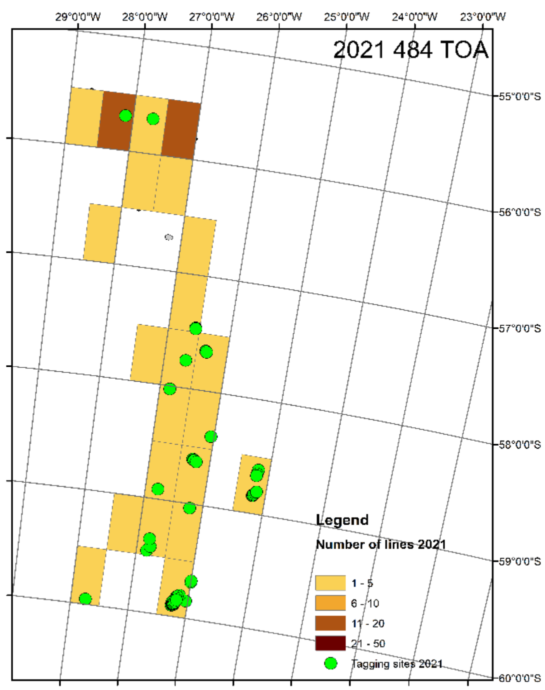
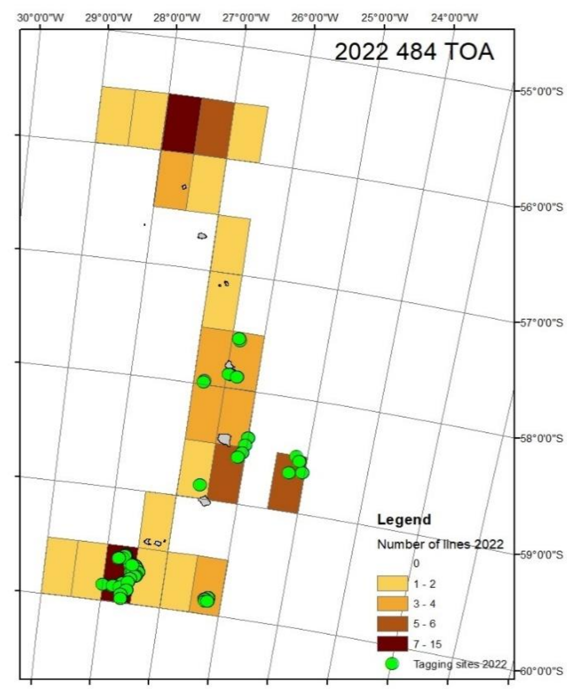
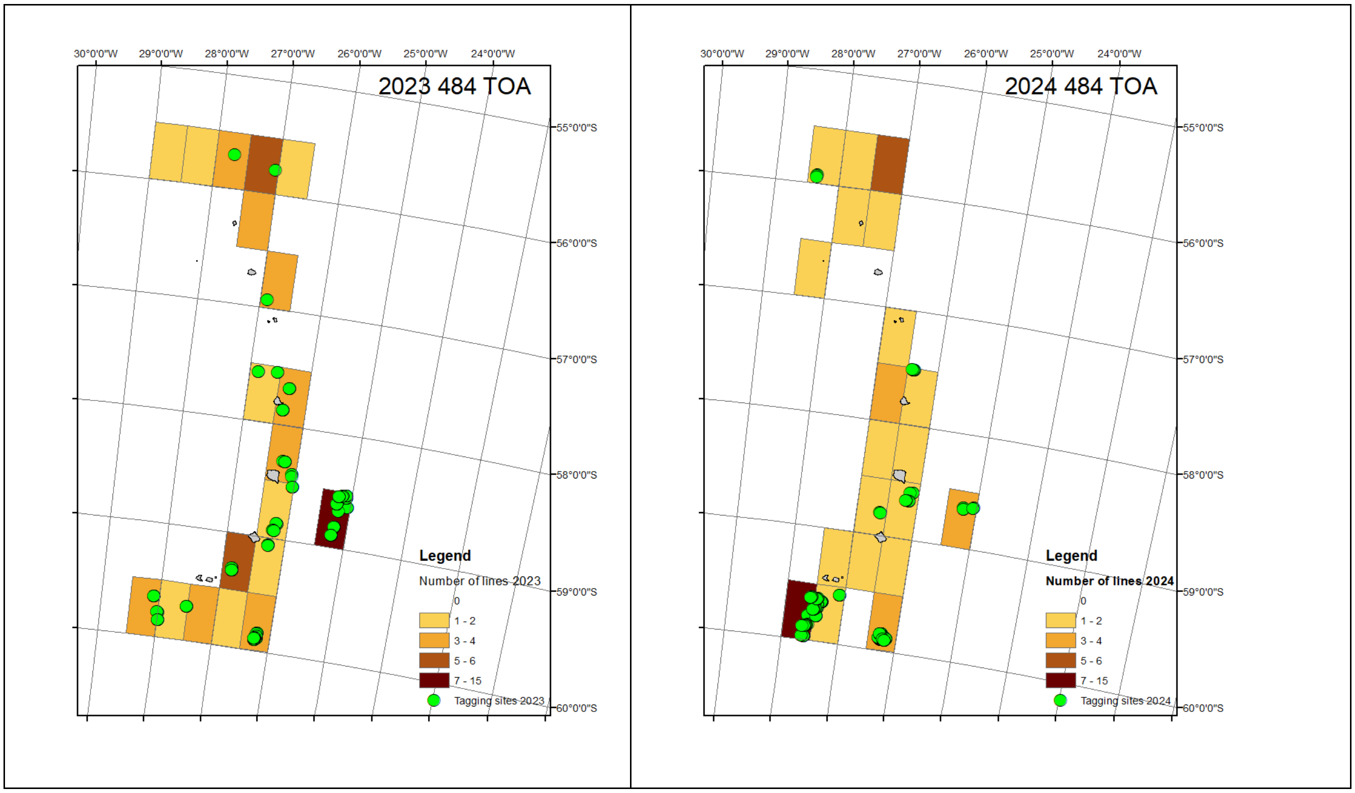
Number of lines 2020
1 - 5
6 - 10
11 - 20
21 - 50
Tagging sites 2020


2021 484 TOA
29°0'0"W
28°0'0"W
27°0'0"W
26°0'0"W
25°0'0"W
24°0'0"W
23°0'0"W
55°0'0"S
56°0'0"S
57°0'0"S
58°0'0"S
59°0'0"S
60°0'0"S
Legend
Number of lines 2021
1 - 5
6 - 10
11 - 20
21 - 50
Tagging sites 2021


2022 484 TOA
30°0'0"W
29°0'0"W
28°0'0"W
27°0'0"W
26°0'0"W
25°0'0"W
24°0'0"W
55°0'0"S
56°0'0"S
57°0'0"S
58°0'0"S
59°0'0"S
60°0'0"S
Legend
Number of lines 2022
0
1 - 2
3 - 4
5 - 6
7 - 15
Tagging sites 2022


2023 484 TOA
30°0'0"W
29°0'0"W
28°0'0"W
27°0'0"W
26°0'0"W
25°0'0"W
24°0'0"W
55°0'0"S
56°0'0"S
57°0'0"S
58°0'0"S
59°0'0"S
60°0'0"S
Legend
Number of lines 2023
0
1 - 2
3 - 4
5 - 6
7 - 15
Tagging sites 2023
2024 484 TOA
Legend
Number of lines 2024
0
1 - 2
3 - 4
5 - 6
7 - 15
Tagging sites 2024

Appendix 2: Species composition preliminary analysis

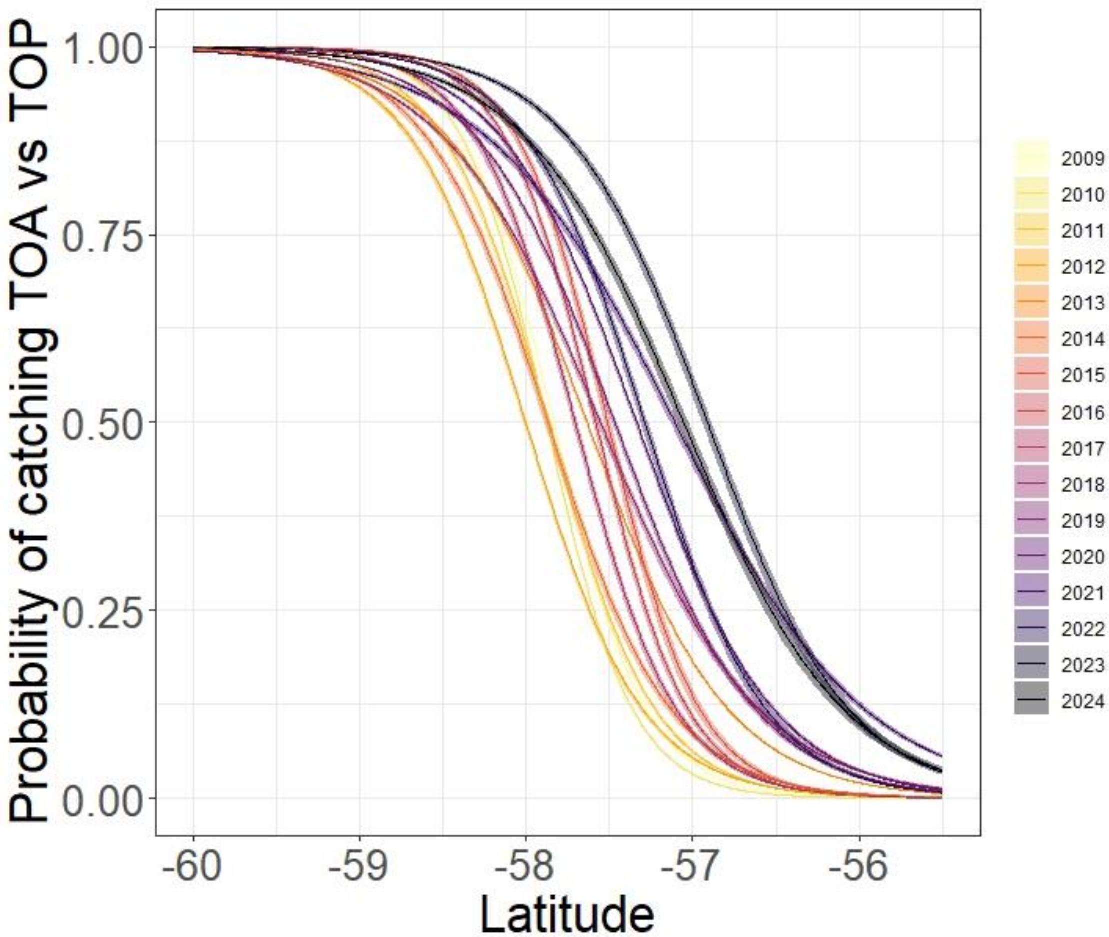


Figure A1. Model predicted probability of catching Antarctic toothfish (relative to Patagonian toothfish) over time and latitude. Solid line shows the mean estimate and shaded area denotes the 95% confidence intervals.

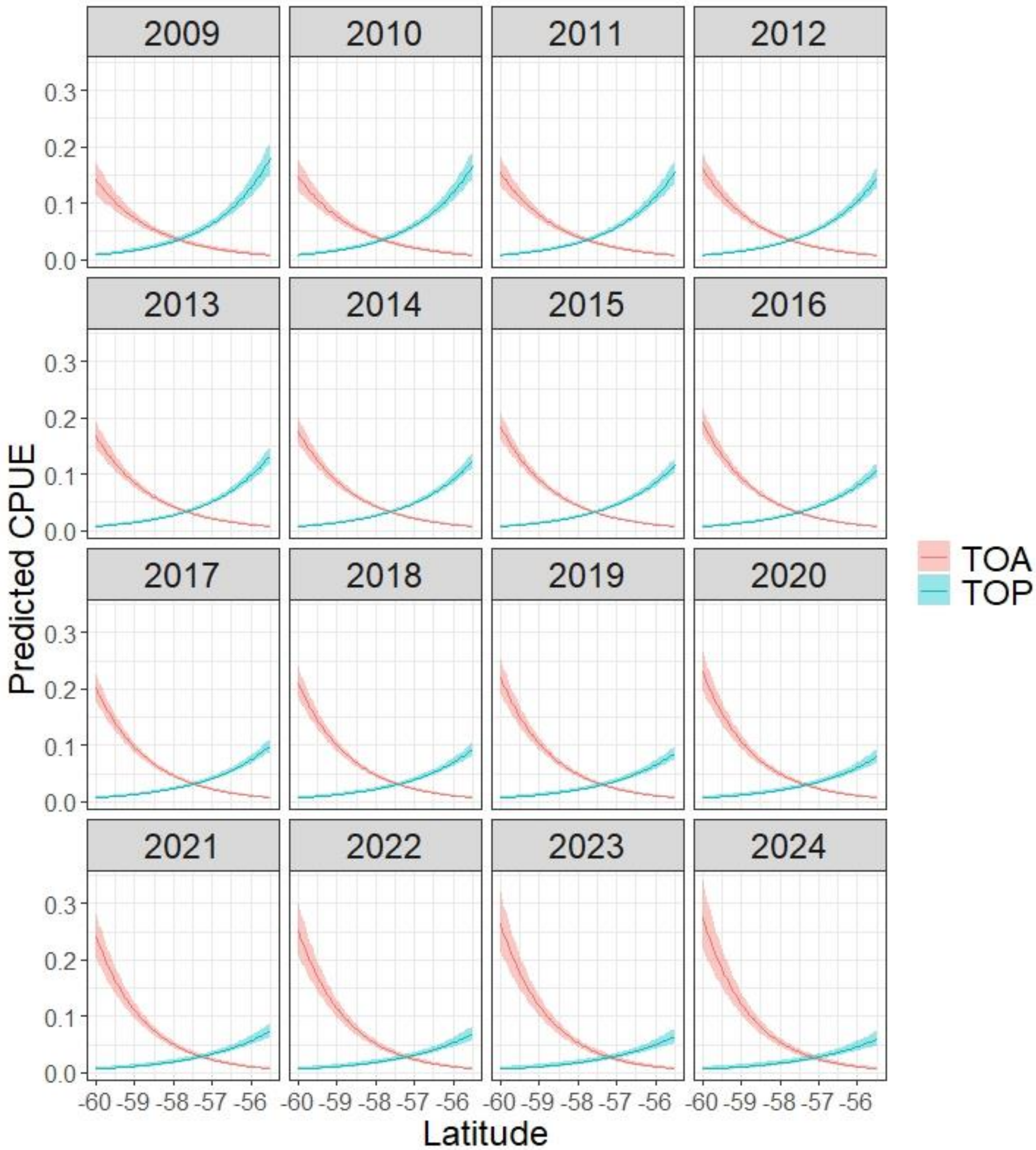


Figure A2. Model predicted CPUE over time and latitude for each species. Solid line shows the mean estimate and shaded area denotes the 95% credible intervals.

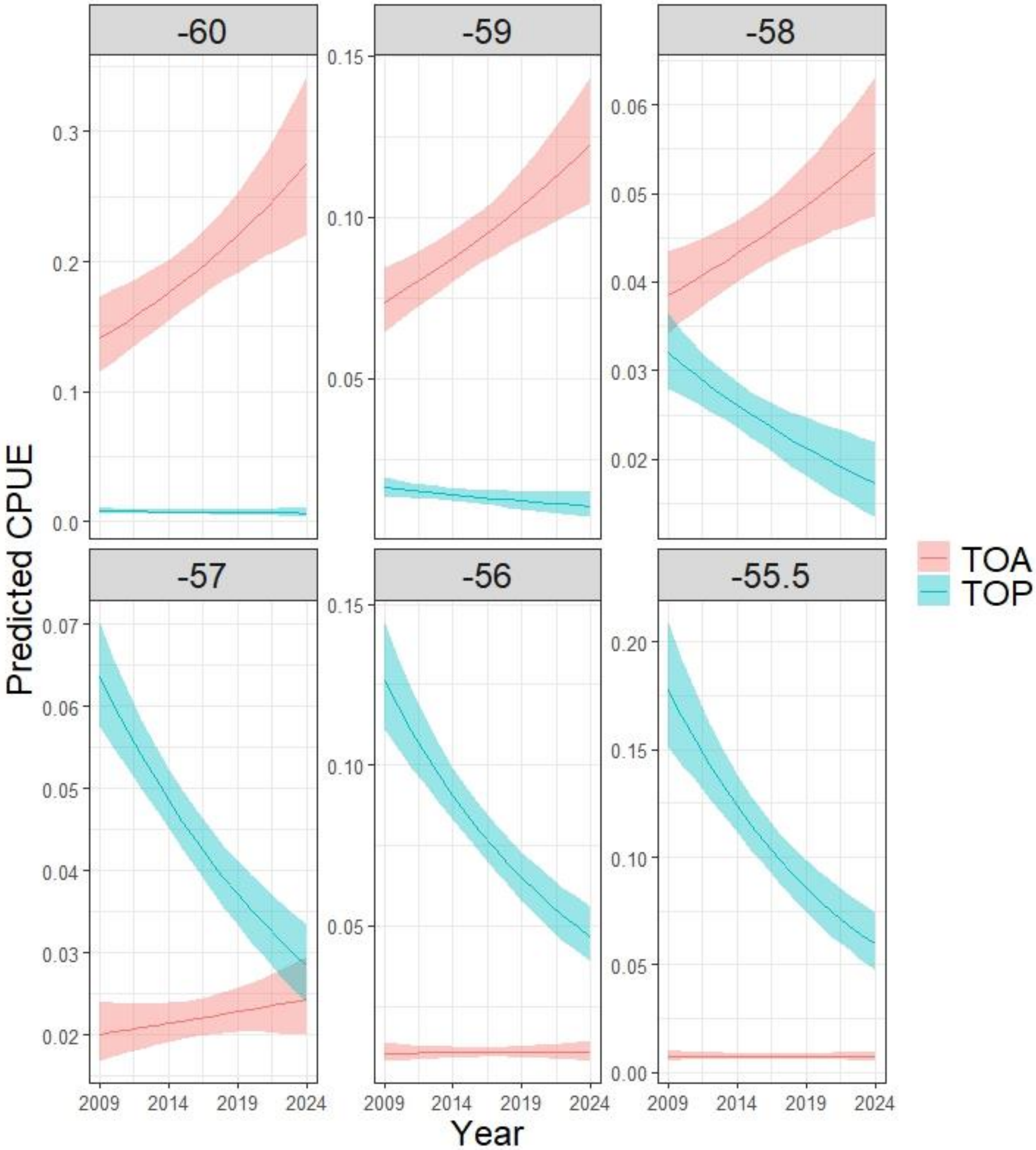


Figure A3. Model predicted CPUE over time and categories of latitude for each species. Solid line shows the mean estimate and shaded area denotes the 95% credible intervals. Note the y axis differs between panels.

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