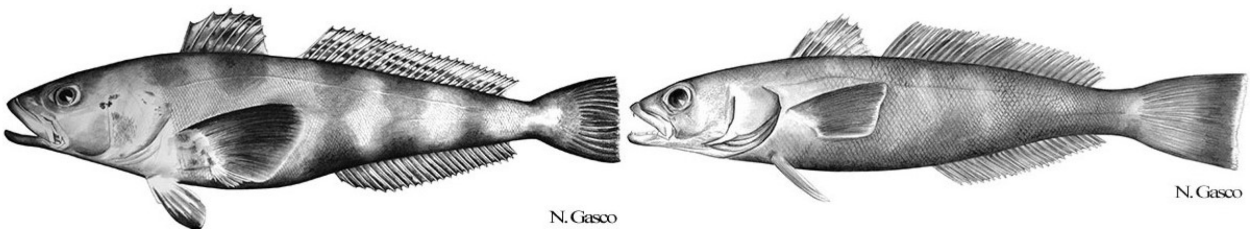
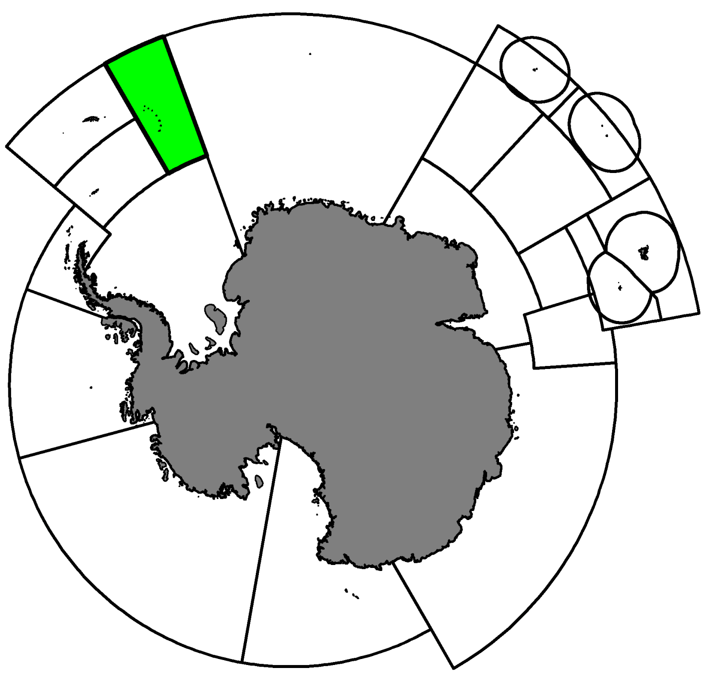
Stock Assessment Report 2021: *Dissostichus eleginoides* and *Dissostichus mawsoni* in Subarea 48.4

CCAMLR Secretariat

26 April 2022



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



Map of the management areas within the CAMLR Convention Area. Subarea 48.4, the region discussed in this report is shaded in green. Throughout this report, "2021" refers to the 2020/21 CCAMLR fishing season (from 1 December 2020 to 30 November 2021).

CCAMLR

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Commission pour la conservation de la faune et la flore marines de l'Antarctique
Комиссия по сохранению морских живых ресурсов Антарктики
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Assessment of Patagonian toothfish (Dissostichus eleginoides) in Subarea 48.4

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WG-FSA

EN

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

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Abstract

This paper describes an updated CASAL based assessment of Patagonian toothfish (*D. eleginoides*) in Subarea 48.4. The assessment data are updated with the observations for the 2019 and 2020 seasons[1]. Stock projections indicate that the stock was at 65% of B_0 in 2021 and that a yield of 23 tonnes in 2022 and 2023 is consistent with the application of the CCAMLR harvest control rule.

The assessment would lead to a recommendation from Working Group FSA to Scientific Committee that the catch limit for *D. eleginoides* in Subarea 48.4 should be set at 23 tonnes for 2021/22 and 2022/23.

1. Introduction

The fishing for Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4 began in 2003 and a pilot tagging program was initiated in 2005. Data for the stock assessment are taken from the 2005 season onwards and have been updated to include the observations from the 2019 and 2020 seasons, for which CCAMLR agreed a catch limit of 27 tonnes. Historically catches fluctuated from 18.7 tonnes (2006) to 97.6 tonnes (2007) but averaging generally around 40-50 tonnes, with 17.1 tonnes caught in 2019 and 18.6 tonnes in 2020 (Table 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). Fishing effort by season is shown in Annex 1.

[1] Seasons are referred to by the year that the CCAMLR season ends in, as this is when the fishing occurs, e.g. the 2020 season runs from 1st December 2019 to 30th November 2020.

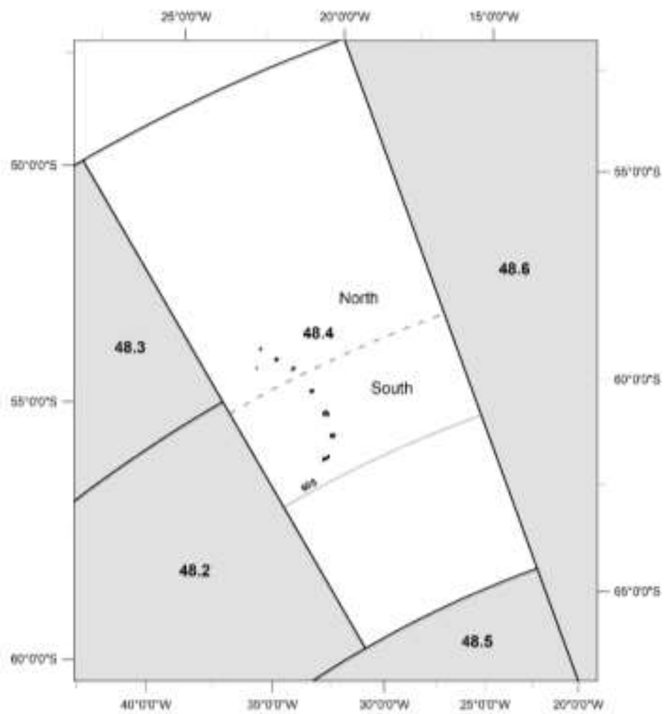

Figure 1. Map of area 48.4. Dashed line at 57.33˚S indicates previous North and South rectangles, which since 2012 have been combined into a single assessment.

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). The northern component was assessed as a single species (*D. eleginoides*) whilst the southern component was assessed as a species complex including both *D. eleginoides* and *Dissostichus mawsoni*. Both species are caught throughout Subarea 48.4 although *D. eleginoides* is predominantly caught in the north whilst *D. mawsoni* is mainly caught in the south. The stocks were managed through separate TACs for the northern and southern regions and the management measures allowed for a directed fishery for *D. eleginoides* in the north, in which the targeting of *D. mawsoni* was prohibited, and a mixed fishery for *Dissostichus spp*. in the southern region. The northern region stock was assessed through a length-based CASAL (C++ Algorithmic Stock Assessment Laboratory, https://www.niwa.co.nz/fisheries/tools-resources/casal) model, and the stock in the southern region was assessed with a tag-recapture based Petersen biomass estimation (Walker *et al.,* 2015).

Since 2013, the assessment for *D. eleginoides* was expanded to cover the entire 48.4 area and included the southern component into an age-based CASAL model, while the assessment for *D. mawsoni* remained assessed with a tag-recapture based biomass estimation. Data for stock assessment are taken from the 2005 season onwards, and the resulting catch limit applies to the entire area for *D. eleginoides*. This paper describes an updated assessment of *D. eleginoides* for subarea 48.4.

Table 1. 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

2. Input data

In WG-FSA-17 paragraph 3.20 (CCAMLR, 2017) the Working Group recommended that:

"…where some data series are incomplete at the time of assessment, the assessment presented to the Working Group should be based on data that have been through data quality assurance processing rather than placing an emphasis on including the most recent data. It further recommended that toothfish stock assessments should be carried out up to, and including, the current season and include the reported catch data where fishing has been completed, or the anticipated catch for the current season."

As a result, data are included in this assessment up to the end of the 2020 season, with an assumption that catch in 2021 will reach the catch limit of 27 tonnes.

The following additional data sources are used in the updated assessment:

- **Catch tonnage:** Catch tonnage for the 2019 and 2020 seasons was added.
- **Scanned length distribution:** Data for the 2019 and 2020 seasons were added.
- **Tag release data:** Data for the 2018 and 2019 seasons were added.

- **Tag recapture data:** Data for the 2019 and 2020 seasons were added.
- **Otolith aging data from a sample of the catch:** Data for the 2019 and 2020 seasons were added.

With the exception of otolith data, all data were taken from the CCAMLR data extraction dated 03/12/2020.

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 2020 (Figure 2) tracks one peak of potentially several year classes throughout time, 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 has decreased in relation to the preceding and subsequent weaker year classes until 2018 when it is no longer possible to distinguish this peak.

The age distribution of the catches has been determined annually since 2011 by random sampling of otoliths from the catch (Figure 3). In addition to the random sampling, the catch was sampled using a stratified sampling scheme in 10 cm bin distributions since the 2015 season in order to provide data for the age-length-key (ALK) at smaller and larger sizes than those targeted by the fishery. The number of otoliths read for construction of the ALK is shown in Table 2. The sample size for age determination has varied over time, but in recent years has averaged around 200.

Table 2. Sample size for age determination collected by scientific observers in Subarea 48.4 for D. eleginoides.

Year	Sample size for age determination
2011	85
2012	191
2013	63
2014	153
2015	208
2016	158
2017	76
2018	235
2019	314
2020	199

An age-length key is calculated independently for each year (Figure 3) and used to raise the length distribution observed in the catch to an age distribution. The parameters of a von Bertalanffy growth model are estimated within the stock assessment model. Consecutive age compositions (Figure 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.

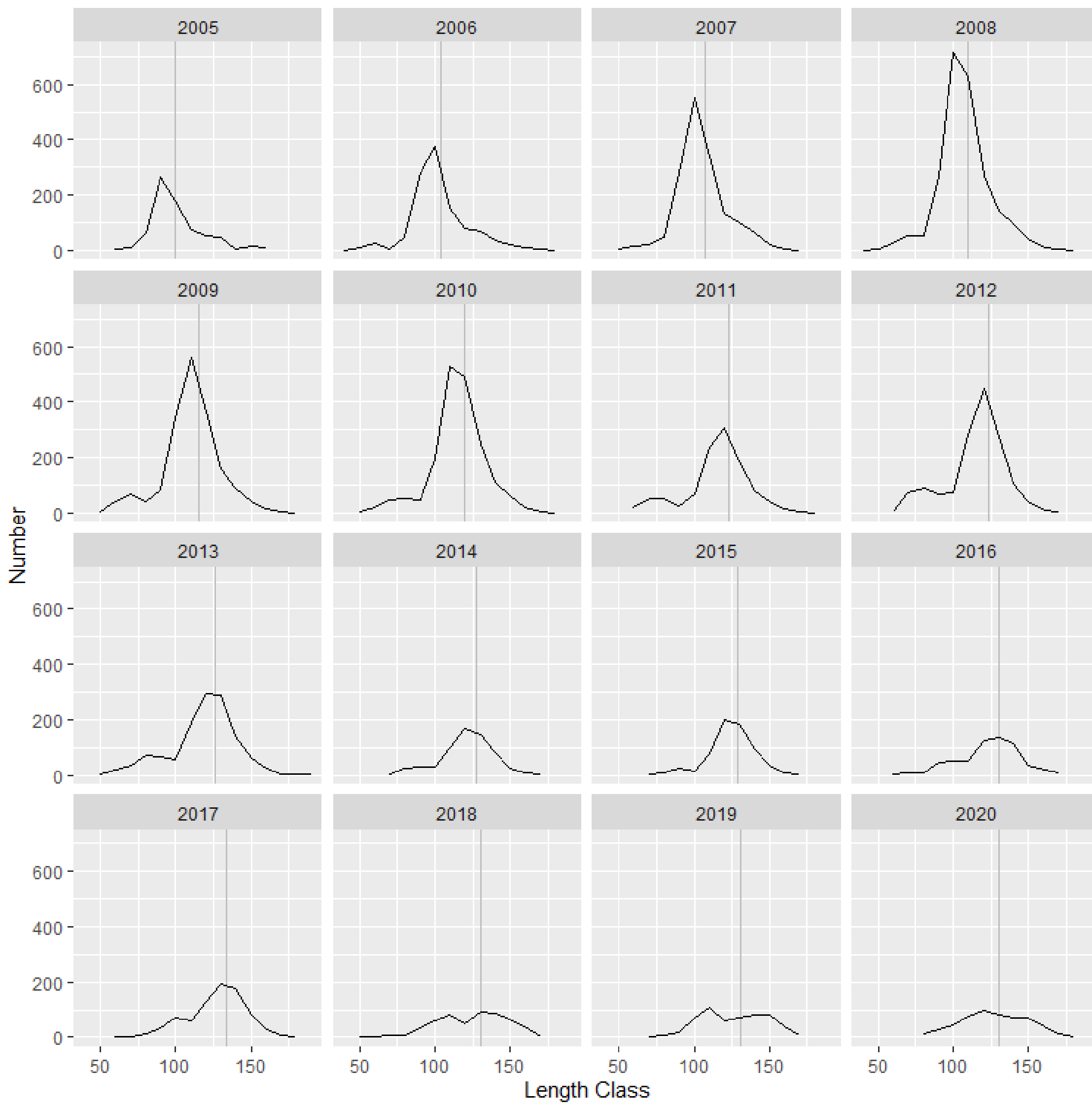

Figure 2. Catch length frequency by 10cm length class 2005-2018. Grey lines represent the median length for each year.

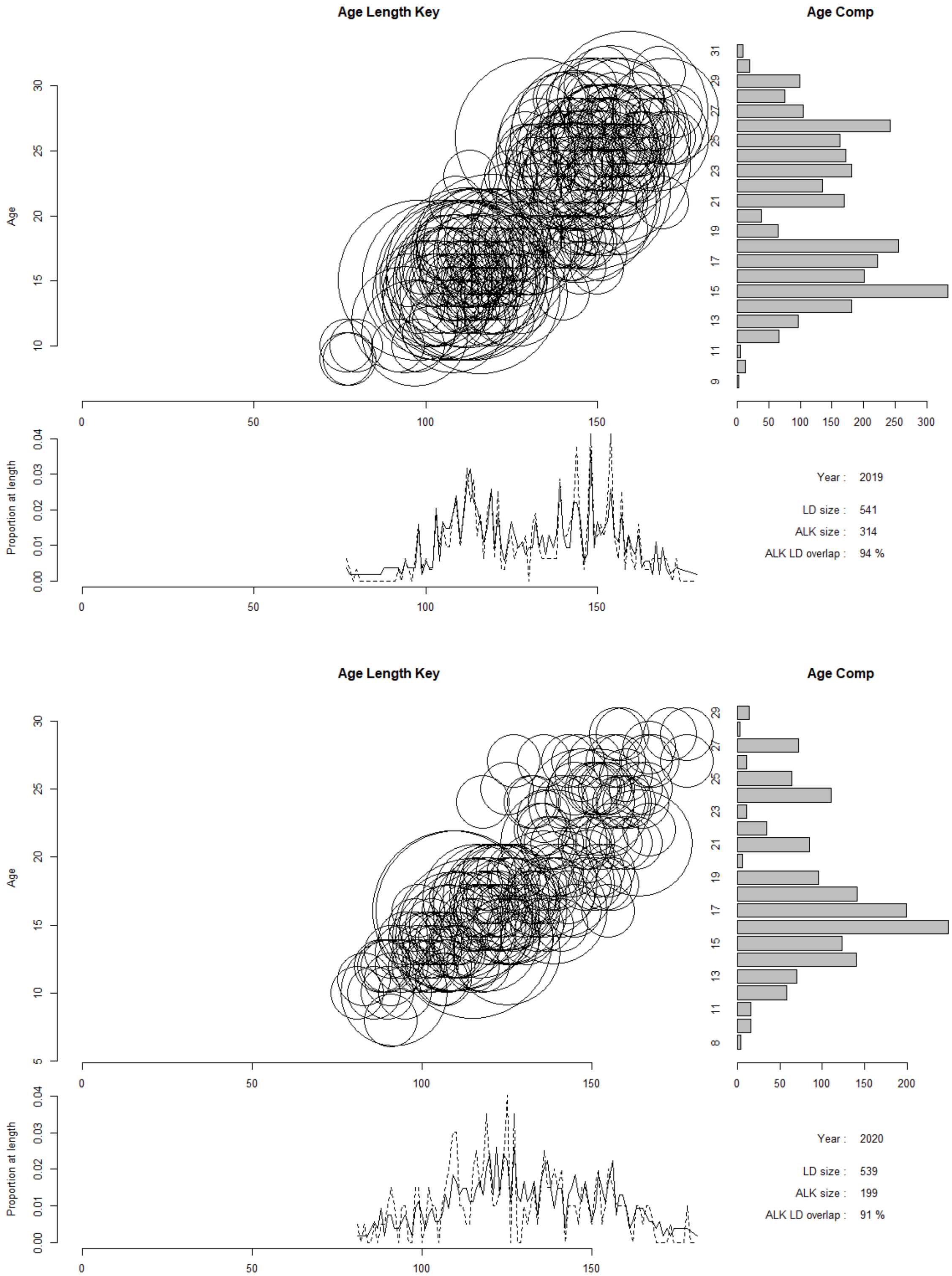

Figure 3. 2019 and 2020 ALKs. Lower panel of each plot shows length distribution of fishery (solid) and aged samples (dotted). The upper left panel shows the age and length of aged fish, with size of circles indicating the number of samples. The right panel shows the derived age composition.

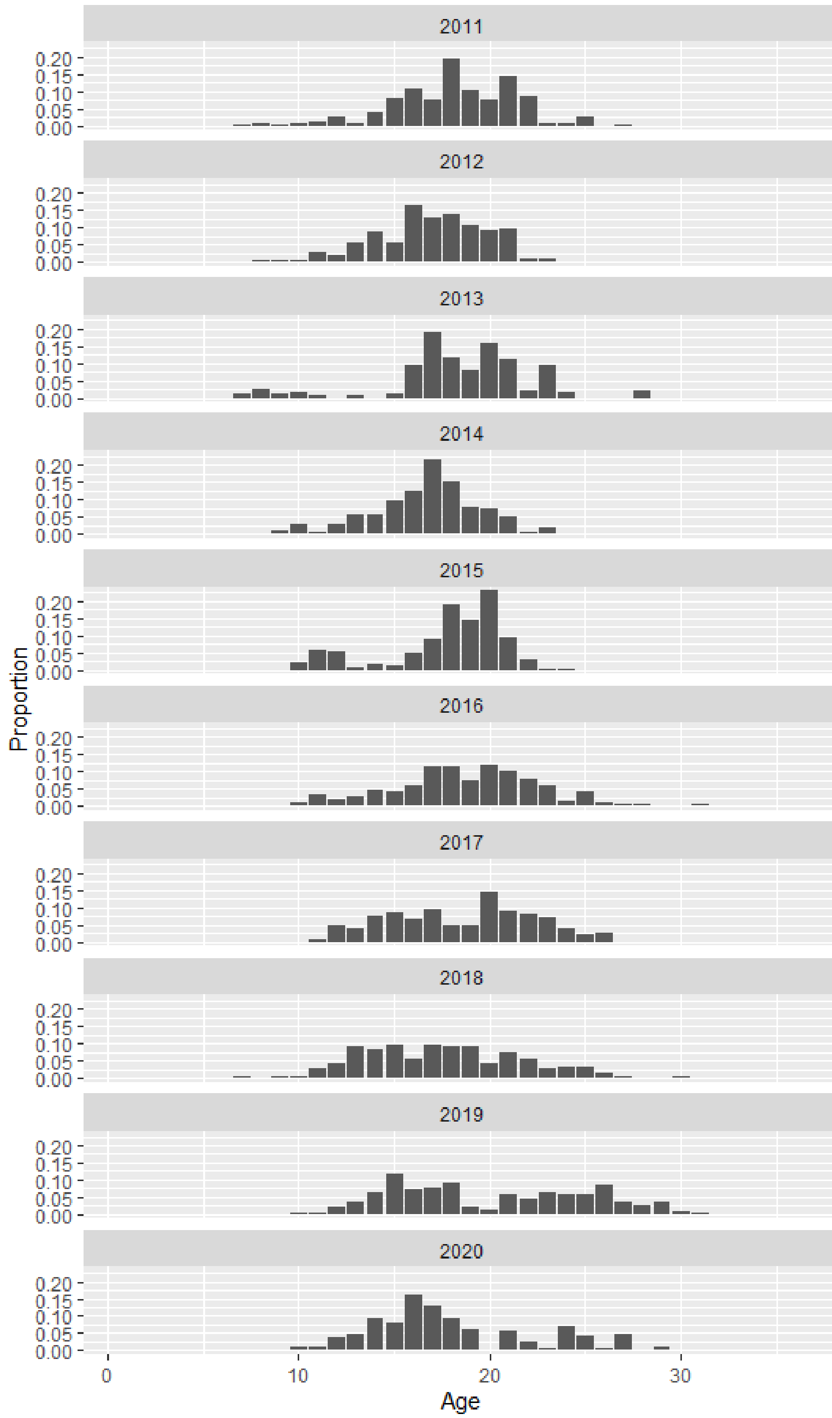

Figure 4. Raised age composition of otolith samples from the catch by year 2011-2020.

4. Tagging data

Between 2005 and 2019, a total of 3941 *D. eleginoides* were tagged and released in Subarea 48.4 (Table 3). To date, a total of 488 were recaptured in 48.4 (Table 3). This region encompasses both *D. eleginoides* and *D. mawsoni*; 17 fish have been misidentified upon release; therefore, the tag recaptures only include fish that have been identified as *D. eleginoides* at both release and recapture. Another 136 *D. eleginoides* have been released in 48.4 and recaptured in 48.3 and are also currently excluded from the assessment. The 56 fish that have been recaptured in 48.4 in 2019 and 2020 had been released across a range of years.

Table 3. Tag-recaptures of D. eleginoides in 48.4. Numbers in bold indicate the tags used in the assessment

Release Year	Total Releases	Recapture Year															All Years
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
2005	42	**0**	**0**	**2**	**2**	0	1	0	0	0	1	0	0	0	0	0	6
2006	134	0	**2**	**8**	**5**	**2**	1	2	2	0	0	2	1	0	0	0	25
2007	291		0	**13**	**13**	**1**	**4**	5	4	2	1	0	0	2	2	0	47
2008	504			0	**8**	**11**	**8**	**11**	10	3	3	7	6	2	3	2	74
2009	551				3	**16**	**12**	**12**	**8**	2	5	3	4	0	1	4	70
2010	418					2	**13**	**2**	**12**	**4**	1	4	3	2	2	3	48
2011	220						0	**0**	**2**	**3**	**0**	4	2	1	1	1	14
2012	303							0	**7**	**3**	**2**	**2**	3	5	3	1	26
2013	468								0	**23**	**19**	**15**	**7**	1	4	3	72
2014	223									0	**20**	**12**	**9**	**1**	2	2	46
2015	226										0	**11**	**12**	**7**	**4**	1	35
2016	224											0	**5**	**1**	**4**	**3**	13
2017	159												1	**1**	**1**	**2**	5
2018	87													0	**1**	**3**	4
2019	91														0	**3**	3

5. Biological Parameters

The biological parameters used in the CASAL assessment are provided in Table 4 and are unchanged from the 2019 assessment.

Table 4. Parameters used in the CASAL model for 48.4 TOP

Component	Parameter	Value
Natural mortality	*M*	0.13
Length to mass (cm to t)	*a*	$4.091e^{-09}$
	b	3.196
Maturity range (0 to full maturity)		1 - 23
Tag-related growth retardation (years)		0.75
CASAL tag loss rate ($years^{-1}$)		0.0064
Immediate tagging survivorship		0.9
Tag probability of detection		1
Stock-recruit relationship	*h*	0.75

6. CASAL model structure and results

As in the previous assessment, the CASAL population model is a combined-sex, single-area model with an annual cycle comprising 4 periods. During the first period only recruitment and natural mortality occurs; the second period includes both natural mortality and fishing and contains the spawning period; half the mortality in that particular period being accounted for before spawning occurs; the third period has only natural mortality occurring and the final period 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 2021, with an initial unexploited equilibrium age structure.

The distribution of periods within the annual cycle are currently synchronised with 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. A change in this direction will be considered in the future two area models exploring the linkage between Subareas 48.3 and 48.4.

7. MPD fits

The 2021 model encountered memory allocation from some initial values that had run without problem in previous years following the addition of an extra two years of data. This was resolved by using finite differences for the MPD run (and the MPD provided a suitable starting point for the MCMC chains to run successfully). This issue, combined with the increasing length of time taken for MCMC runs suggests that the model parameterisation will need to the revised before the next model run, and we propose to present work to WG-SAM to address this.

The individual contributions to the overall objective function (Figure 5) show that the 2018 and 2019 size at age data contribute 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 (Figure 6 – Figure 10 and Figure 1-8 in separate diagnostics paper), show that the fit to the age compositions is variable, matching particularly well in 2012, 2016 and 2019, but less so 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 a period with the model over-estimating returns between 2008 and 2012. 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 (Diagnostics Figure 8). The curve fitted the data suitably and showed a slightly better fit to the data from small fish compared to the previous assessment. The parameter t_0 was set to zero; it was not possible to estimate t_0 because of the absence of data from fish smaller than 50cm and 6 years old.

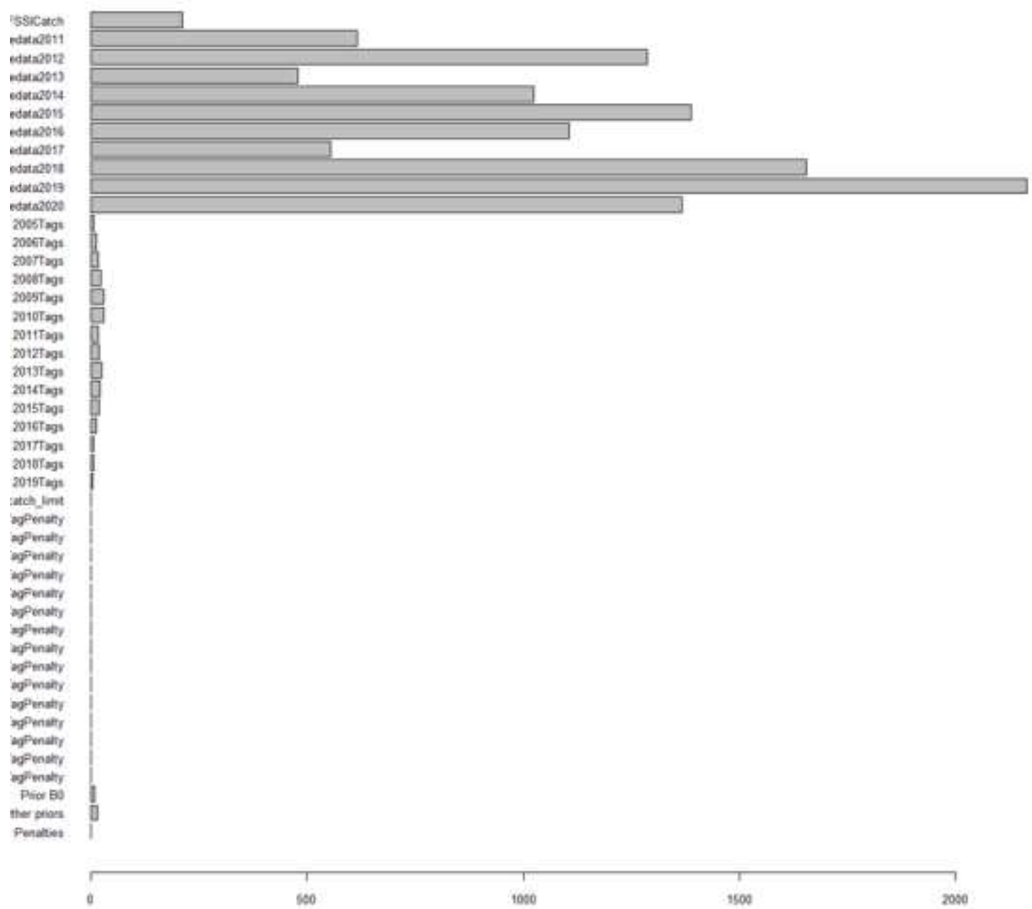

Figure 5. Likelihood components of the MPD fit

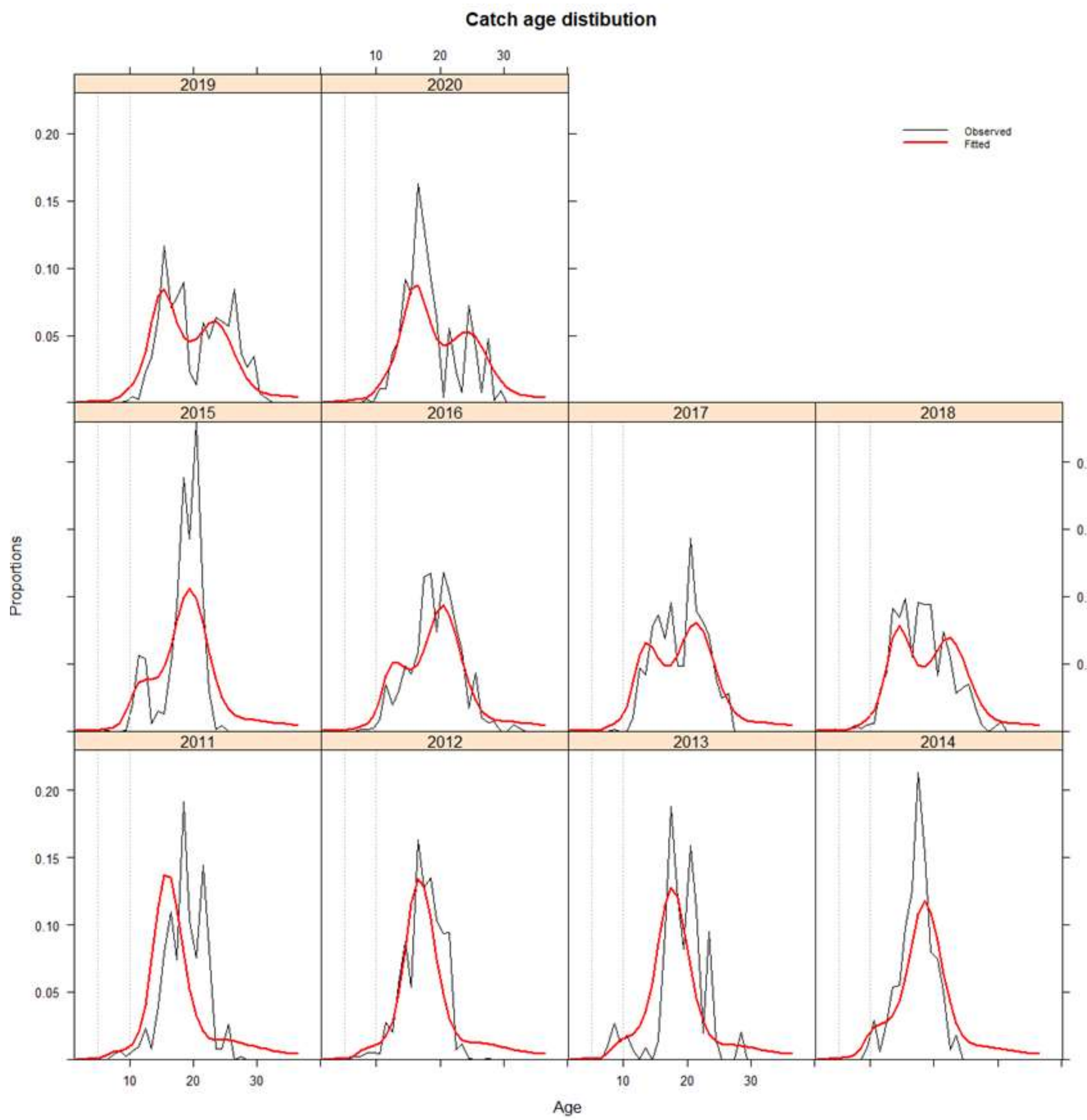

Figure 6. Fit to catch age composition data

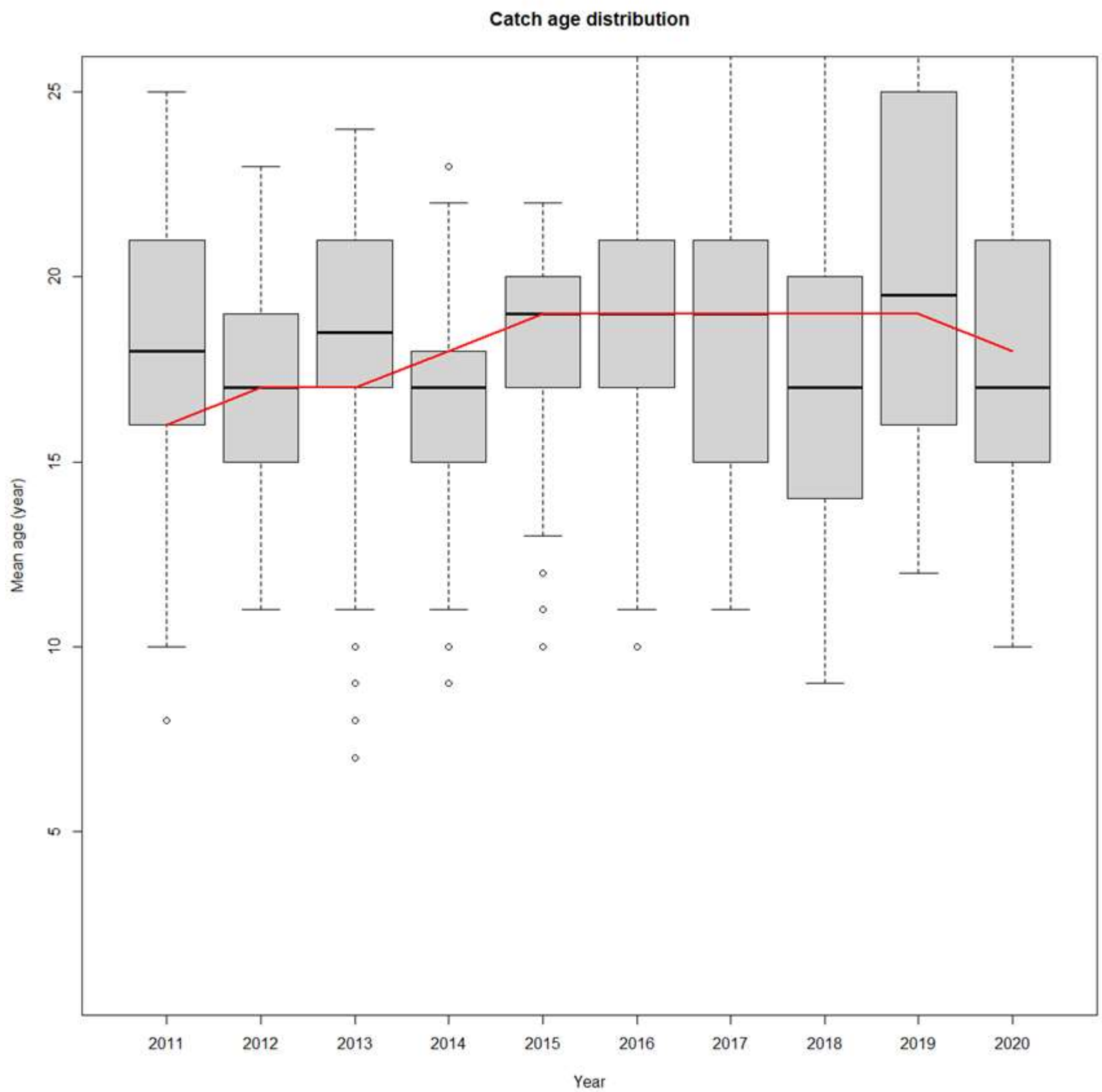

Figure 7. Median age in the catch estimated by the model (red) and observed (black boxes).

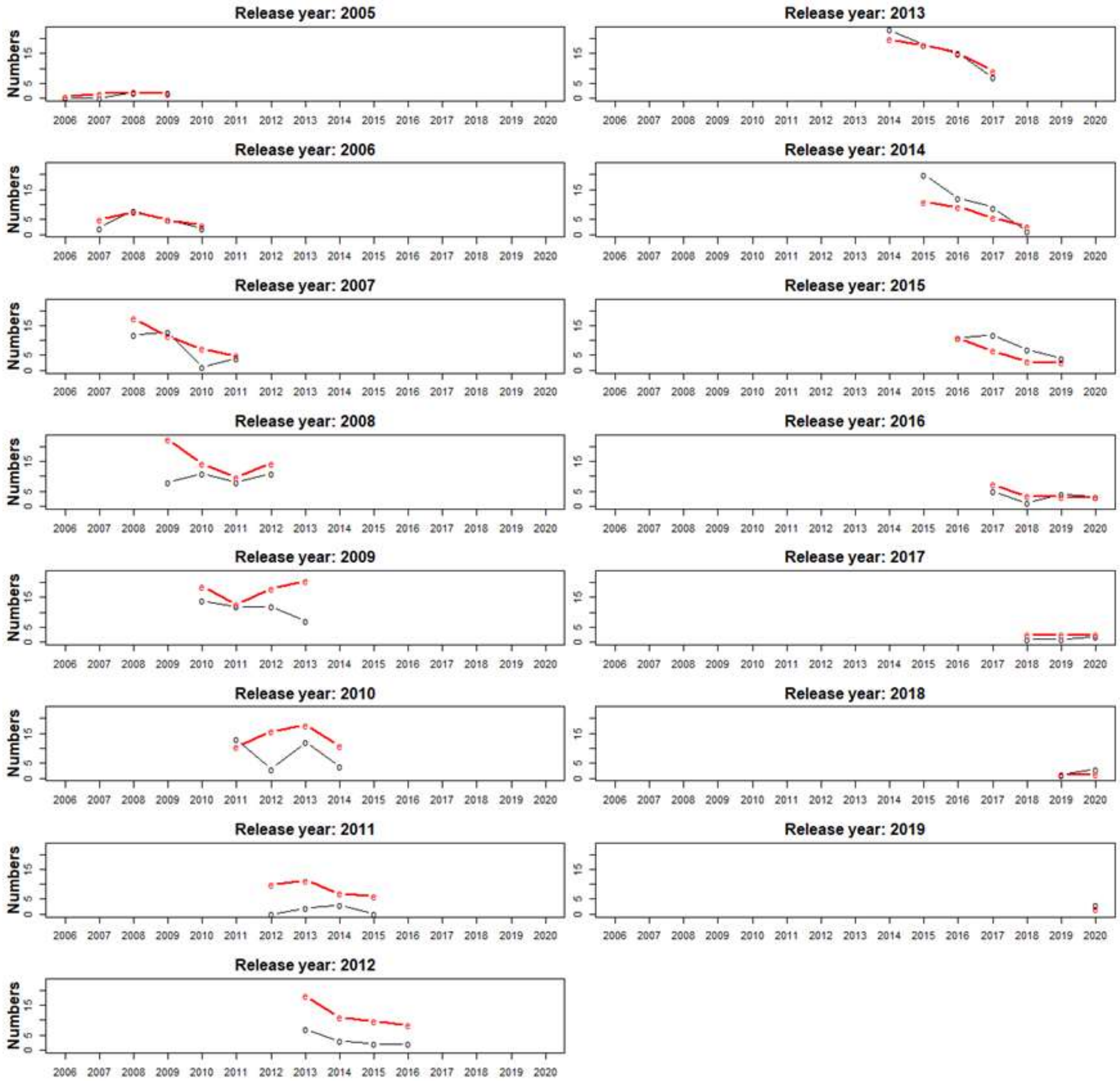

Figure 8. Fits to the numbers of tags recovered in each tag cohort.

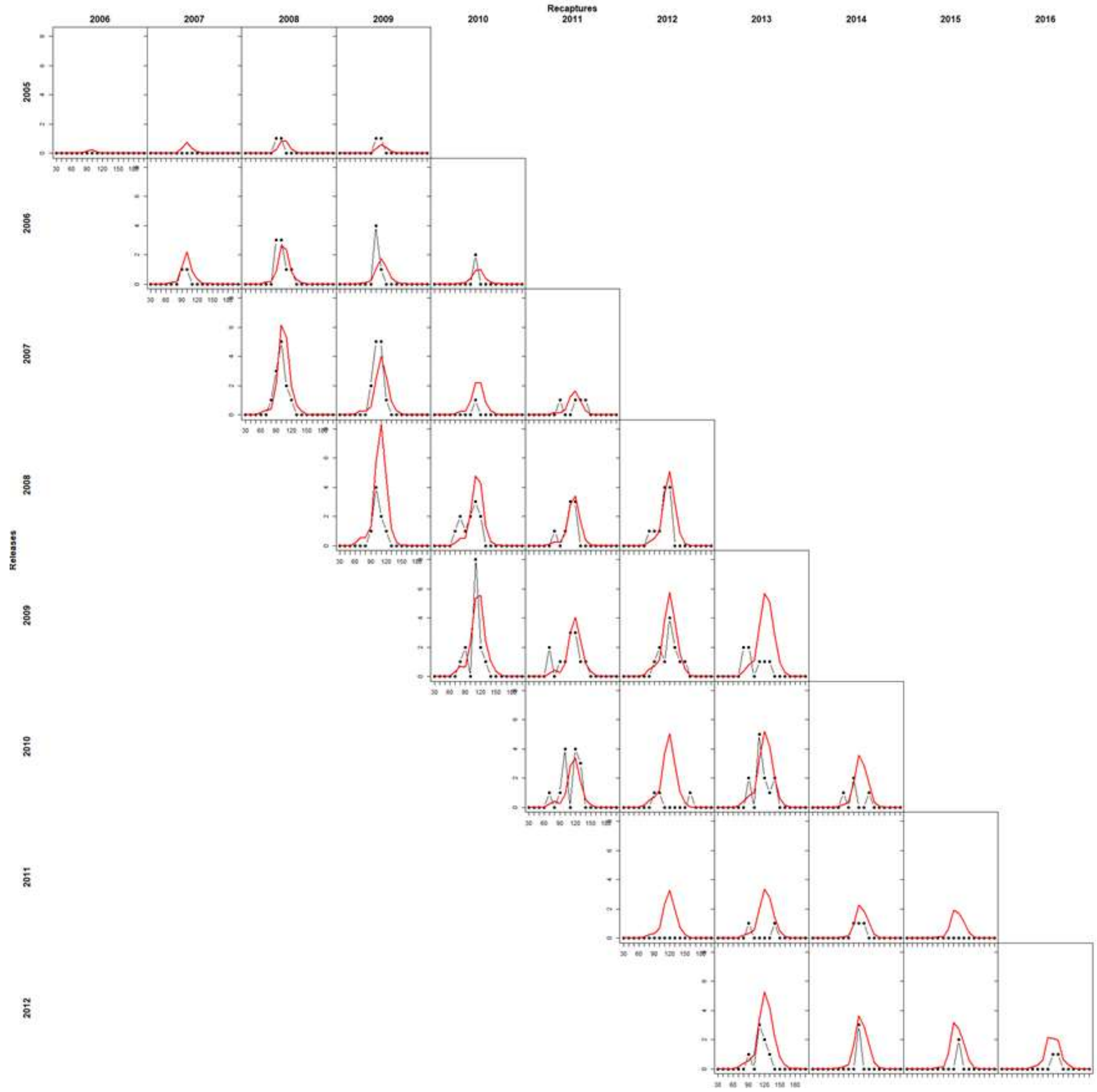

Figure 9. Fits to tagging data by length (releases up to 2012)

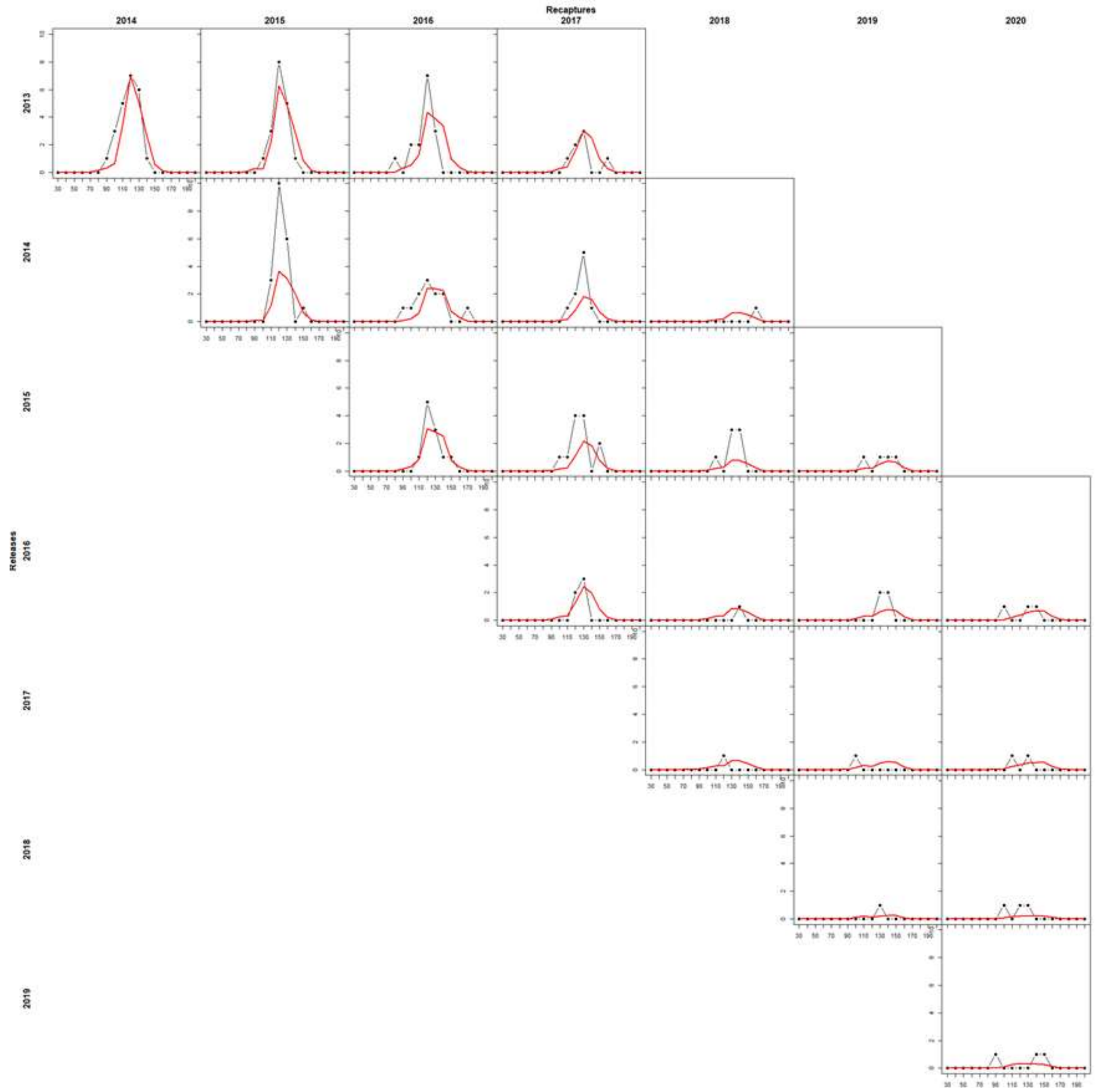

Figure 10. Fits to tagging data by length (releases since 2013)

8. Output quantities

Estimates of parameters for each of the MPD model runs are shown in Table 5. The estimated parameters remain similar to the last two assessments.

Table 5. MPD estimated parameters from the 2017, 2019 and 2021 assessments.

	2017 assessment	2019 assessment	2021 assessment
B_0 (tonnes)	965	1004	955
k	0.058	0.055	0.054
L_{inf} (cm)	194	200	202
Age of 50% selectivity (years)	14.1	13.7	13.6
Selectivity range (years)	5.6	5.2	4.8

The MPD assessment outputs (Figure 11) show a stable spawning stock biomass across the years 1990 – 2000, after which it 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 65% of B_0 in 2021. The difference in perceived SSB status between the current model and the 2019 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 2019 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 be gradually increasing over the past few years, although the recent estimates will have a high uncertainly associated with them.

Table 6. B_0 and SSB output quantities across assessment years.

	B_0	SSB_y in last year	SSB_y/B_0
2013 assessment	1311	1070	0.82
2015 assessment	1434	1133	0.79
2017 assessment	965	645	0.67
2019 assessment	1004	674	0.67
2021 assessment	955	616	0.65

The recruitment peak in 1996 appears to be consistent with the potential year-class evident in the raw age data compositions (Figure 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 appears again in subsequent years.

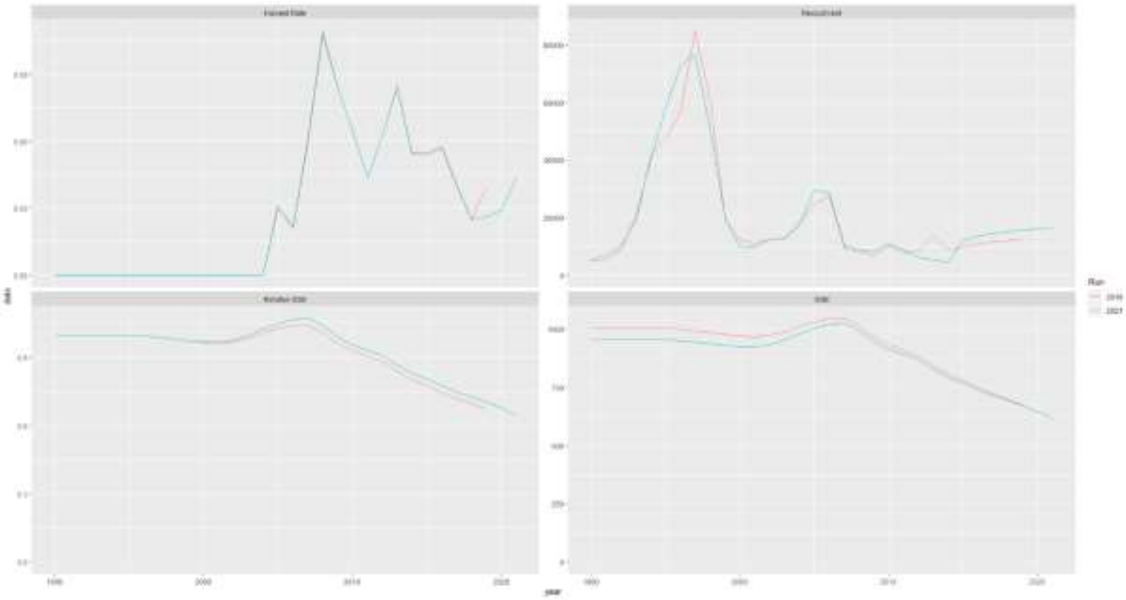

Figure 11. output quantities of MPD estimates of vulnerable biomass, year class strength, harvest rate and spawning biomass of D. eleginoides in subarea 48.4 compared to the previous (2019) assessment.

9. Likelihood profiles

Likelihood profiles for B_0 (Figure 12) show the tag data overall indicate an estimate of virgin biomass 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 demonstrate that three years of tagging data convey a different profile to the other years of tagging data (2013, 2014, 2015). These release years have a particularly high number of tags recovered in the four years following release (Table 3), so we see a more well defined estimate.

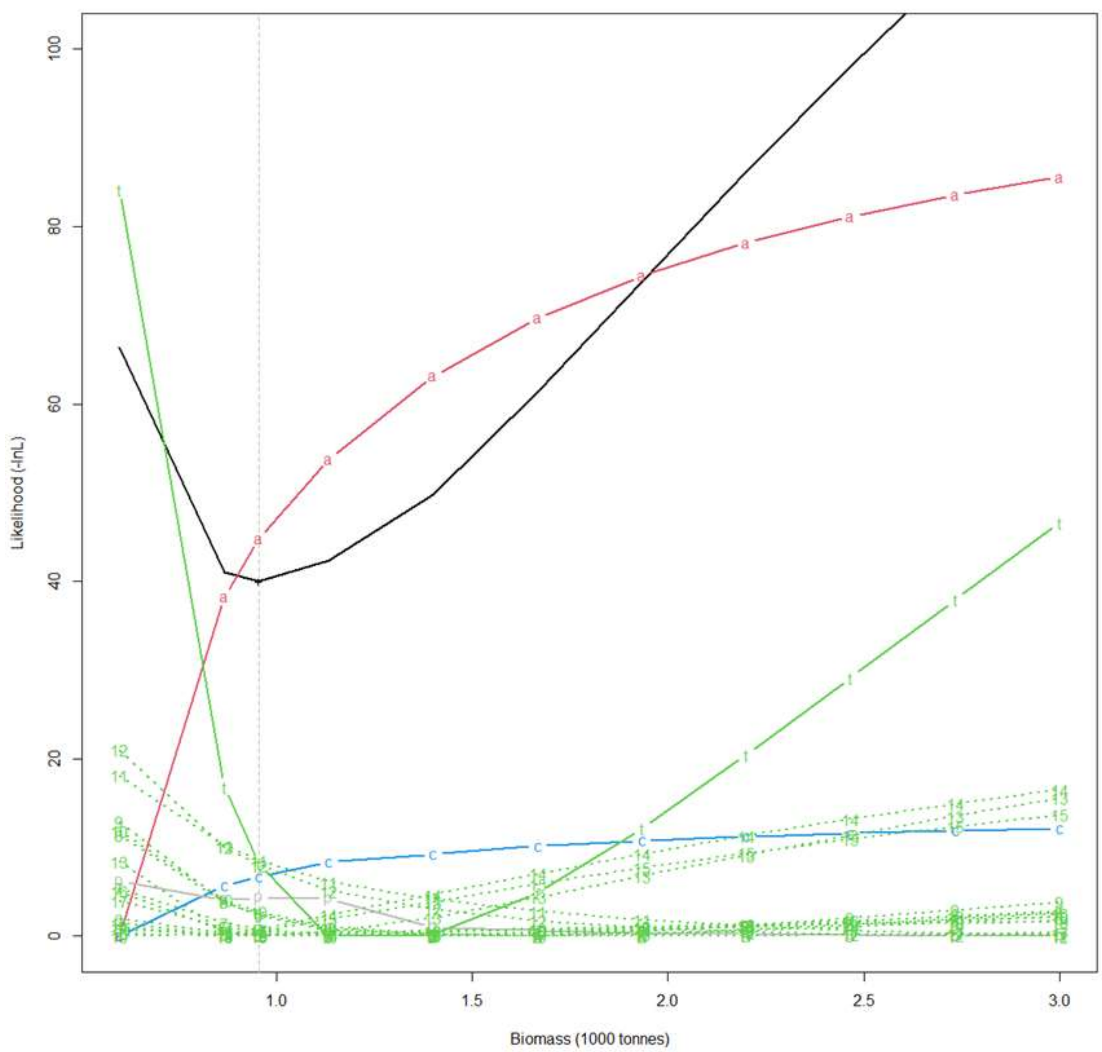

Figure 12. Likelihood profiles for B_0 tag data by cohort (green dots, marked by release year), total tag data (green line marked by 't'), catch data (blue 'c'), size at age (red 'a') and priors and penalties (grey 'p').

10. 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 1000. Convergence to the posterior distribution was tested using the coda (output analysis and diagnostics for MCMC) package in R (Figure 13 and diagnostics paper). Geweke convergence tests indicated successful convergence for some of the estimated parameters, though not all. Heidelberger and Welch tests indicated sufficient chain length and stationary in all but 19 out of the 38 estimated parameters (The parameters that failed were some of the YCS parameters). A test of auto-correlation, showed significant autocorrelation in samples at lags of up to 5 samples in B_0 (Figure 13). In general, MCMC analyses performed adequately, but still showed susceptibility to poor convergence, which was probably due to the high influence on the model of a relatively small amount of data.

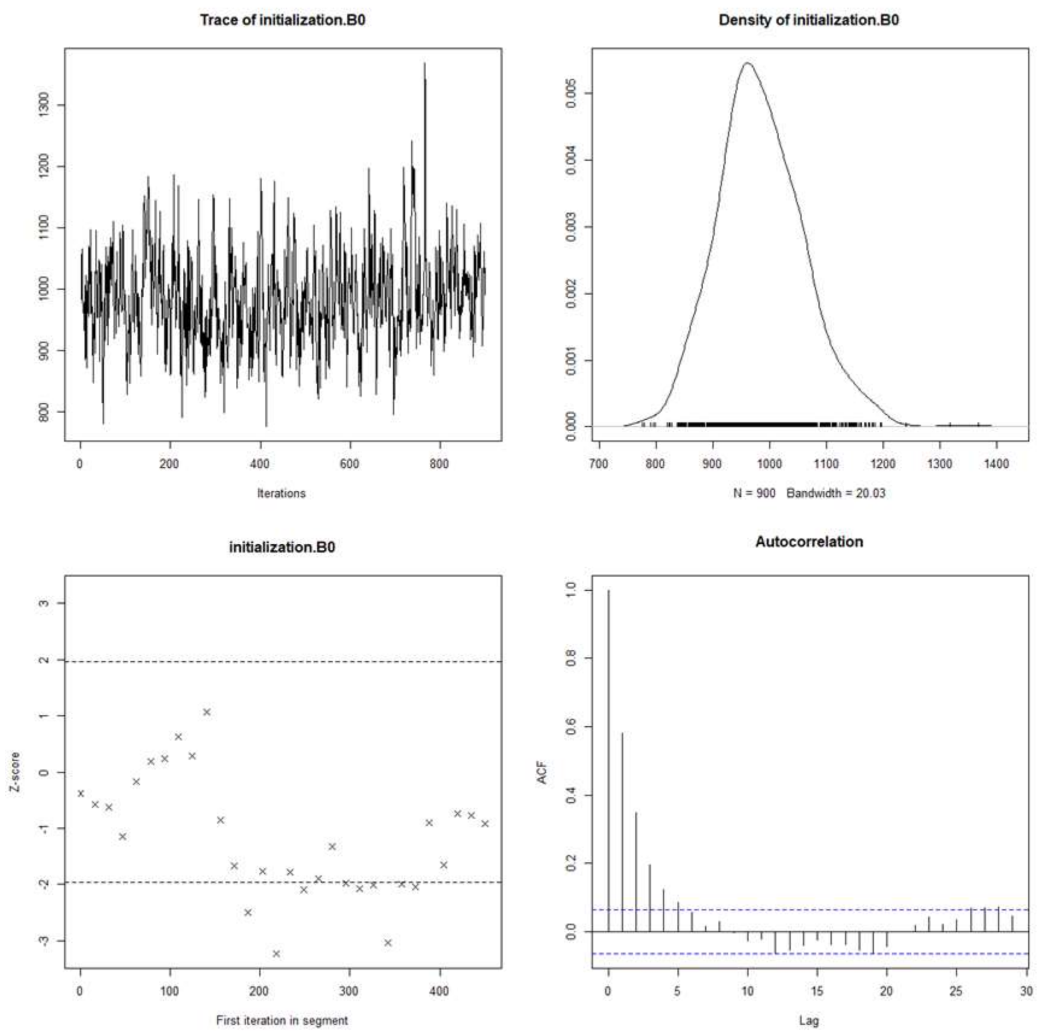

Figure 13. MCMC trace for B_0 (top left), distribution (top right), Geweke diagnostic plots (bottom left) and autocorrelation diagnostic (bottom right) after trimming and removal of burn-in period

11. Projections

Figures 14–16 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, except for 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. Stochasticity in recruitment was introduced using log-normally distributed annual year-class strength multipliers with standard deviation (on the log scale) of 1.0 from 2013 onwards. Projections with a constant TAC of 23 tonnes are shown in Figures 14–16 and show that this will maintain the stock above 50% of $B_{0,}$ with a 0.7% probability of going below 20% of B_0 under the assumption that recruitment continues to follow a lognormal distribution with parameters estimated by the model.

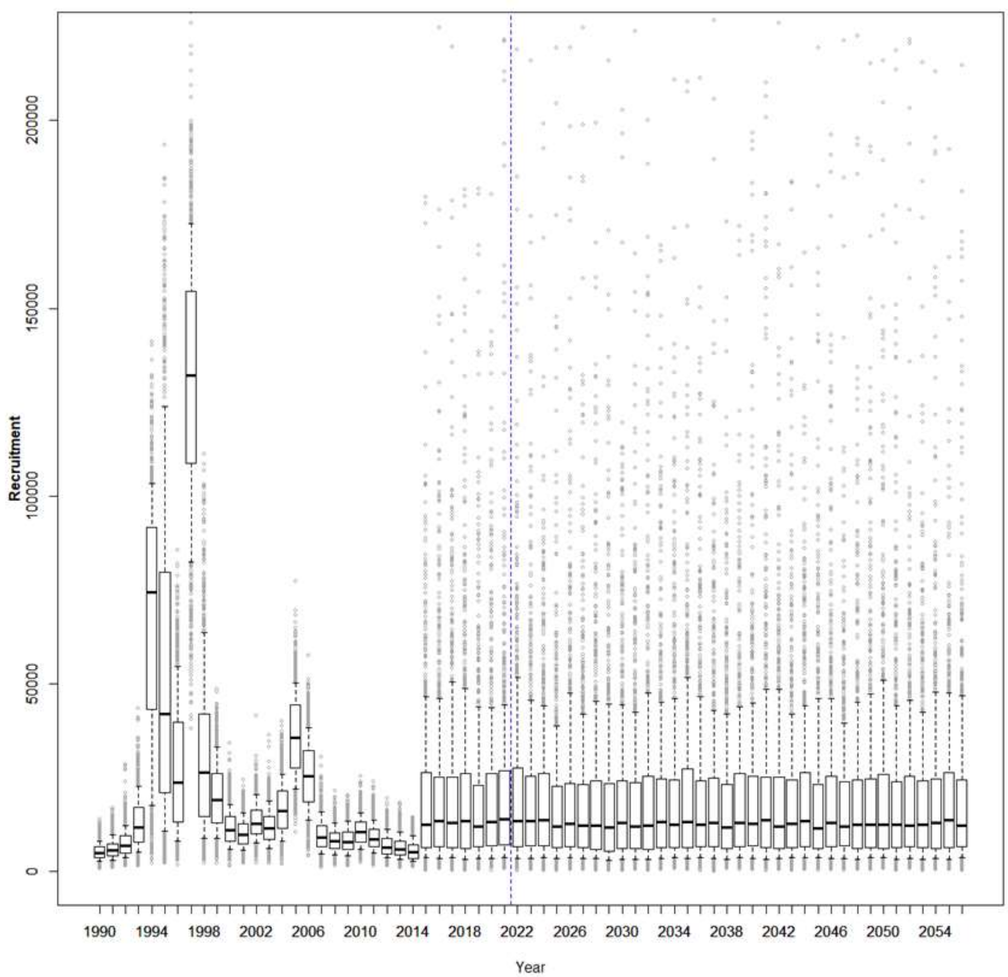

Figure 14. MCMC recruitment uncertainty and projection until 2056 based on a constant catch of 23 tonnes. Projections assume recruitment with a lognormal distribution from 2015 onwards.

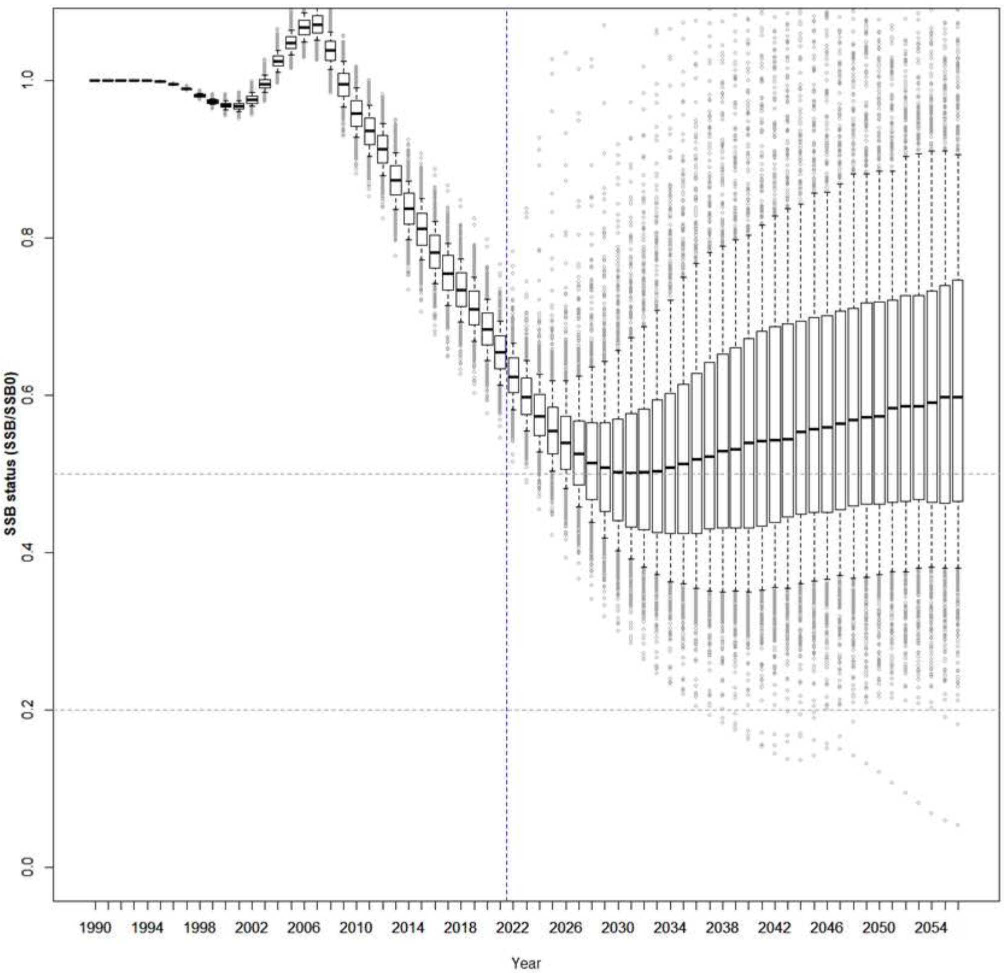

Figure 15. SSB status relative to B_0, MCMC projection until 2056 based on a constant catch of 23 tonnes.

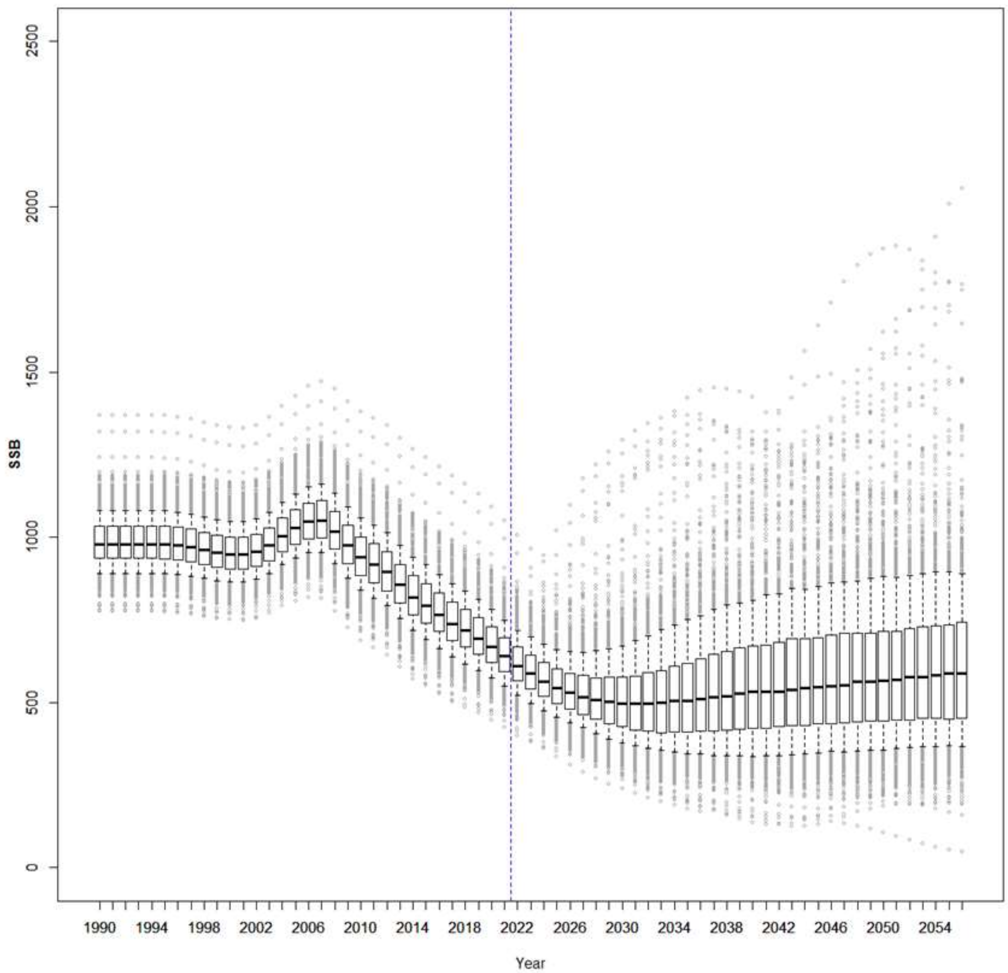

Figure 16. SSB, MCMC projection until 2056 based on a constant catch of 23 tonnes.

12. Equilibrium harvest

Long term simulations from an equilibrium age structure suggest that an F of 0.063 would be consistent with the CCAMLR decision rules. This would lead to average yields of 31t.

13. Summary

The model estimates of stock size continue to fluctuate slightly between assessments due to the influence of the additional data. Despite this, the estimates of recruitment, stock status and trends remain similar.

A TAC of 23 tonnes is consistent with the CCAMLR decision rule. This would maintain the stock above 50% of B_0 for the next 35 year and result in an SSB of 61% of B_0 after the 35 year period.

14. References

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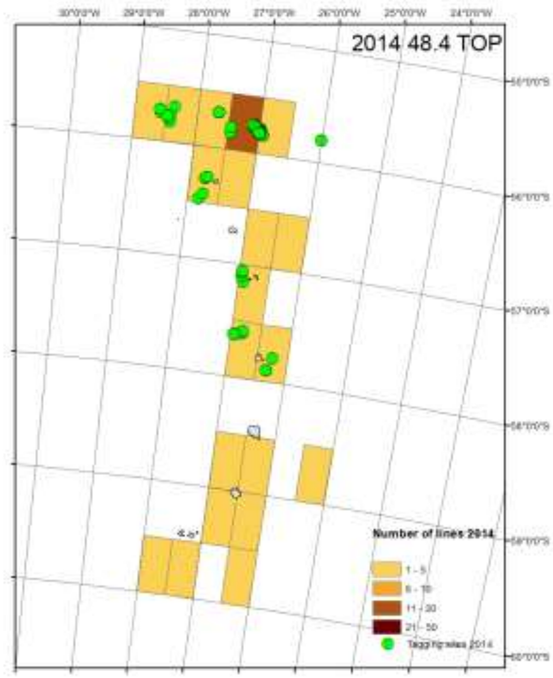
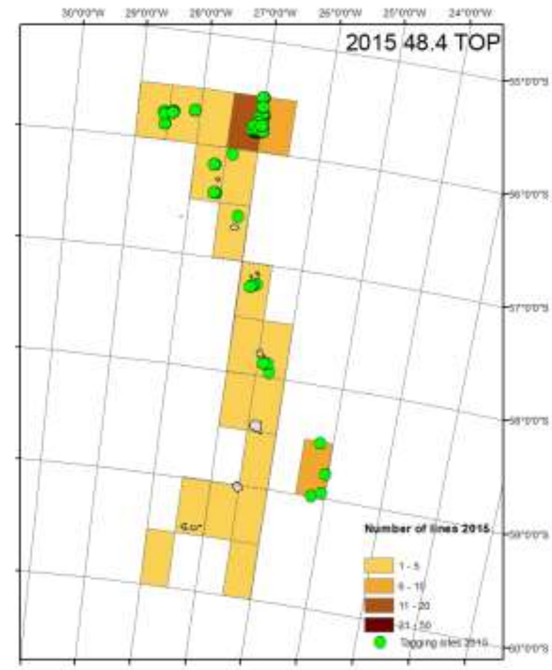
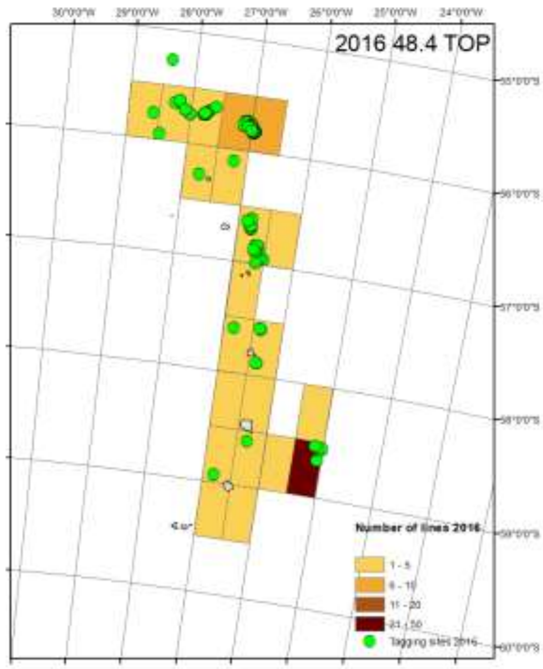
Walker, N., Laptikhovsky, V., Earl, T. and Soeffker, M. 2015. Tag-recapture based population assessment of Antarctic toothfish in Subarea 48.4. Document submitted to CCAMLR Working Group on Fish Stock Assessments, 2015. WG-FSA-15/31, CCAMLR, Hobart.

Annex 1: Fishing effort plots






2016 48.4 TOP
Number of lines 2016
1 - 5
6 - 10
11 - 20
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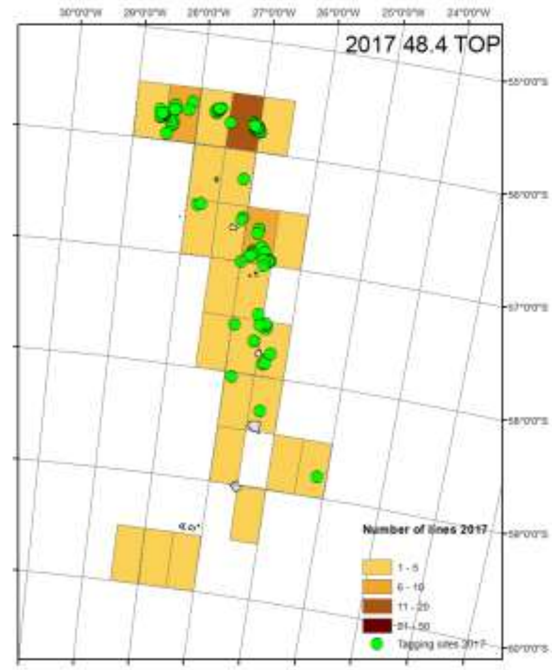
Tagging sites 2016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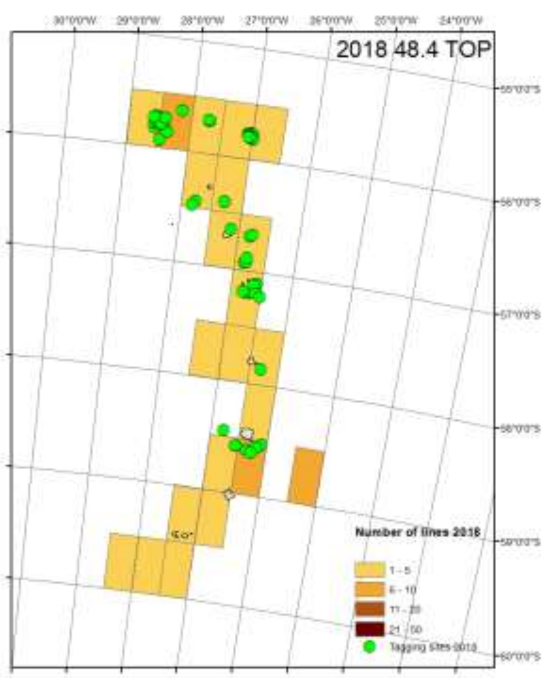
Tagging sites 2017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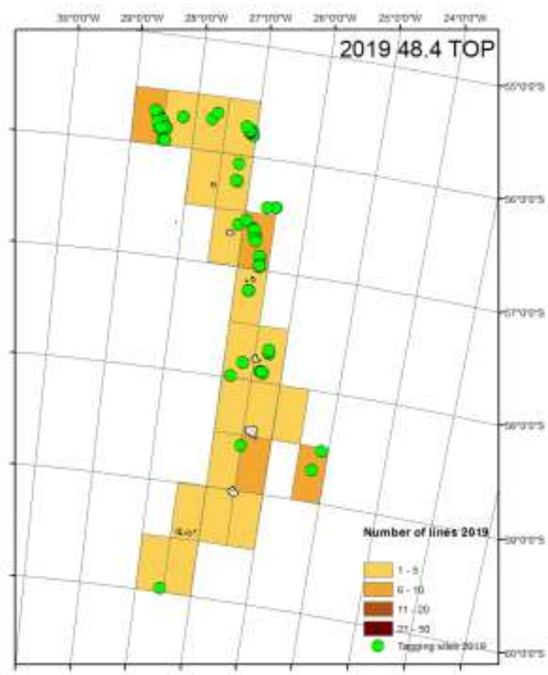
Tagging sites 2018


2019 48.4 TOP
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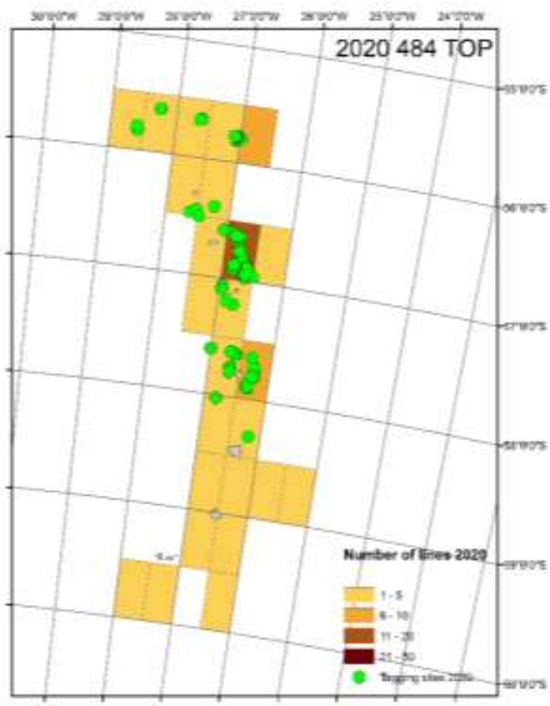
Tagging sites 2019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Комиссия по сохранению морских живых ресурсов Антарктики
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Preliminary tag-recapture based population assessment of Antarctic toothfish (Dissostichus mawsoni) in Subarea 48.4 – 2021 fishing season

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Preliminary tag-recapture based population assessment of Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.4 - 2021 fishing season

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Abstract

The biomass of Antarctic toothfish (*Dissostichus mawsoni*) in CCAMLR Subarea 48.4 is estimated from tagging returns, giving a geometric mean of 1,311 tonnes since 2016. Applying the CCAMLR agreed precautionary assumption of a 5-year geometric mean biomass, and harvest rate of $\gamma = 0.038$, implies a 2022[1] yield of 50 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 southern South Sandwich Islands 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.

The assessment would lead to a recommendation from Working Group FSA to Scientific Committee that the catch limit for *D. mawsoni* in Subarea 48.4 should be set at 50 tonnes for 2021/22.

1. Introduction

Fishing for both species of toothfish (*Dissostichus eleginoides* and *Dissostichus mawsoni*) in Subarea 48.4 (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 a single assessment.) began in 2003 and a pilot tagging program was initiated in 2005. In recent years the fishery has been carried out by two vessels with annual combined 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 and southern parts of Subarea 48.4 (Scott, 2012). In the northern area, between latitudes 55°30'S and

[1] The seasons are labelled, henceforth, according to calendar year in which the season finishes e.g. the 2020 season refers to the season from 1 December 2019 to 30 November 2020.

57°20'S and longitudes 25°30'W and 29°30'W, the bulk of catches comprise Patagonian toothfish (*D. eleginoides)* and targeting of Antarctic toothfish (*D. mawsoni*) is prohibited. In the southern area, bounded by latitudes 57°20'S and 60°00'S and longitudes 24°30'W and 29°00'W, both species of toothfish are caught together (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 a single assessment.). Any Antarctic toothfish captured in the northern part may be retained but are counted against the catch of *D. mawsoni* in the southern area. 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 using an age and length based CASAL assessment model (Earl and MacLeod, 2019), whereas Antarctic toothfish is estimated using a mark-recapture formulation.

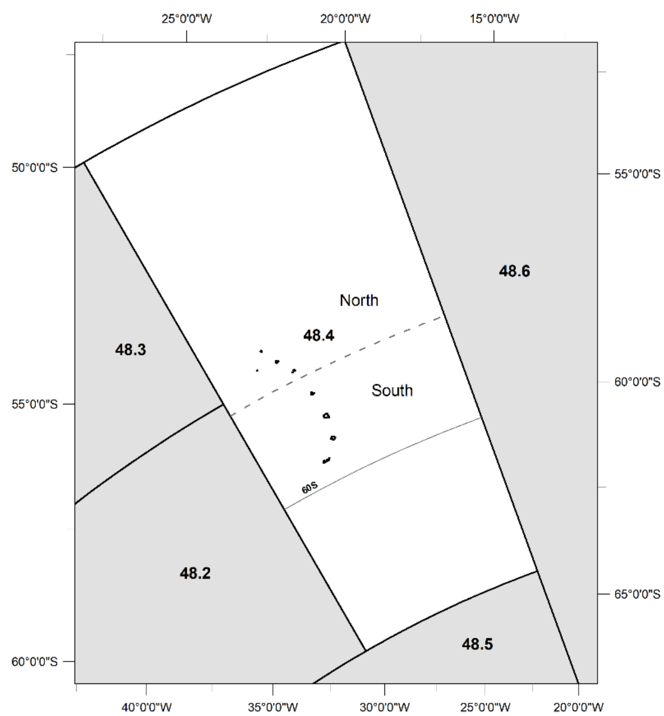

Figure 1. Map of area 48.4. Dashed line at 57.33˚S indicates previous North and South rectangles, which since 2012 have been combined into a single assessment.

Table 1. Catch and catch per unit effort of the Antarctic toothfish in Subarea 48.4.

Year	Vessel	Fishing Period	kg	kg/hook
2009	Argos Georgia	02/03-18/05	32,464	0.06
2009	San Aspiring	21/03-23/04	26,629	0.05
2010	Argos Froyanes	26/03-30/04	25,601	0.04
2010	San Aspiring	21/03-14/04	30,710	0.09

2011	Argos Georgia	31/03-25/04	10,315	0.02
2011	San Aspiring	03/04-06/06	4,843	0.02
2012	Argos Georgia	01/04-23/04	16,331	0.06
2012	San Aspiring	30/03-08/06	5,906	0.01
2013	Argos Froyanes	22/03-12/04	15,236	0.04
2013	San Aspiring	18/03-13/04	24,295	0.07
2014	Argos Georgia	20/03-29/03	11,992	0.13
2014	San Aspiring	07/03-24/03	11,897	0.07
2015	Argos Georgia	05/04-19/04	13,957	0.07
2015	San Aspiring	27/03-08/04	13,683	0.08
2016	Tronio	06/05-24/05	10,226	0.04
2016	San Aspiring	26/03-13/04	17,549	0.06
2017	Tronio	18/04-09/05	1,486	0.01
2017	San Aspiring	16/03-12/04	17,902	0.07
2018	Argos Froyanes	01/04-25/04	15,363	0.08
2018	San Aspiring	24/03-11/04	16,565	0.09
2019	Argos Froyanes	06/02-21/02	16,834	0.11
2019	San Aspiring	07/04-29/04	16,222	0.07
2020	Nordic Prince	02/03-11/03	32,560	0.26
2020	San Aspiring	04/04-25/04	11,334	0.04
2021	Argos Georgia	04/03-15/03	23,731	0.18
2021	San Aspiring	06/04-28/04	19,396	0.06

In 2013-2015 the tag-based population assessment for Antarctic toothfish followed the CCAMLR standard approach at the time, whereby tag-based assessments used a Petersen-Lincoln method mark-recapture formulation to estimate abundance (Hillary, 2008; CCAMLR 2011). CCAMLR then agreed to use the Chapman assessment formulation from 2015.

A total of 2,625 Antarctic toothfish have been tagged in the northern and southern parts of Subarea 48.4 during 2010-2021, of which 148 have been recaptured (including five that were identified as Patagonian toothfish at tagging); with a long-term average tag return rate of around 5.7%. From releases since the start of 2010, 104 tags recaptures have been used in the assessment, which were released and recaptured between 1-3 years after release (releases and recaptures South of 60°00'S are excluded, Table 2).

The fishery, though varying spatially between years, has from 2008 onwards covered the entire northern and southern areas. Distribution of fishing and tag releases, for 2014-2021 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). Previously a geometric mean biomass of all years since 2010 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 geometric mean 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 2021 season.

Table 2. Tag – recaptures of the Antarctic toothfish in Subarea 48.4. Numbers in bold indicate the tags used in the assessment.

Release year	Number of releases	Recaptures													All Years
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
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**	16
2021	224													12	12
Total	2,625	2	22	7	4	0	3	15	22	12	12	8	8	33	148

1.1. Historic overview of key changes to the assessment

Based on the known bias of the Petersen tag-based population abundance estimate, resulting from low tag recapture rates, WG-FSA-14 (CCAMLR, 2014) recommended the use of the Chapman method, which 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). The stock hypotheses for this 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 Antarctic toothfish tags within

Subarea 48.4 south are rarely 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 below in Table 3:

Table 3. Summary of stock assessment development.

Year	**Key changes**	**Estimated stock status**
Until 2012	combined assessment with 48.4 TOP, spatially segregated into N and S	1,368 t (2012)
2013	Petersen tag-based assessment, Subarea-wide, TOA only	640 t
2014	As 2013 (no changes)	1,027 t
	at FSA-14: Chapman estimation with numbers of fish, individual tag release/recapture cohorts, geometric mean	736.8 t
2015	as at FSA-14, but corrected numbers of fish for weight of fish	621 t
	at FSA-15: Chapman estimation with numbers of fish, overall tag release/recapture cohort, geometric mean	1,014 t
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 t
2017	As at FSA-16	980 t
2018	As at FSA-17	982 t
2019	As at FSA-18 but limited to a 5-year geometric mean.	1,187 t
2020	As at FSA-2019	1,381 t
2021	As at FSA-2020	1,311 t

2. Data and approach used for the assessment

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

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, 104 tags recaptured between 2010 and 2021 were included in the assessment (Table 2).

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 each captured Antarctic toothfish for the 2009-2020 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:

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

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 2006-2021 (Figure 2) as:

$$W = 0.00001193\, L^{2.975317}$$

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, $\overline{w}$ was calculated to be 0.0385 tonnes. Figure 3 shows Antarctic toothfish length distribution by year (2010-2021).

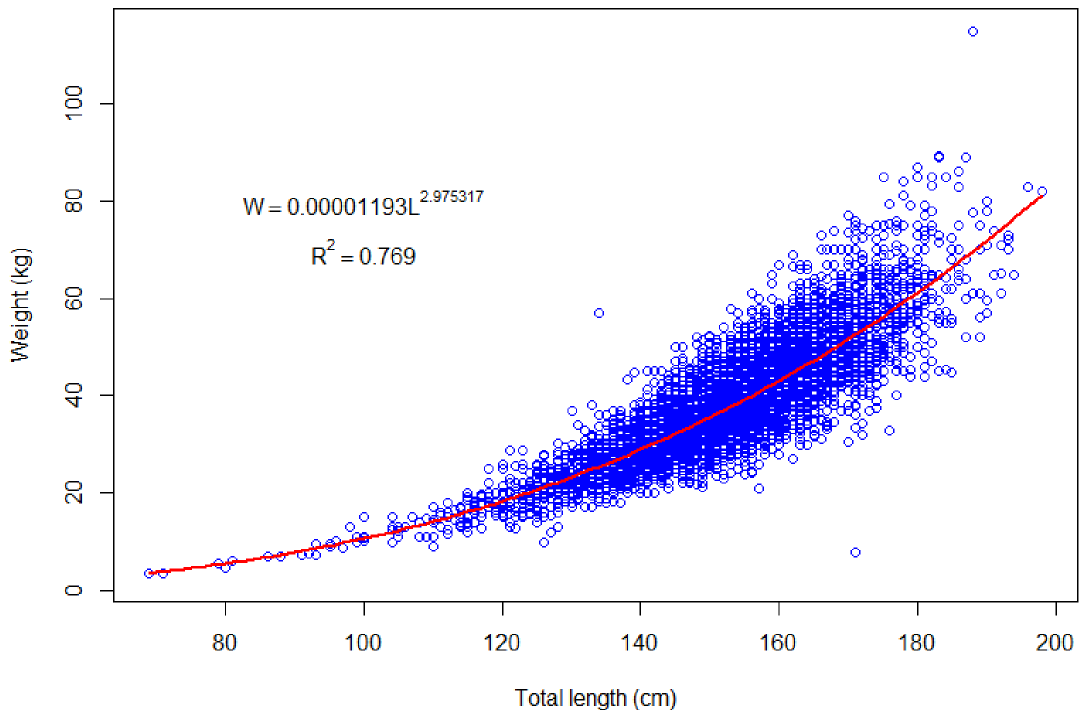

Figure 2. Length – weight relation for the Antarctic toothfish in Subarea 48.4.

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

Year	Mean weight (kg)
2009	39.7
2010	39.7
2011	38.6
2012	35.7
2013	39.2
2014	39.2
2015	40.1
2016	37.4
2017	38.0
2018	37.8
2019	38.3
2020	37.8
2021	36.8

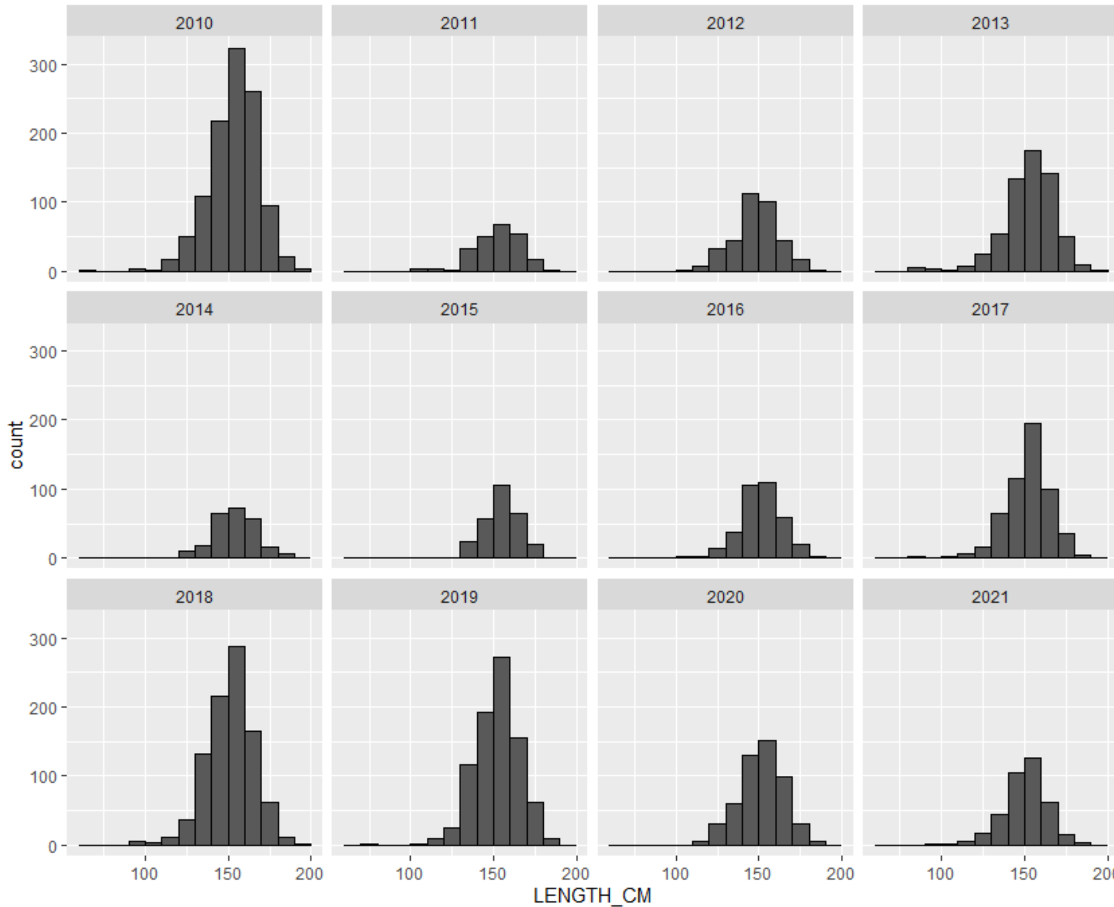

Figure 3. Raw length distribution by year (2010-2021), of Antarctic toothfish in Subarea 48.4.

3. Results

The estimated stock biomass remains variable, but relatively stable across the time series (Table 5). The very high CPUE observed for one vessel, Argos Georgia, resulted from high catches in two fishing events with high catches of Antarctic toothfish (Figure 4; Table 1). Figure 5 presents the vessel CPUE against the week of the year in which fishing is conducted; there is a significant relationship with CPUE lower in the later weeks of the year; consistent with a change in catchability or seasonal movement of toothfish.

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 1,311 tonnes using the 5-year geometric mean biomass. Applying the agreed harvest rate of γ = 0.038 to the 5-year geometric mean results in a yield of 50 tonnes.

*Table 5. Biomass estimates by year of tag release from the stock assessment of the Antarctic toothfish in Subarea 48.4 using Chapman method and restricting tag availability to 3 years. *This number was incorrectly reported as 1,466 in Earl and Riley (2020)*

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Biomass (tonnes)	478	502	1,300	-	3,462	656	1,257	970	2,301	1,471 *	1,585	744
Confidence intervals (tonnes)	213	320	1,029	-	3,908	312	604	517	1,581	1,076	1,020	300

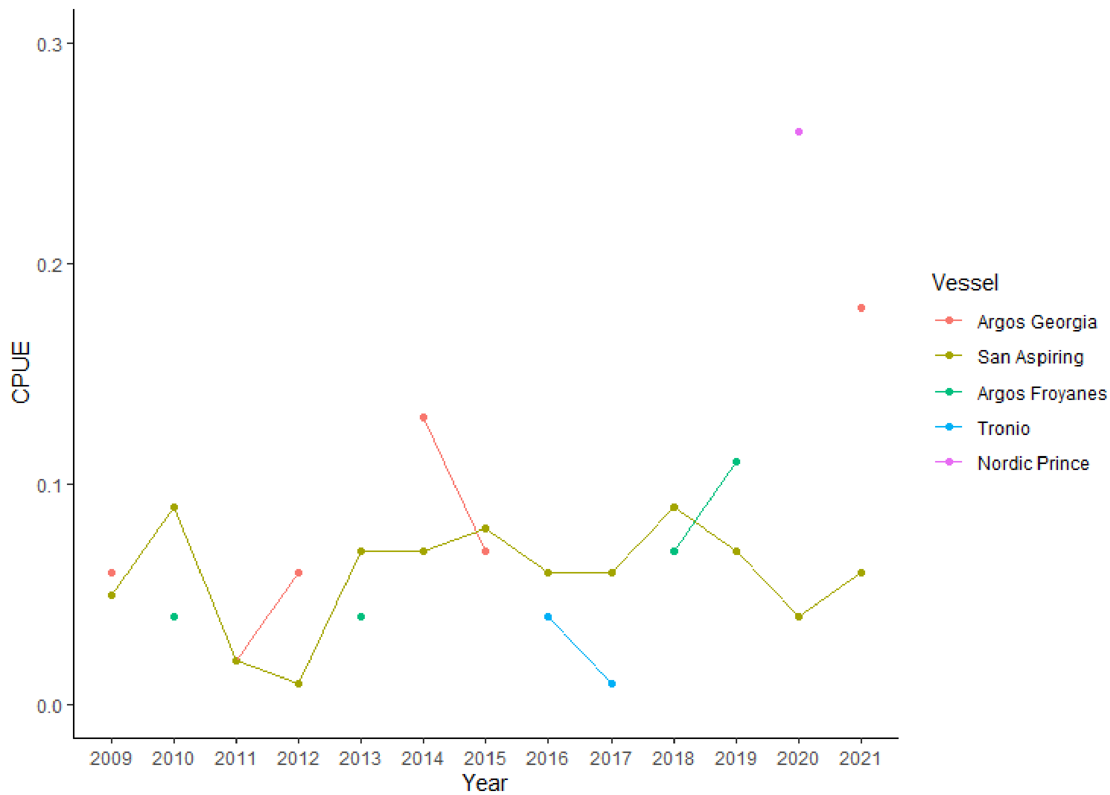

Figure 4. Time series of catch per unit effort (kg/hook) of Antarctic toothfish for vessels fishing in Subarea 48.4.

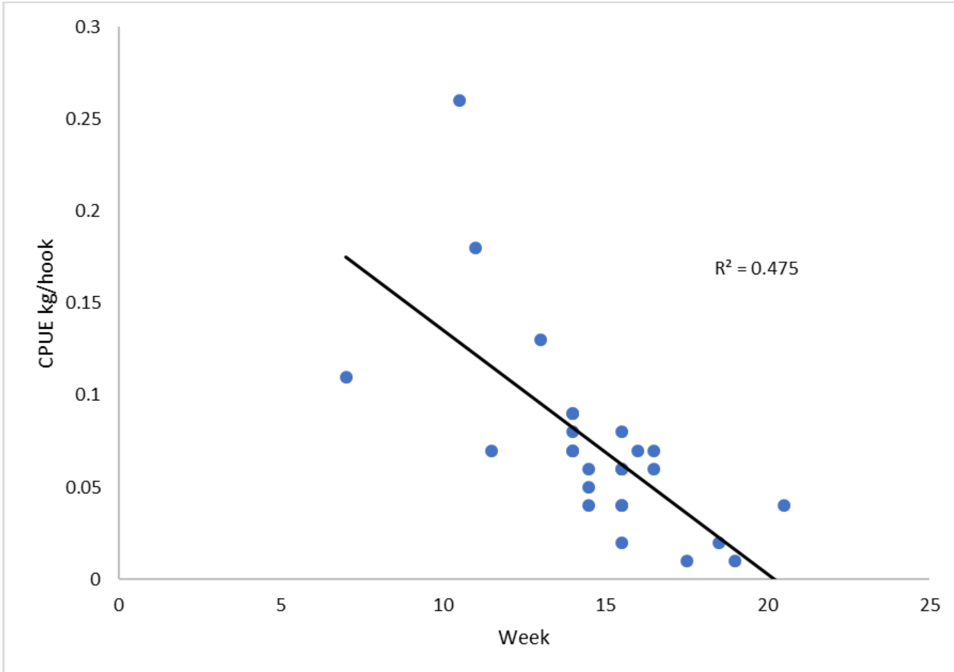

Figure 5. Time series(2009-2021) of catch per unit effort (kg/hook; Table 1) of Antarctic toothfish for vessels fishing in Subarea 48.4 in the week of the year in which fishing occurred.

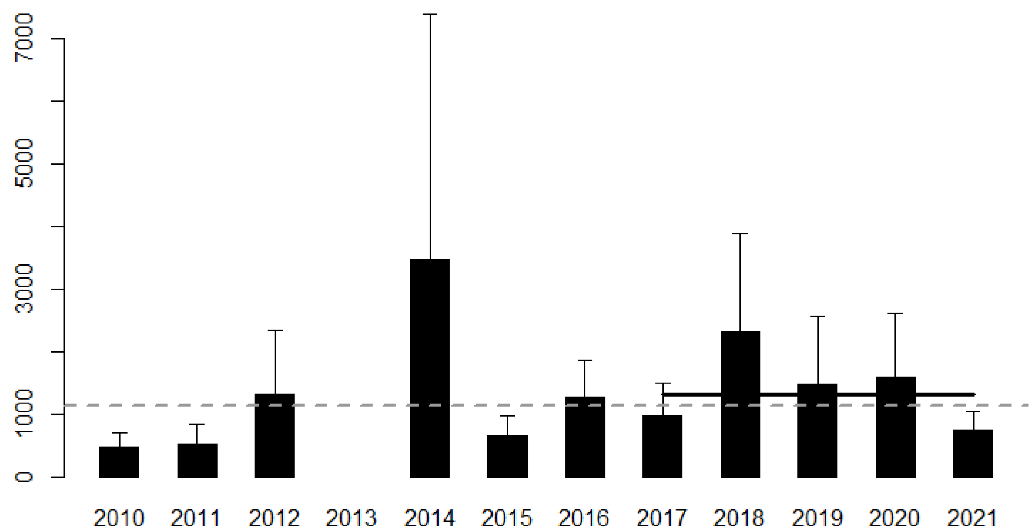

Figure 6. Stock assessment of the Antarctic toothfish in Subarea 48.4 using the method agreed by WG-FSA-14. The solid horizontal line shows the 5-year geometric mean biomass at 1,311 tonnes, between 2016 and 2021, and the dashed grey line shows the historic geometric mean estimate of biomass at 1,119 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 southern South Sandwich Islands have been hypothesised as being part of a much larger stock that extends south into Subareas 48.2, 48.6 and possibly 48.5 (Soeffker *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 South Georgia. Five tags, released in Subarea 48.6, four on the Antarctic shelf and one released ~200 km south east of Bouvet Island, have been recaptured in Subarea 48.4, between 2017 and 2021. All fish were large adults at recapture, with length ranging from 131 – 158 cm, and their maturity was recorded as developing or developed, supporting the hypothesis proposed by Soeffker *et al*. (2018). No tagged fish released in 48.4 have been caught in other subareas of Area 48.

5. Conclusions

Application of the previously applied harvest rate for the stock (γ = 0.038, based on *D. eleginoides* in Subarea 48.3) results in a yield in 2022 of 50 tonnes using the 5-year geometric mean biomass. The 2021 biomass estimate is 744 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 7 years, and so the geometric mean over the more recent time period is considered more robust.

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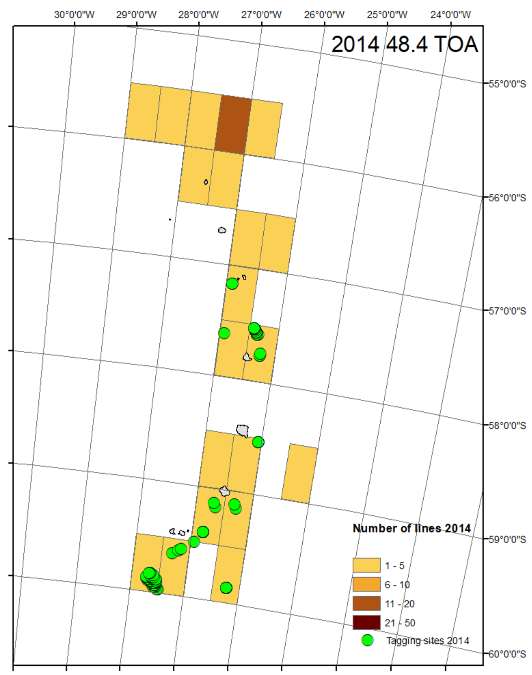
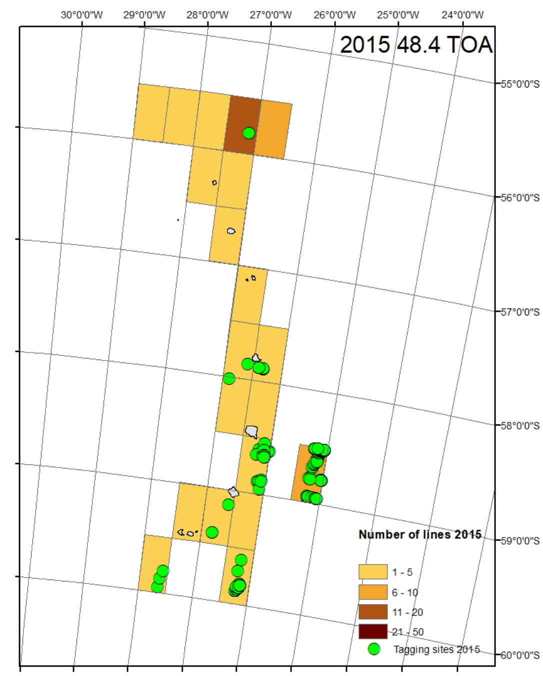
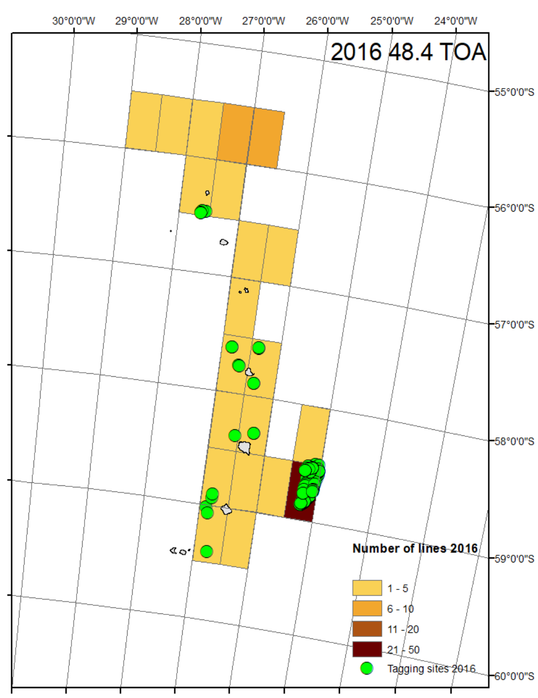
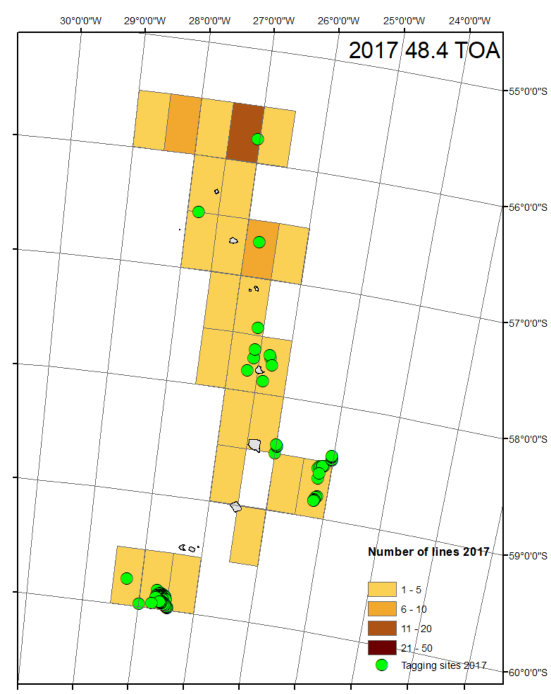
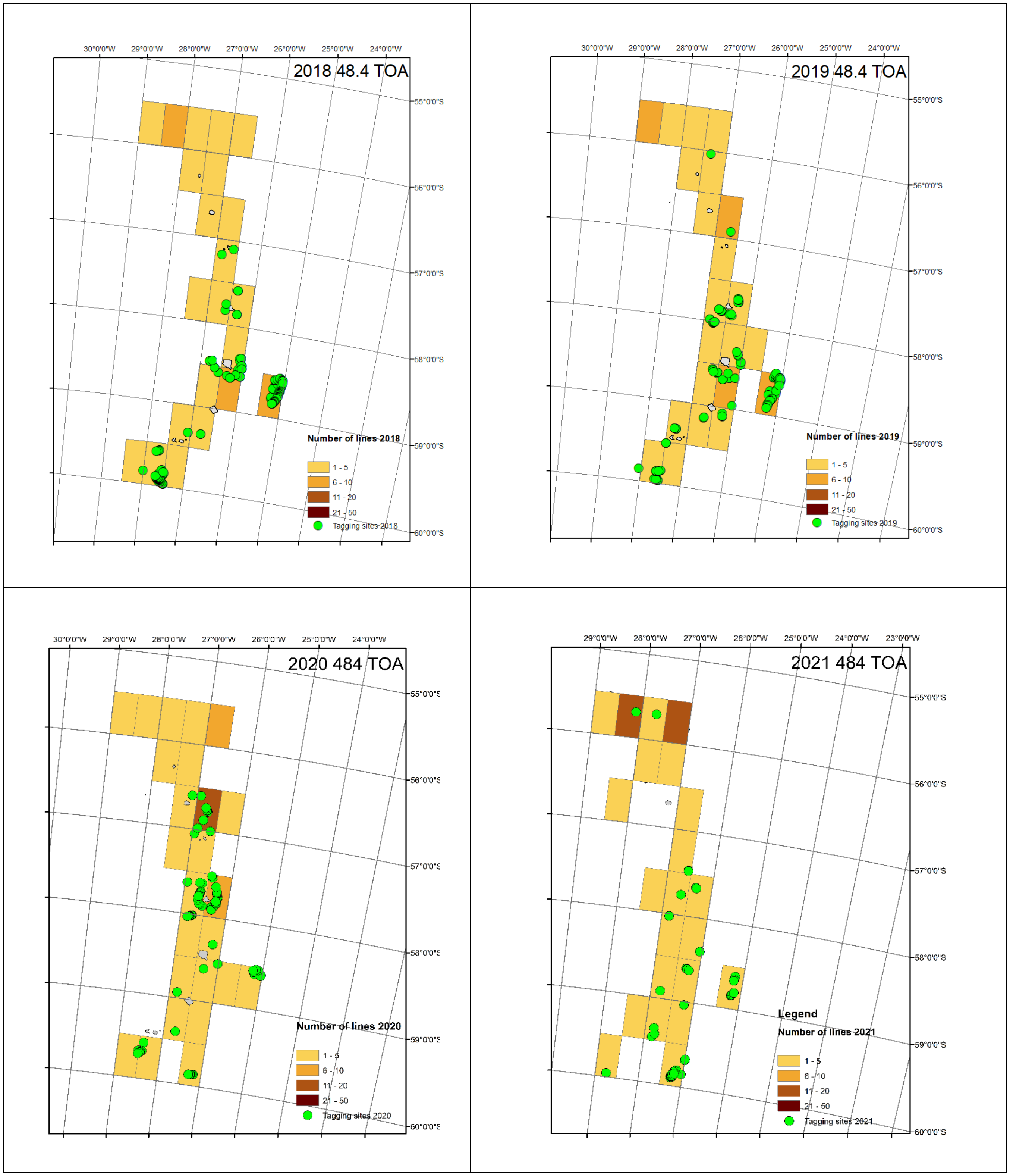
Appendix 1: Fishing Effort Plots










2018 48.4 TOA
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Tagging sites 2018
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Tagging sites 2019
2020 484 TOA
Number of lines 2020
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Tagging sites 2020
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Additional Resources

- Fishery Summary: pdf, html
- Fishery Report: pdf, html
- Species Description for Patagonian Toothfish: pdf, html
- Species Description for Antarctic Toothfish: pdf, html
- Fisheries Documents Browser