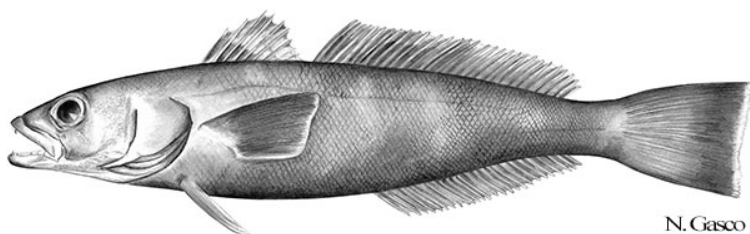


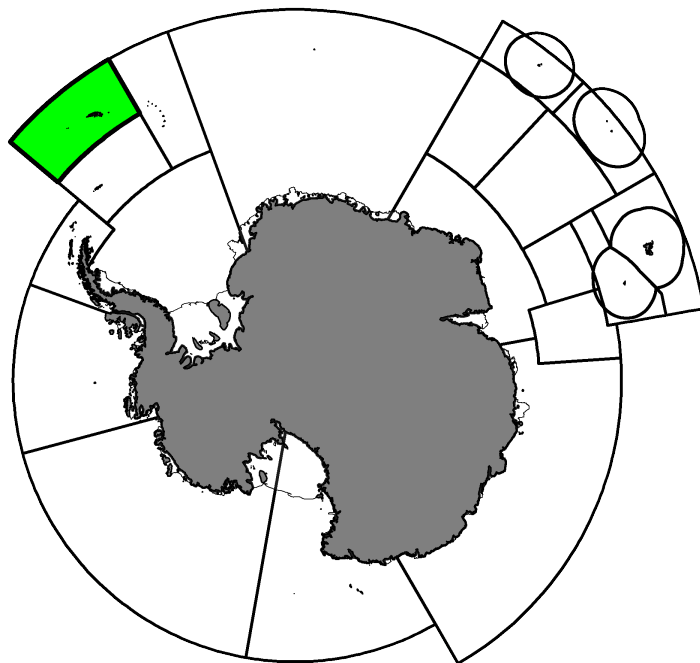
Stock Assessment Report 2023: *Dissostichus eleginoides* in Subarea 48.3

CCAMLR Secretariat

16 February 2024



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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Commission for the Conservation of Antarctic Marine Living Resources
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Комиссия по сохранению морских живых ресурсов Антарктики
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Assessment of Patagonian Toothfish (*Dissostichus eleginoides*) in Subarea 48.3

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Assessment of Patagonian Toothfish (*Dissostichus eleginoides*) in Subarea 48.3

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Abstract

Assessment of the Patagonian toothfish (*D. eleginoides*) in Subarea 48.3 indicates that the current status of the stock is at 47% of B_0 . Projections indicate that a constant catch of 2,000 tonnes in the 2024¹ and 2025 seasons would be consistent with the CCAMLR decision rule after accounting for recent mammal depredation rates.

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 2,000 tonnes for 2023/24 and 2024/25.

1. Introduction

The history of the Subarea 48.3 toothfish fishery is summarised in Marsh and Earl (2023) and the history of the stock assessment is outlined in the stock annex (Earl *et al.*, 2023). In 2023, after an initial run in CASAL, further developments were carried out in Casal2, as recommended by WG-SAM-2021, paragraph 3.28. In addition to the change of assessment software, the following changes have been made compared to the assessment presented at WG-FSA-2022 (Earl and Readdy, 2022):

- Inclusion of an additional year's data from the fishery
- Inclusion of the results from the 2023 groundfish survey (Hollyman *et al.* 2023)
- Revision of tag mortality
- Revision of age compositions in the fishery 1998-present, and estimates of the von Bertalanffy growth parameters following the method agreed by WG-SAM-2023 (Marsh *et al.*, 2023)
- Revision of the estimates of tagging data for scanned fish (fish caught and checked for tags) and releases
- Revision of estimates of recruitment
- Use of a GAMM for CPUE estimation
- Updated parameters for maturity and tag loss

These changes are evaluated in a stepwise analysis summarised in Table 1.

¹ The seasons are labelled according to calendar year in which the season finishes *e.g.* the 2020 season refers to the season from 1st December 2019 to 30th November 2020.

Table 1: Model runs developing the assessment from that presented to WG-FSA-2022 (Earl and Readdy, 2022).

Software Model run	Objective
Casal 2022	Included from Earl and Readdy (2022) for comparison
Casal base	Initial run adding additional year of data
Casal2 base	Running the equivalent model in Casal2
Casal2 tagging	Update historic tag effective releases and scanned fish
Casal2 ageing	Update age distributions and growth parameters (following Marsh et al., 2023)
Casal2 compatibility2	Investigate the effect of moving to the simplex method of estimating recruitment strength Investigate the influence of removing the “casal compatability” option applied to the tag releases
Casal2 survey selectivity	Improve the estimation of the survey selectivity ogive by including a plusgroup (80cm+)
Casal2 CPUE	Use a GAMM to estimate CPUE trends, rather than the GLM used previously (Earl et al., 2021)
Casal2 final	Updated maturity ogive following Marsh et al. 2022b Update to tag loss rate following Marsh et al., 2022a

2. Input data

At WG-FSA-17, in 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, and following previous practice, fisheries data are included in this assessment up to the end of the 2022 season. The following data sources are used in the updated assessment:

- **Catch tonnage corrected for depredation:** Catch tonnage for the 2022 season was added, and the depredation factors since 2003 were recalculated as part of the CPUE standardisation.

- **Tag scanned length distribution:** Data for the 2022 season were added.
- **Catch per unit effort data:** Data for the 2022 season were added. A GLM and GAMM were fitted including all data from 2003 onwards used to estimate CPUE from 2004 onwards.
- **Observer data on orca and sperm whale sightings:** Data for the 2022 season were added. Depredation rates were estimated from the CPUE GLM and GAMM.
- **Tag release data:** Data for the 2021 season were added. As tag recaptures are only included at least one season after release, the 2022 tag releases are not included.
- **Tag recapture data:** Recapture data for the 2022 season were added.
- **Survey biomass and length distributions:** Biomass and length distributions from the 2023 survey were included.
- **Otolith ageing data from a sample of the catch:** Data from the 2022 season were added, as well as additional readings from otoliths collected during 1998-2018.

3. Standardised CPUE

As previously, commercial catch per unit effort (kg per hook) was standardised following the approach described in Clark and Agnew (2010) and Peatman et al. (2011) using a GLM with explanatory variables (season, month, area, vessel nationality, depth class and cetacean presence) included as factors. Standardised CPUE was calculated for the period of 2004 to present based on data from 2003 onwards. In addition, a GAMM was used applying the Berg et al. method (2014) implemented in the `surveyIndex` package (Berg, 2020), as applied to Subarea 48.3 in Earl et al. (2021) accounting for location, depth, vessel, sperm and killer whale abundance, day of year and season.

The two CPUE time series are shown in Figure 1 and the corresponding partial effects are shown in Figures 2 and 3. The trends are broadly similar between the methods, although it is notable that the confidence intervals for the GAMM are wider than those estimated for the GLM. The average catch correction derived from the CPUE GLM for the last ten years (Figure 4) was 4.1%, and for the GAMM was 4.9%.

Estimates of CPUE for the period 1998 to 2003, which do not include cetacean presence, are input to the assessment as a separate block. These values have not been re-estimated and remain unchanged from previous years. Both blocks of CPUE use the same selectivity ogive as the recent catch compositions, but different catchability rates (q) are estimated for the two blocks.

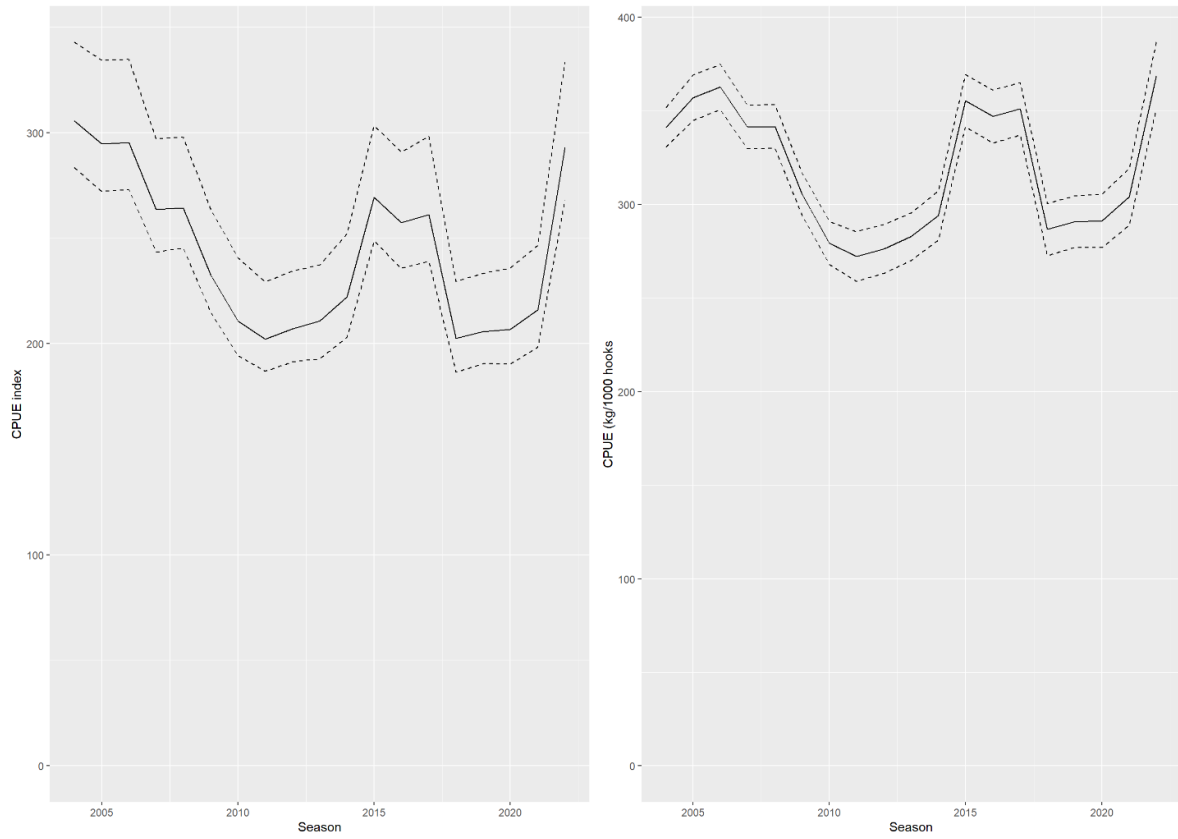


Figure 1: CPUE estimates by year from the GAMM (left) and GLM (Right). Bold black line with dashed intervals shows model fit, with 95% confidence intervals.

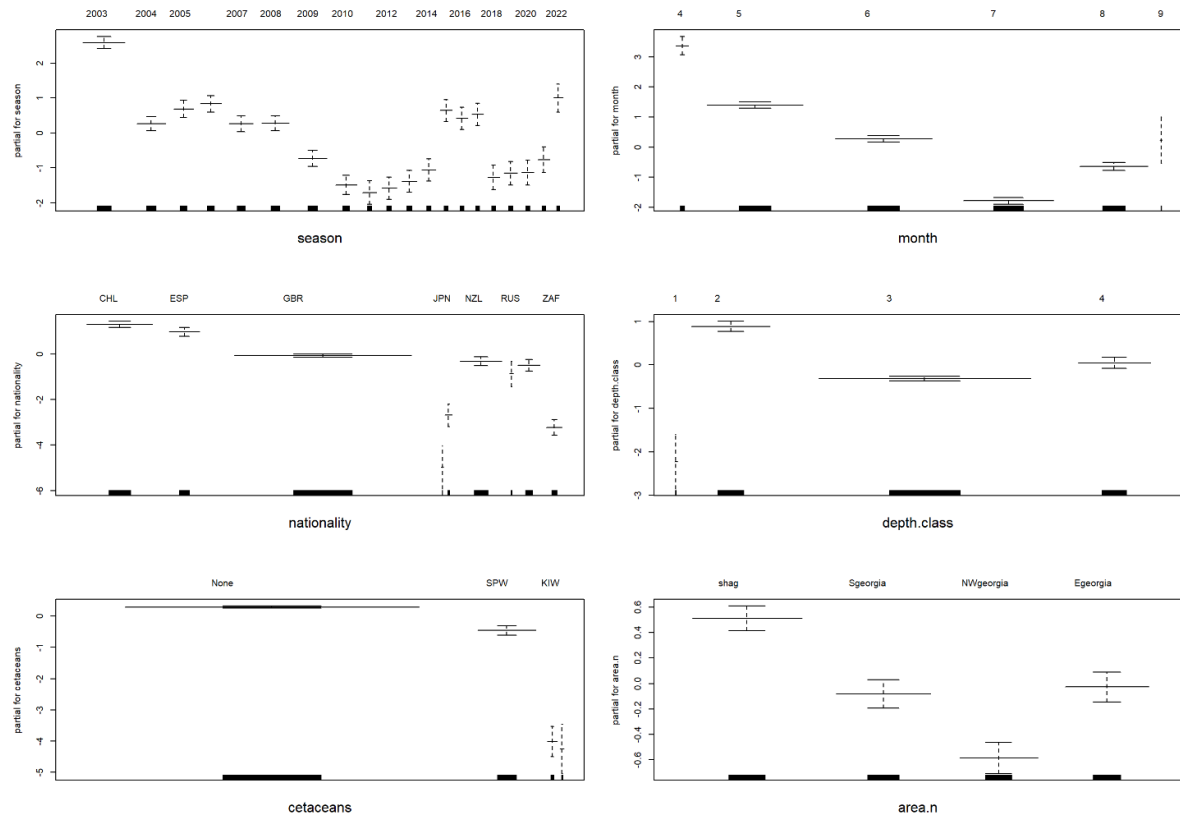


Figure 2: Magnitude of the effects on CPUE of the factors included within the GLM described.

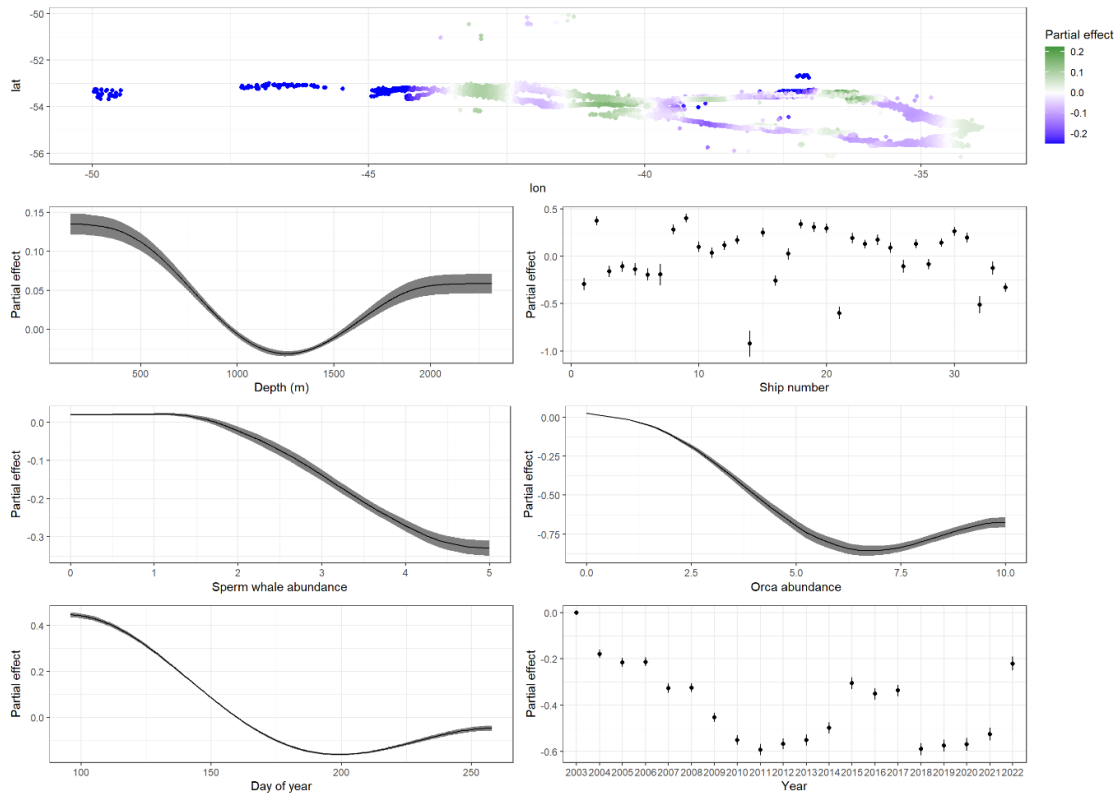


Figure 3: Magnitude of the effects on CPUE of the factors included within the GAMM described. "Ship number" is a code given to each vessel to anonymise them.

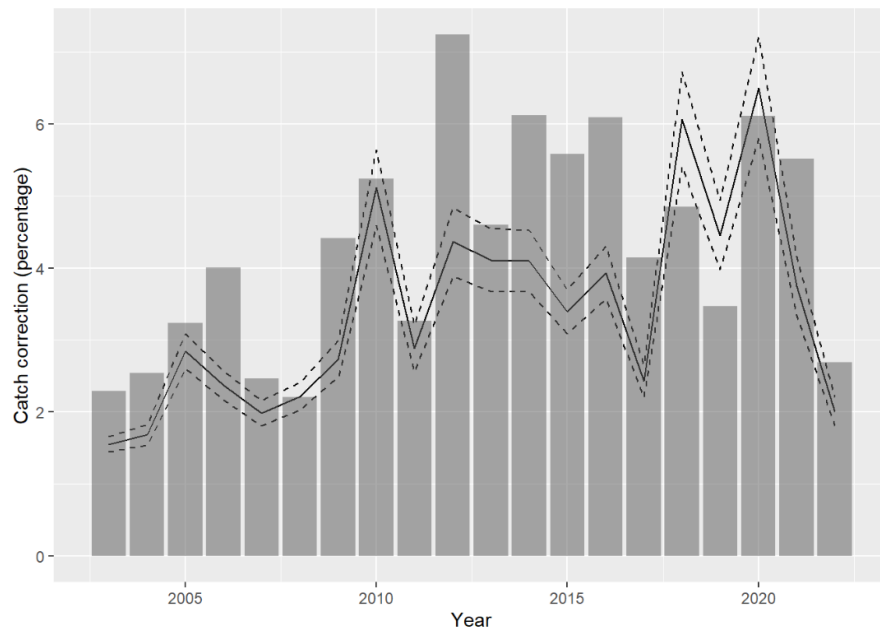


Figure 4: Correction factor applied to the catch to account for depredation, estimated from the frequency of sightings, and the effect of cetacean presence on CPUE as estimated by the GLM (lines) and GAMM (bars).

4. Catch

Within the CASAL and Casal2 models, catch is split into two periods, each with a separate selectivity ogive. The period 1988-1997 covers a period where ageing data are not available, and so catch composition is specified as proportions at length. A summary of the catch data is provided in Table 2, and in Earl and Readdy (2023) Figure 1. In the Casal2 model we explicitly split the removals into a part relating to catch, and an estimate of depredation, whereas in CASAL these are combined. Because the depredation and catch have the same selectivity, this choice makes no difference to the model fitting, but clarifies how depredation is included in the model and forecast.

*Table 2: Catches and estimated depredation (tonnes) used in the assessment. *indicates an assumed catch based on the catch calculated by Earl and Readdy (2022).*

Year	Catch	Depredation
1985	517.00	0
1986	732.00	0
1987	1,954.00	0
1988	876.00	0
1989	6,962.00	0
1990	6,828.00	0
1991	3,529.80	24.71
1992	6,861.67	48.03
1993	7,036.61	49.26
1994	5,248.43	31.49
1995	4,970.94	49.71
1996	3,529.00	77.63
1997	3,808.17	79.98
1998	3346.20	63.58
1999	4,292.48	94.43
2000	5,909.79	177.29
2001	4,230.85	126.93
2002	5,715.80	171.47
2003	7,503.12	112.55
2004	4,459.02	113.33
2005	3,029.53	98.01
2006	3,515.20	140.66
2007	3,524.49	86.85
2008	3,806.30	84.12
2009	3,381.55	149.35
2010	2,518.42	131.88
2011	1,732.46	56.61
2012	1,836.07	132.86
2013	2,093.58	96.18
2014	2,179.94	133.27
2015	2,195.10	122.46
2016	2,195.85	133.62
2017	2,194.90	90.95
2018	1,949.97	94.59
2019	2,124.41	73.65
2020	1,883.84	115.03
2021	1,812.79	99.99
2022	1,578.08	42.45
2023	1,970.00*	96.81

5. Catch age and length distribution

The length distribution of the catches has been determined annually since 1998 by simple random sampling of the catch. This is combined with ageing data to calculate the age structure of the catch from 1998 to present, and is used within the CASAL and Casal2 models as the numbers at length of fish scanned for tags within 10 cm length bins.

The number of otoliths read for construction of the age-length key (ALK) is shown in Table 3. The sample size for age determination has historically been around 300 per year based on random sampling. A program of resampling historic otoliths for age reading, to supplement these otoliths to

better reflect a length and age stratified design, has been completed during 2022 and 2023 (Marsh et al., 2022b; c; 2023), resulting in additional otoliths from 1998 onwards being read and included in this assessment, compared to Earl and Readdy (2022). All age compositions were re-estimated and the resulting age distributions are summarised in Figure 5, with more details shown in Appendix 1 of the associated diagnostics paper (Earl and Readdy, 2023).

Table 3: Sample size for age determination of fish caught in Subarea 48.3.

Year	Sample size for age determination
1998	414
1999	479
2000	392
2001	619
2002	408
2003	464
2004	601
2005	406
2006	408
2007	485
2008	560
2009	718
2010	536
2011	447
2012	538
2013	296
2014	498
2015	507
2016	544
2017	600
2018	593
2019	623
2020	601
2021	578
2022	413

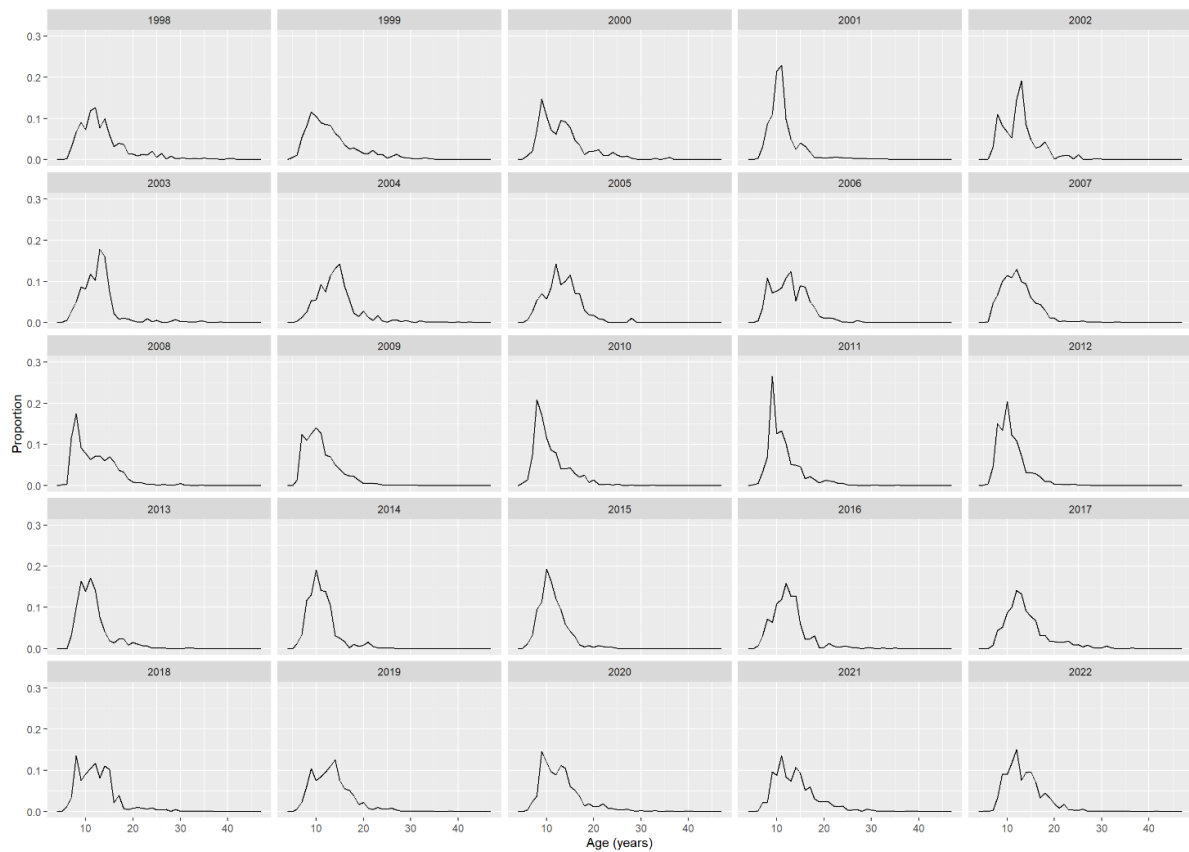


Figure 5: Raised age distribution in the catch over time.

6. Tagging data

Tagging data used within this assessment are shown in Table 4, where in-year recaptures are removed (i.e not included in the model, and deducted from the releases), and release numbers are corrected for length-dependent instantaneous tagging mortality. In 2023 there was a minor revision to the length-based instantaneous mortality to ensure that the values were consistent with Agnew *et al.* (2007) included in the update of historic tag data. In addition, the scanned number of fish was recalculated using the numbers of fish reported in C2 data, rather than being calculated from the weight and an estimated length-weight relationship as previously. The previous method had the possibility to be biased by a small number of non-random large fish significantly reducing the estimated number of fish in the catch. Comparison between the methods showed an increase in the number of scanned fish by around 10%. These changes are included in the “tagging” step of the model update.

In total, the effective release number of tags used in the assessment after removing in-year recaptures and instantaneous mortality is 58,000 up to the end of the 2022 season. Of these releases, 7,810

recaptures are used in the assessment (recaptured length of at least 60 cm and within one to four fishing seasons following release).

Table 4: Tagging release and recapture data used within the assessment. *releases are effective releases after accounting for tag shock and in-year recaptures.

	Release	Year	Length class (cm)							
			40	50	60	70	80	90	100	110
Releases*	2003	2003	1	19	87	178	117	14	2	0
Recaptures	2003	2006			0	7	10	1	0	1
Recaptures	2003	2007			1	1	3	8	0	0
Releases*	2004	2004	0	103	552	1205	960	181	12	3
Recaptures	2004	2006			3	51	47	10	2	1
Recaptures	2004	2007			5	29	41	10	1	0
Recaptures	2004	2008			1	30	51	17	4	0
Releases*	2005	2005	4	189	814	1343	1047	259	37	0
Recaptures	2005	2006			10	60	63	16	3	1
Recaptures	2005	2007			6	43	42	14	5	0
Recaptures	2005	2008			4	41	52	19	3	0
Recaptures	2005	2009			5	40	36	16	3	2
Releases*	2006	2006	5	90	854	1852	1287	375	50	5
Recaptures	2006	2007			13	81	52	19	2	0
Recaptures	2006	2008			12	77	63	20	3	0
Recaptures	2006	2009			5	38	54	27	6	0
Recaptures	2006	2010			3	28	49	32	6	1
Releases*	2007	2007	0	164	1079	1705	1075	382	36	0
Recaptures	2007	2008			34	91	55	25	1	2
Recaptures	2007	2009			8	62	53	11	6	0
Recaptures	2007	2010			6	53	40	19	4	0
Recaptures	2007	2011			0	19	31	11	7	0
Releases*	2008	2008	0	76	811	1822	1185	314	34	0
Recaptures	2008	2009			25	96	73	33	5	0
Recaptures	2008	2010			5	54	58	26	2	0
Recaptures	2008	2011			0	27	50	21	5	0
Recaptures	2008	2012			1	27	35	13	0	0
Releases*	2009	2009	0	16	562	1603	887	191	23	0
Recaptures	2009	2010			11	78	40	8	2	0
Recaptures	2009	2011			0	20	30	12	3	1
Recaptures	2009	2012			2	20	34	4	3	0
Recaptures	2009	2013			0	9	31	17	4	1
Releases*	2010	2010	0	3	346	1509	739	159	28	3
Recaptures	2010	2011			5	26	30	7	2	1
Recaptures	2010	2012			1	27	33	2	1	1
Recaptures	2010	2013			0	15	23	8	2	0
Recaptures	2010	2014			0	12	23	17	2	2
Releases*	2011	2011	0	3	64	1012	1004	400	144	32
Recaptures	2011	2012			2	36	35	14	9	2
Recaptures	2011	2013			0	24	43	15	5	3
Recaptures	2011	2014			0	10	41	20	7	0
Recaptures	2011	2015			0	3	18	14	4	1
Releases*	2012	2012	0	11	81	1006	1103	418	120	31
Recaptures	2012	2013			0	30	63	18	5	1
Recaptures	2012	2014			0	18	39	25	4	4
Recaptures	2012	2015			0	7	31	27	6	3
Recaptures	2012	2016			0	1	37	20	13	1
Releases*	2013	2013	0	3	49	932	1350	486	160	52
Recaptures	2013	2014			0	26	61	25	4	5
Recaptures	2013	2015			0	11	48	18	9	2
Recaptures	2013	2016			0	9	47	27	6	1
Recaptures	2013	2017			0	7	35	32	8	3

Releases*	2014	2014	0	3	32	584	1641	748	177	29
Recaptures	2014	2015			0	15	65	39	4	0
Recaptures	2014	2016			0	10	72	32	12	0
Recaptures	2014	2017			1	4	44	43	10	3
Recaptures	2014	2018			0	9	25	29	9	1
Releases*	2015	2015	0	3	74	611	1621	824	196	30
Recaptures	2015	2016			1	14	71	64	10	6
Recaptures	2015	2017			0	16	62	51	12	2
Recaptures	2015	2018			0	7	32	43	11	3
Recaptures	2015	2019			0	5	31	46	21	7
Releases*	2016	2016	0	3	79	521	1414	881	196	47
Recaptures	2016	2017			2	15	64	84	22	4
Recaptures	2016	2018			0	4	37	53	12	3
Recaptures	2016	2019			1	6	38	38	16	2
Recaptures	2016	2020			0	4	32	36	27	9
Releases*	2017	2017	0	0	25	411	1174	1010	349	80
Recaptures	2017	2018			3	7	64	69	18	6
Recaptures	2017	2019			0	6	52	52	19	7
Recaptures	2017	2020			0	4	27	61	18	11
Recaptures	2017	2021			0	5	18	32	20	3
Releases*	2018	2018	0	3	45	463	1270	874	272	73
Recaptures	2018	2019			1	14	52	50	23	8
Recaptures	2018	2020			0	8	40	43	19	7
Recaptures	2018	2021			0	6	32	36	17	4
Recaptures	2018	2022			0	1	23	32	9	10
Releases*	2019	2019	0	0	36	440	1204	919	282	56
Recaptures	2019	2020			0	11	59	74	19	14
Recaptures	2019	2021			0	8	69	55	14	5
Recaptures	2019	2022			0	3	36	44	21	3
Releases*	2020	2020	0	0	10	282	1039	875	269	74
Recaptures	2020	2021			0	14	57	75	27	9
Recaptures	2020	2022			0	1	33	46	28	5
Releases*	2021	2021	3	0	8	233	1026	908	263	71
Recaptures	2021	2022			0	5	60	80	22	5

7. Survey biomass

Estimates of juvenile toothfish abundance are determined from shallow water (<400m) trawl surveys around Shag Rocks, which constitute part of the biennial UK groundfish survey at South Georgia (Hollyman et al., 2023). The juvenile abundance index is raised to an estimate of numbers per km² using information on the distance towed and the wing spread of the net. Only random tows (i.e. those which do not target concentrations of fish that have been identified prior to fishing) are considered for the index.

This index of juvenile abundance can be highly variable (Figure 6 and Table 5) and results may be heavily influenced, in some years, by a small number of stations in the survey. For example, the very high estimate for 2011 is driven by high catches at just two stations that were relatively close together. Subsequent estimates are much lower (less than 10% of this high value), and so it seems as if the 2011 index is an anomalously high estimate. The 2023 value is the third highest value in the time series, suggesting a strong recent recruitment event.

Table 5: Average density and CV estimates for juvenile toothfish caught in the groundfish survey hauls shallower than 400 m around Shag Rocks.

Year	Average numbers/km ²	CV
1987	259.5	0.328
1988	722.9	0.790
1990	1,495.1	0.537
1991	832.1	0.313
1992	1,193.2	0.387
1994	1,249.5	0.566
2000	435.5	0.469
2002	689.6	0.350
2004	269.9	0.352
2005	334.8	0.327
2006	376.1	0.413
2007	18.9	0.399
2008	77.1	0.374
2009	25.1	0.528
2010	137.8	0.280
2011	2,605.5	0.758
2012	110.2	0.354
2013	206.7	0.712
2015	115.8	0.484
2017	24.7	0.570
2019	50.5	0.391
2021	329.9	0.307
2023	1,313.0	0.440

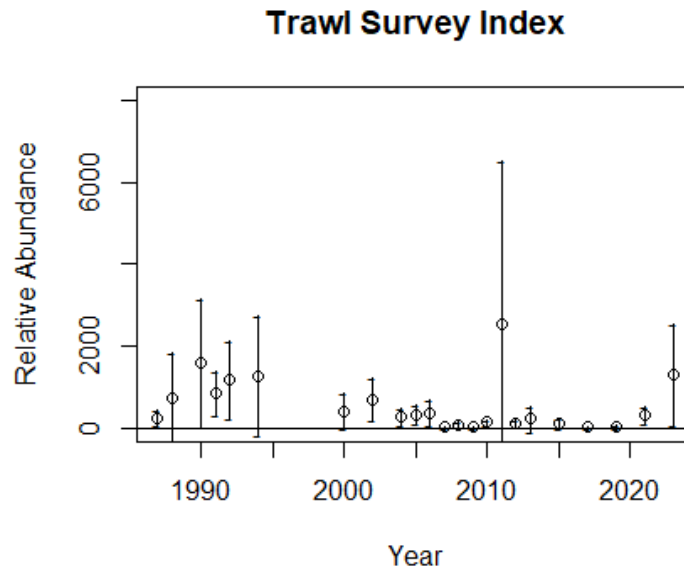


Figure 6: Relative biomass estimates with 95% confidence intervals from the groundfish survey biomass index.

8. Survey length distribution

Length distributions are recorded for all toothfish caught in the survey and are shown in Figure 7. There is some evidence that cohorts can be tracked, for example between the surveys in 1990-1992. Note that whereas in CASAL the length distributions were in 5cm bins, in Casal2 they are in 10cm bins to ensure consistency with other observations such as tagging. Dunn *et al.* (2022) showed that despite this, there was negligible difference to the model fit.

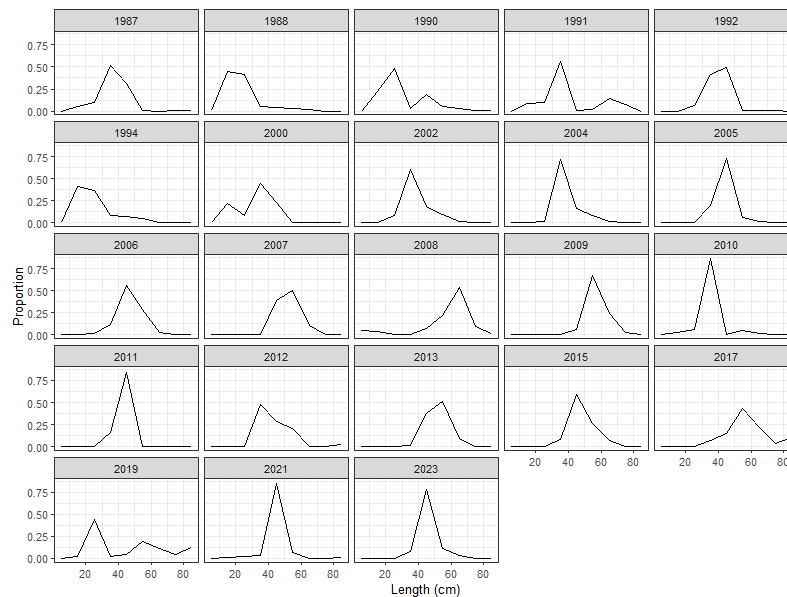


Figure 7: Groundfish survey length distribution in cm by 10cm bins, proportions by year.

9. Model structure

The CASAL model structure was unchanged from previous assessments (e.g. Earl and Readdy, 2022). This structure was implemented in Casal2 with one change, the tag loss that occurred during the fishing season in CASAL was separated into an instantaneous timestep following the fishery in Casal2, with the aim of ensuring the best possible consistency between the models. The full structure of the model is shown in Earl and Readdy (2023).

Model runs were completed in CASAL version v2.30-2012-04-03 03:09:50 UTC (rev.4686) and Casal2 version v23.08 (2023-08-24). Model parameters are given in Table 6, changes to maturity (Marsh *et al.*, 2022b c; Figure 8), growth (following Marsh *et al.*, 2023; Figure 9) and tag loss (Marsh *et al.* 2022a) have been updated following intersessional work. Following the suggestion of WG-SAM-2022 (paragraph 3.43) we fix maturity at ages 1-7 to zero based on biological expectations for such a long-lived species, as well as the difficulty of estimating the abundance of these ages in the stock assessment.

Table 6: Biological parameter values for *Dissostichus eleginoides* in Subarea 48.3. *parameters marked with an asterisk have been updated compared to Earl and Readdy 2022.

Component	Parameter	Value	Component	Parameter	Value
Natural mortality	M	0.13	Tag-related growth retardation		0.75
VBGF*	K	0.0653	Casal2 tag loss rate*		0.0061
VBGF*	t_0	-1.4869	Immediate tagging survivorship		Applied as a vector to length-based tag-release data
VBGF*	L_∞	154.1977	Tag probability of detection		1
Length-weight relationship	a	6.76×10^{-9}			
	b	3.085	Stock-recruit relationship steepness	h	0.75
Maturity range*: 0 to full maturity		1–41	Lognormal recruitment SD		Estimated

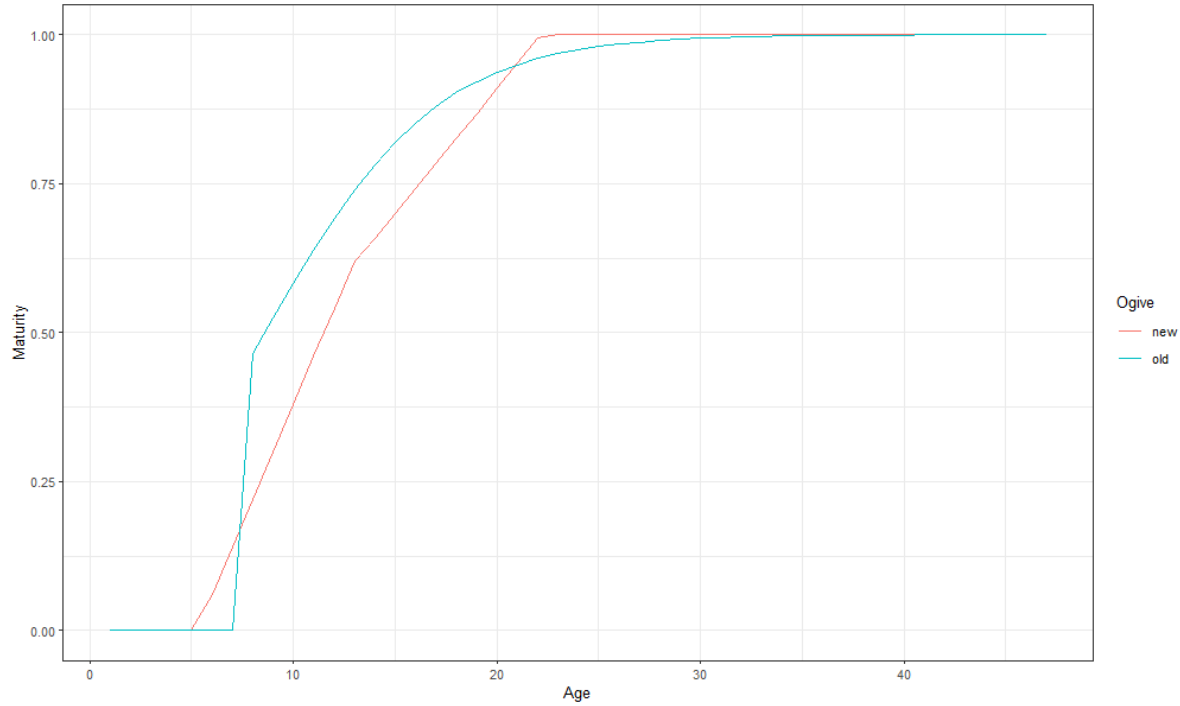


Figure 8: Old (blue) and new (red) maturity ogives used in the assessment.

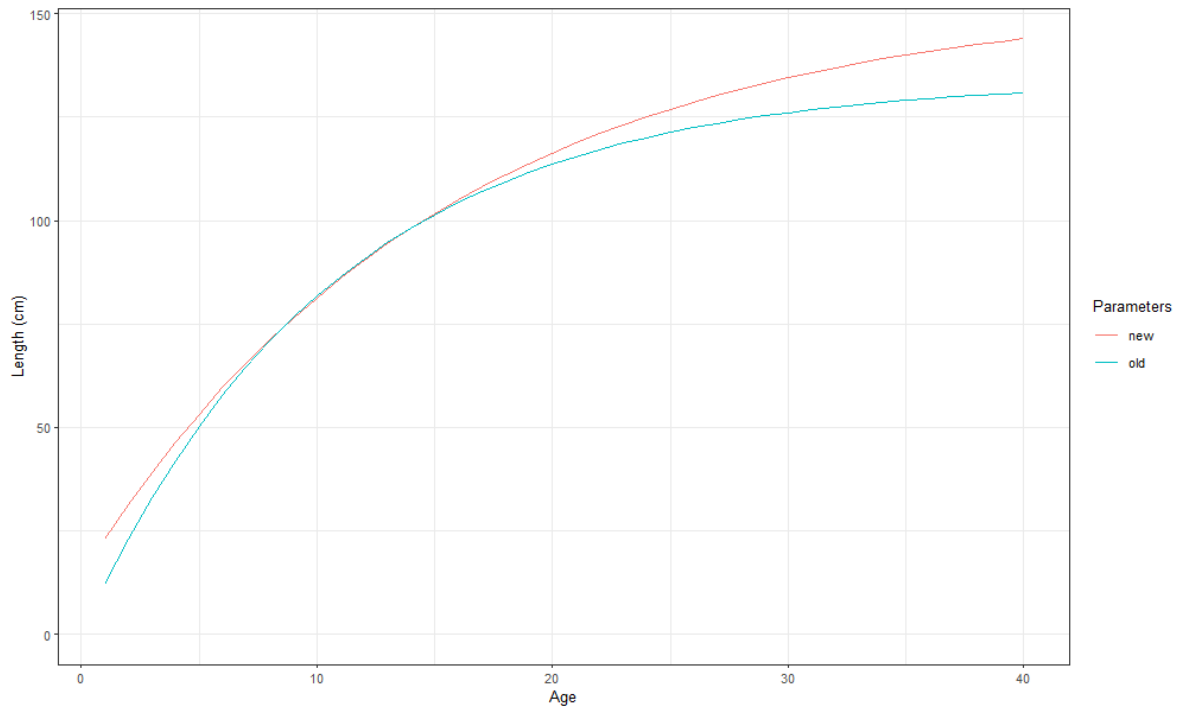


Figure 9: Old (blue) and new (red) growth curves used in the assessment.

10. Data weighting

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

- Tag dispersion constant across all years
- Catch age distribution effective sample size given by number of otoliths aged in each year
- Survey length composition weighted by number of hauls in Shag Rocks
- Survey index and CPUE have CVs calculated outside the model, and process error constrained to near zero.

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

1. Catch age and length compositions and survey length compositions were scaled according to method TA1.8 from Francis (2011) implemented in Francis (2015)
2. Tag dispersion is updated using the `Reweight.tags` function (Francis, 2015)
3. Survey process error is freed to be estimated in the model fit.

The results of these steps are shown in detail for the final model in Table 7, and summarised for other model runs in Table 8.

Table 7: Data weighting steps in the 2023 assessment.

	Initial weighting	Weighting step A	Weighting step B	Estimates from step B**
ESS* per haul	1	0.178	0.178	-
ESS* per length	1	0.387	0.387	-
ESS* per otolith 1998-present	1	0.035	0.035	-
Tag dispersion	8.68	8.68	7.31	-
Early CPUE process error	0.0015	0.0015	0.0015	0.142
Late CPUE process error	0.0015	0.0015	0.0015	0.258
Survey process error	0.0015	0.0015	0.0015	1.39

*ESS: Effective sample size

**Estimated as parameters in the CASAL model fit

11. Model outputs

Maximum Posterior Density (MPD) fits

Initially we verify the effects of the addition of an extra year of data, and transition from CASAL to Casal2 (Table 8, Figure 10). The update of the assessment causes a small rescaling of SSB, but otherwise estimated quantities remain similar between models. The transition from CASAL to Casal2 results in only very minor changes in the perception of the stock, as we have seen previously (Dunn et al. 2022).

The `tagging` model run with re-calculated tag data increases the estimated SSB following the increased number of scanned fish included in the model (Table 8, Figure 11). This results in a minor increase in the perception of stock status, as well as a slightly increased fit to the recent tag data. A further increase in the stock size and re-estimation of the recruitment strengths is caused by updating the growth and age composition data. The effective sample size per otolith estimated during the data weighting has increased slightly following the additional age data, which combined with the increased number of otoliths leads to this dataset receiving more weight.

The `compatibility` and `survey selectivity` model runs made little difference to the perception of the stock (Table 8, Figure 12), but allow better estimation of model parameters. The `recruitment` run uses the simplex method for recruitment recommended by WG-SAM-2023 (CCAMLR, 2023; para 6.37),

which provides an alternative method of parameterising recruitment strength compared to the Haist parameterisation used previously. By including a plusgroup of fish over 80cm in the survey length compositions, the right hand limb of its selectivity can potentially be better estimated by MCMC runs.

Finally, two further updates are implemented to incorporate work previously presented separately (Table 8, Figure 13). We replace the GLM used previously with a GAMM in run `CPUE`. Although the estimates of CPUE trend are similar, the larger confidence intervals estimated by the GAMM mean that it has less influence on the model fit, and so the fit to the CPUE is poorer, while the fit to the tagging data is improved. This highlights a difference in the trends implied by the two data sources. Finally, we complete the model update by updating the maturity ogive assumed for the stock. This has the effect of significantly altering the estimated SSB trajectory, while the recruitment and fishing pressure remain relatively unaltered.

MPD fits of the model estimates to observations are shown in Earl and Readdy (2023) Figures 6-20. Of particular note is the improved fit to the survey biomass (Figure 15), poor fit to the CPUE (Figure 17) and improved fits to the tag recaptures at length (Figures 19 and 20).

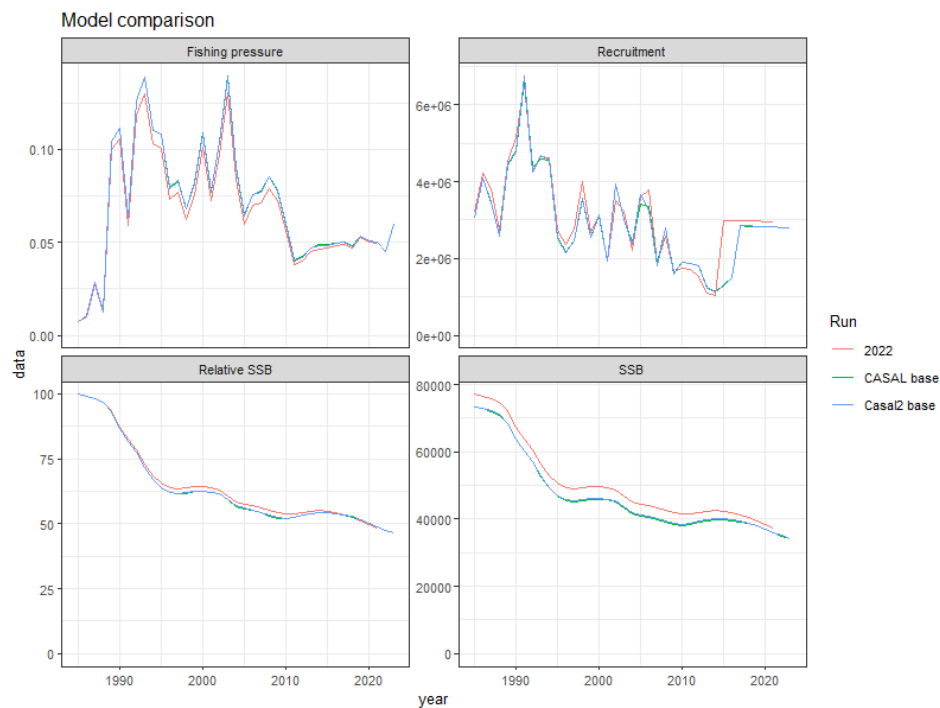


Figure 10: Initial MPD runs: 2022, CASAL base and Casal2 base.

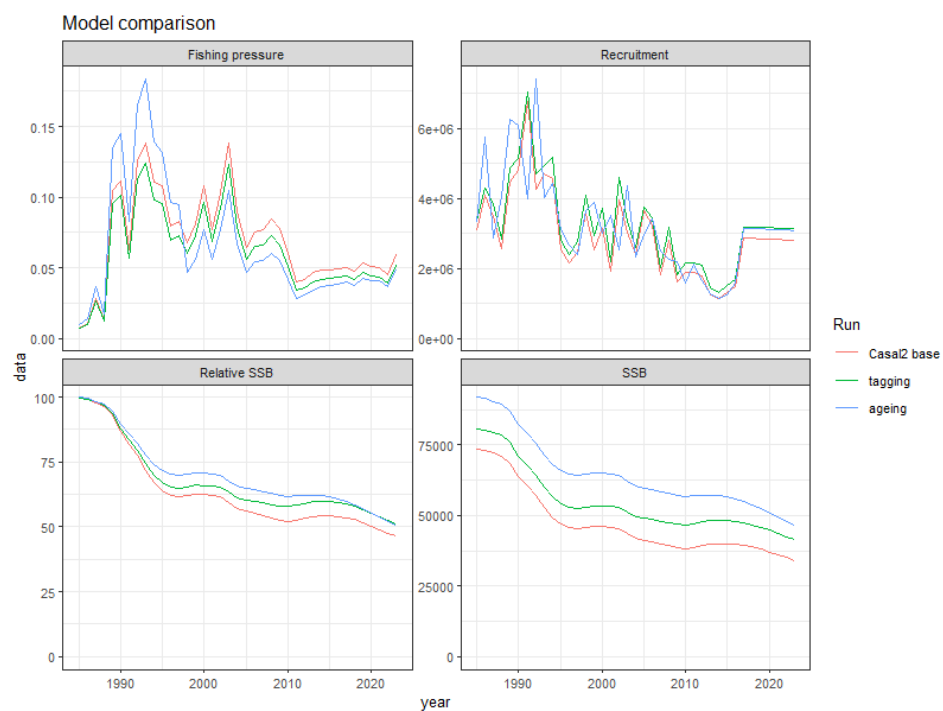


Figure 11: MPD runs updating data: Casal2 base, tagging, ageing.

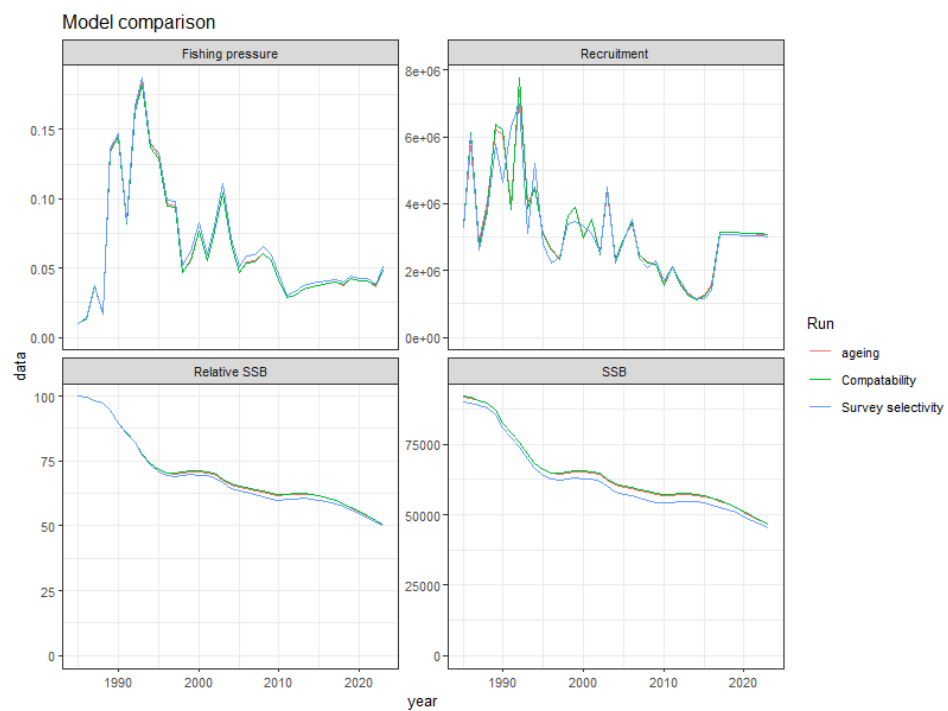


Figure 12: MPD runs updating data: ageing, compatibility, Survey selectivity.

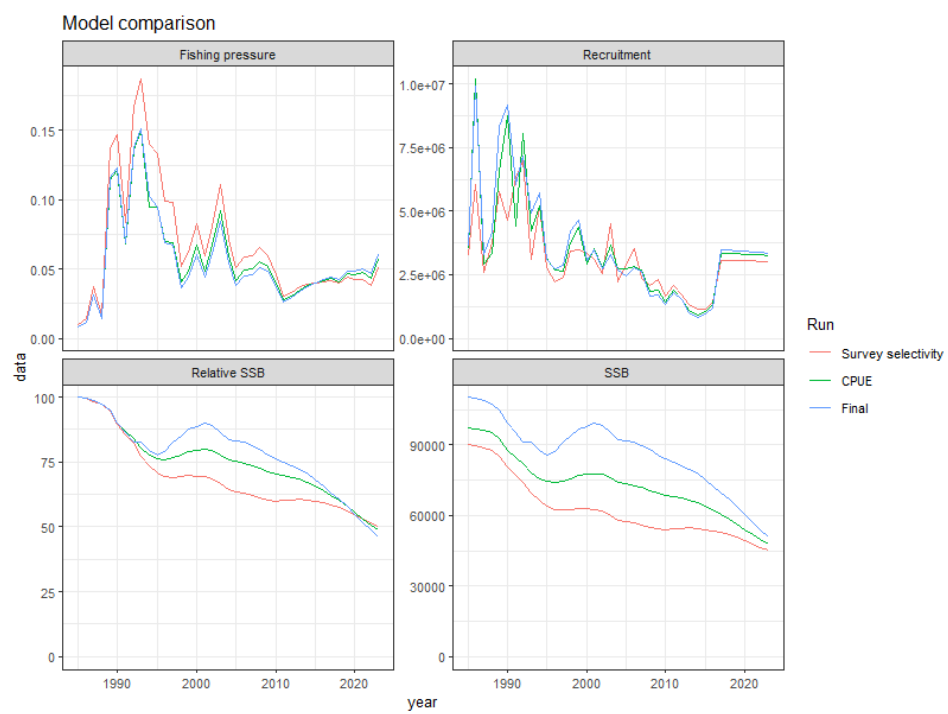


Figure 13: MPD runs updating data: Survey selectivity, CPUE, Final.

Table 8: Summary of estimated effective sample sizes, parameter estimates and negative log likelihood for each of the model sensitivity runs.

Value	Casal base	Casal2 base	Casal2 tagging	Casal2 ageing	Casal2 compatibility	Casal2 survey selectivity	Casal2 CPUE	Casal2 final
ESS** per haul	0.161	0.161	0.161	0.158	0.159	0.175	0.178	0.178
ESS** per length	0.398	0.397	0.413	0.374	0.372	0.374	0.384	0.387
ESS** per otolith 1998-2022	0.028	0.028	0.028	0.031	0.031	0.031	0.035	0.035
Tag dispersion	13.4	13.4	16.5	16.3	16.4	16.2	10.8	7.3
B_0	73516	73641	80933	91976	92120	90276	97528	110386
Early CPUE process error	0.11	0.11	0.11	0.13	0.13	0.12	0.14	0.14
Late CPUE process error	0.12	0.12	0.13	0.16	0.16	0.15	0.21	0.26
Survey process error	1.92	1.92	1.95	1.63	1.63	1.66	1.48	1.39
Early Selectivity (1985-1997)	10.52	10.52	10.41	9.05	9.04	9.04	8.99	9.03
	1.97	1.97	1.94	0.05*	0.05*	0.05*	0.05*	0.05*
	14.67	14.63	14.18	8.94	8.97	8.96	9.85	9.44
Late selectivity (1998-2021)	11.52	11.52	11.20	7.08	7.08	9.54	7.07	7.05
	2.98	2.98	2.76	0.05*	0.05*	1.71	0.05*	0.05*
	13.65	13.62	12.93	19.02	18.89	15.24	16.18	15.40
Survey selectivity	3.11	3.12	3.12	3.49	3.50	3.04	4.99	5.00
	1.34	1.34	1.34	2.07	2.08	1.71	3.45	3.44
	310.40	310.60	477.84*	1.76	1.76	2.30	0.12	0.10

*parameters estimated at or close to bounds

**ESS: Effective sample size

Profiling on B_0

Profiling of the MPD model was performed on B_0 for a range of values between 70,000 and 140,000 tonnes (the MPD estimate of B_0 using the 2023 model was 110,386). Likelihood components are shown in Earl and Readdy (2023) Figures 22–25. As with previous assessments, the tag release cohorts have a substantial trend in the B_0 at which they achieve a minimum. In Casal2, we also show that this is true for recapture year, but there is evidence that it is not related directly to time at liberty.

Markov chain Monte Carlo (MCMC) fit

An MCMC analysis was run for the 2023 assessment to give an indication of the uncertainty in the MPD model fit and provide a basis for the stochastic projection. The MCMC trace of B_0 , shown in Earl and Readdy (2023) Figure 26, indicates no obvious signs of lack of convergence. MCMC diagnostics for other model parameters are presented in Figures 27 - 65 and Table 5 of that document. R hat statistics (Figure 66 of Earl and Readdy, 2023) comparing three chains show that chains are well mixed for all

estimated parameters. Performance is generally good, although parameters associated with the selectivities show some auto-correlation within the chains, and in the case of the left-hand limb of the survey selectivity, an inability to estimate the parameter. This is likely to be related to the inclusion of the survey data as proportions at length, and the narrow range of ages caught in the survey. Comparisons with previous assessment models are shown in Table 9. The estimated B_0 is considerably higher than recent assessments, but the current SSB is estimated at 47% of B_0 , similar to the 2022 assessment.

Table 9: Median spawning biomass and 95% CIs for the initial equilibrium SSB (B_0), the current SSB, (B_{current}) and the ratio of current to initial SSB for the 2007-2023 assessments.

Assessment Year	B_0 (000 tonnes)	B_{current} (000 tonnes)	B_{current} / B_0
2007	112 (98.7-125.0)	67.1 (52.9-79.9)	0.59 (0.54-0.64)
2009	98.5 (93.6-103.8)	60.2 (55.0-65.7)	0.61 (0.58-0.64)
2011	85.1 (78.9-92.1)	44.9 (38.9-51.9)	0.53 (0.49-0.56)
2013	84.9 (80.5-89.9)	45.6 (41.4-50.8)	0.54 (0.51-0.57)
2015	85.9 (81.6-91.3)	44.7 (41.4-48.7)	0.52 (0.50-0.54)
2017	83.2 (79.0-88.1)	42.2 (38.9-52.6)	0.51 (0.49-0.53)
2019	79.7 (73.9-86.2)	40.1 (35.6-45.4)	0.50 (0.48-0.53)
2021	72.6 (68.2-78.5)	34.3 (30.5-39.7)	0.47 (0.43-0.53)
2022	76.6 (71.3-82.7)	35.9 (31.5-41.3)	0.47 (0.44-0.51)
2023	106.2 (97.8-116.9)	51.6 (46.0-59.0)	0.47 (0.44-0.52)
2023	109.1 (100.8-119.6)	51.6 (46.0-59.0)	0.47 (0.44-0.52)

Projections

Previously in CASAL, projections were projected forward from the assessments for 35 years using a constant catch, the average recruitment year class strength and CV from 1992 to 2013 for the stock projections with a lognormal empirical randomisation method of recruitment, as specified in WG-FSA-13 (CCAMLR, 2013), and updated at WG-SAM (2022). In the transition to Casal2, we observe that the way that this was estimated in CASAL has the potential to negatively bias estimates of B_0 by forcing the initial equilibrium age structure to have the same recruitment as this period. Instead, we implement the projection using the a lognormal empirical randomisation method of recruitment estimated using recruitment strengths from 1993-2016, but applying a multiplier of 0.85 (estimated to be equivalent to the previous CASAL projections) to the recruitment to capture the previous intent

to model future recruitment to be lower than that which is estimated in the early part of the assessment. Further work on approaches to including potential trends in recruitment within the CCAMLR decision rule is needed across the toothfish stock assessments, particularly in the light of climate change impact on the stocks.

The projection (shown in Figures 14, and in more detail in Earl and Readdy 2023, Table 6 and Figures 67–70) indicated that a catch of 2,000 tonnes with an additional 98 tonnes of depredation assumed (based on a 4.9% average 2013–2022) would be expected on average to keep the stock above 50% of B_0 after 35 years, with ~~less than 0.6%~~ 0.4% of the simulations falling below 20% of B_0 during the 35-year period. The associated statistics are shown in Table 10. Following the procedure agreed by SC-CCAMLR-38 (paragraph 3.70), this implies that the TAC of 2,000 tonnes would be consistent with the CCAMLR decision rules.

Table 10: Forecast summary with a catch of 2,000 tonnes, and an additional 98 tonnes of depredation

<u>Quantity</u>	<u>Value</u>
<u>B_0</u>	<u>109,065 tonnes</u>
<u>Objective function</u>	<u>879</u>
<u>Risk of falling below 20% of B_0</u>	<u>0.004</u>
<u>Risk of falling below 50% of B_0 in 2058</u>	<u>0.493</u>

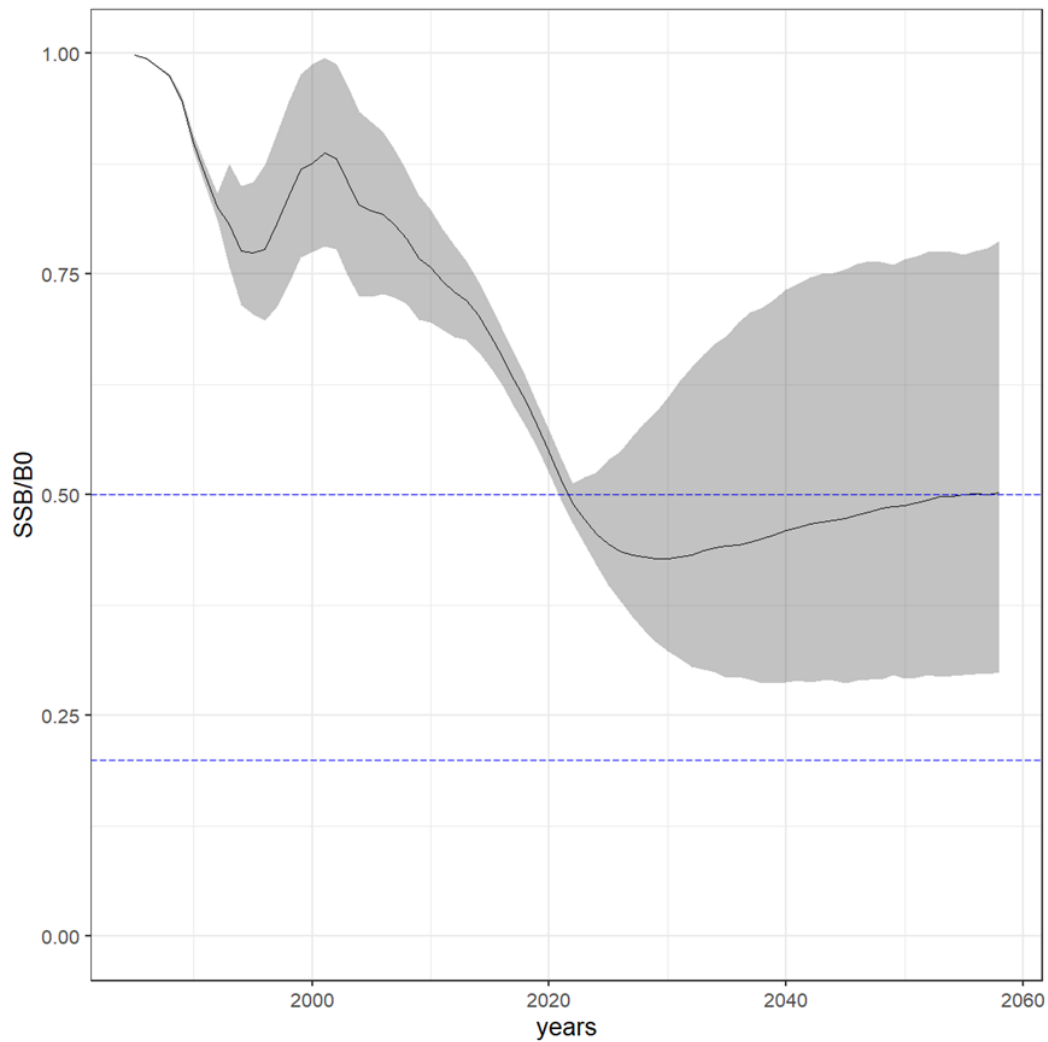


Figure 14: MCMC SSB projections relative to B_0 ; median (line) with 95% confidence intervals (shaded). The blue horizontal lines show the 50% and 20% reference points used in the CCAMLR decision rule.

12. Summary

The assessment has been run in both CASAL and Casal2, and we were able to verify that the results were highly consistent. Therefore, we recommend that CASAL runs are no longer needed for this assessment, and future advice should be based on developing the Casal2 model. The assessment has been updated to take account of an additional year of data, revisions to the historic data and incorporation of the most recent estimates of maturity, tag loss and growth.

The assessment of the Patagonian toothfish (*D. eleginoides*) in Subarea 48.3 indicates that the current status of the stock is at 47% of B_0 . Spawning biomass has been close to 50% of virgin biomass in recent years. Projections indicate that catches of 2,000 tonnes would be consistent with the CCAMLR decision rules.

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Additional Resources

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