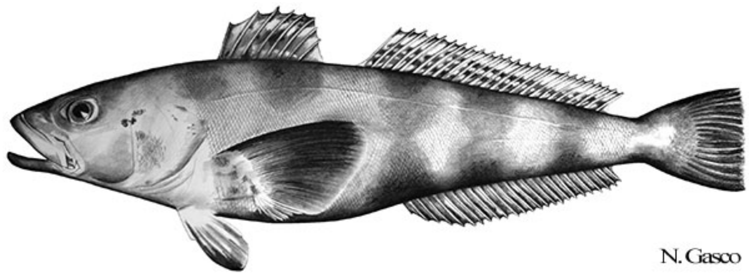
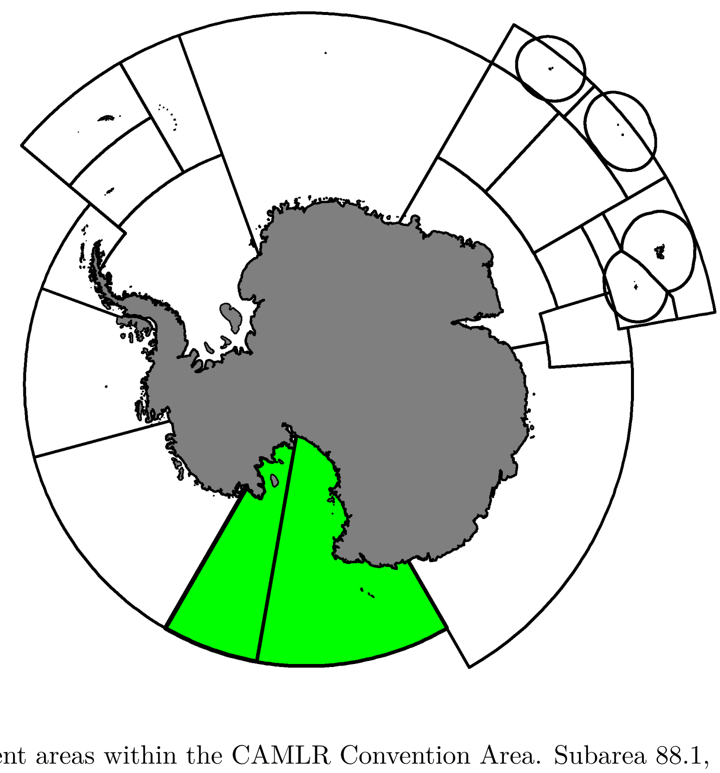
Stock Assessment Report 2022: *Dissostichus mawsoni* in Subarea 88.1

CCAMLR Secretariat

14 March 2023



Antarctic toothfish *Dissostichus mawsoni* Norman, 1937.



Map of the management areas within the CAMLR Convention Area. Subarea 88.1, SSRUs 882A and 882B, the regions discussed in this report are shaded in green. Throughout this report, "2022" refers to the 2021/22 CCAMLR fishing season (from 1 December 2021 to 30 November 2022).

CCAMLR

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Commission pour la conservation de la faune et la flore marines de l'Antarctique
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Assessment model for Antarctic toothfish (Dissostichus mawsoni) in the Ross Sea region to 2020/21

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EN

Assessment model for Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea region to 2020/21

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ABSTRACT

This paper reports on the update of the Bayesian sex- and age-structured integrated stock assessment model for Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea region (RSR; Subareas 88.1 and Small-Scale Research Units (SSRUs) 88.2A-B) using the most recent available data for the RSR Antarctic toothfish fishery. The assessment model uses catch and effort data for 1998–2021, tag-release data for 2001–2020 and associated tag-recapture observations for 2002–2021, commercial fishery age frequencies for 1998–2020, abundance observations from the Ross Sea Shelf Survey (RSSS) for 2012–2021, and age observations from the RSSS for 2012–2021. Observational data (tag releases, tag recaptures, and age/length data) from vessel trips that had been quarantined since the 2019 assessment were also excluded. The model structure was the same as that used in 2019.

The 2021 model (R1.1) maximum posterior density (MPD) estimated the equilibrium pre-exploitation spawning stock biomass (B_0) as 78 892 t, and the current stock status (B_{2021}) as 62.7%. Markov chain Monte Carlo (MCMC) estimated B_0 as 78 373 t (95% CIs 71 999–85 663 t) and the current stock status (B_{2021}) as 62.7% B_0 (95% CIs 59.9–65.6% B_0). The estimated status in 2019 from the 2021 assessment (66.3%) was almost the same as that estimated by the 2019 assessment (66.0%).

Following recommendations from the Working Group on Statistics, Assessments and Modelling (WG-SAM), the sensitivity analyses focused on the diagnostics of excluding the initial three years or six years of tag-release data (2001–2003 or 2001–2006) and associated tag-recapture data. The key outcome of the sensitivity analyses was that exclusion of the initial three years of tag-release data (i.e., for 2001–2003) and associated tag-recapture data (in R1.2) resulted in almost negligible differences in model fits to tag or age data, slightly improved likelihood, and showed almost no differences in estimates of B_0 or current biomass in the R1.1 and R1.2 models.

The precautionary yield calculated using the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) decision rules and applying a catch split of 19% for the area north of 70° S, 66% for south of 70° S, and 15% in the Special Research Zone was 3495 t with the base case model (R1.1). We recommend a catch limit of 3495 t for RSR Antarctic toothfish in the 2021/22 and 2022/23 fishing seasons.

1. INTRODUCTION

The exploratory Antarctic toothfish (*Dissostichus mawsoni*) fishery in the Ross Sea region (RSR; defined as Subareas 88.1 and Small-Scale Research Units (SSRUs) 88.2A-B; see Figure 1) began in 1997[1]. Since 2004, the catch in the Antarctic toothfish fishery in the RSR has been between 2178 t and 3210 t in each fishing season, with catch limits typically set for two-year periods (Grüss et al. 2021b). In 2019 and 2020, the catch limit for the RSR was 3140 t per annum (CCAMLR-38 2019). Detailed description of the stock area, stock assessment methods, and the stock assessment parameters are given in the Stock Annex for the 2021 assessment of RSR Antarctic toothfish (Grüss et al. 2021c). Additional tables of model outputs are detailed in the Appendix of this paper, and complete sets of model diagnostics are provided by Grüss et al. (2021b).

Catch limits for the RSR have been determined using yield calculations from an integrated stock assessment model with catch from the onset of the Antarctic toothfish fishery, age frequency data, data from the Ross Sea Shelf Survey (RSSS), and the tag-release and recapture data from the tagging programme initiated in 2001.

In 2016, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) adopted the Ross Sea region Marine Protected Area (RSrMPA) (CCAMLR-XXXV 2016), which was implemented on 1st December 2017 for the 2017/18 season. The fishery is now managed within four management areas. Within the Special Research Zone (SRZ) of the RSrMPA, the catch limit is fixed at 15% of the total available catch limit (CM 91-05 paragraph 8). Otherwise, the remaining catch limit is spread between north of 70° S (19%) and south of 70° S (66%) in areas outside the RSrMPA (CM 41-09 paragraph 2).

In this report, we use the general stock assessment package CASAL (Bull et al. 2012) for the 2021 version of the RSR stock assessment model and update the 2019 assessment (Dunn 2019). The RSR stock assessment model assumes a single homogeneous area with four geographically defined fisheries, based on the current management areas, i.e., (1) north of 70° S and outside the RSrMPA (N70), (2) south of 70° S and outside the RSrMPA (S70), (3) the SRZ, and (4) remaining areas in the RSR including historical catches taken inside the GPZ (hereafter generally defined as "Other", Figure 1).

Data included in the 2021 Antarctic toothfish assessment are those used in the 2019 assessment (Dunn 2019) with the addition of the most recent available data. These are: (1) the catch for each of the fishery areas, including catches from quarantined vessel trips, estimates of illegal, unreported, and unregulated (IUU) catch, Antarctic toothfish taken in research surveys undertaken under CM 24-01, and Antarctic toothfish taken from outside the Convention area that are likely a part of the RSR biological stock (South Pacific Regional Fisheries Management Organisation (SPRFMO)); (2) catch-at-age frequencies for the four fishery areas; (3) tag-release data up to 2020 and associated tag-recapture data up to 2021; and (4) the RSSS abundance time series up to 2021 and associated age frequencies up to 2021 (Devine & Prasad 2021).

In the following, we describe the 2021 assessment for RSR Antarctic toothfish and the main assessment model diagnostics. Following recommendations from the Working Group on Statistics, Assessments and Modelling (WG-SAM), the sensitivity analyses for the 2021 assessment focused on the effects of excluding either the initial three years or initial six years of tag-release data (2001–2003 or 2001–2006) and associated tag-recapture data.

Summary diagnostics (recommended by SC-CAMLR-XXXIV Annex 5) for the assessment model are available in a separate document (Grüss et al. 2021b), and underlying parameters and stock assessment

[1] Note that this report uses the CCAMLR split year that is defined from 1st December to 30th November. Hence, the term "year" refers to the fishing season in which most fishing occurs, e.g., the season from 1st December 1996 to 30th November 1997 (1996/97) is labelled as 1997.

methods are described in the Stock Annex (Grüss et al. 2021c). The CASAL input and output data files associated with the assessment model are available from the CCAMLR Secretariat upon request.

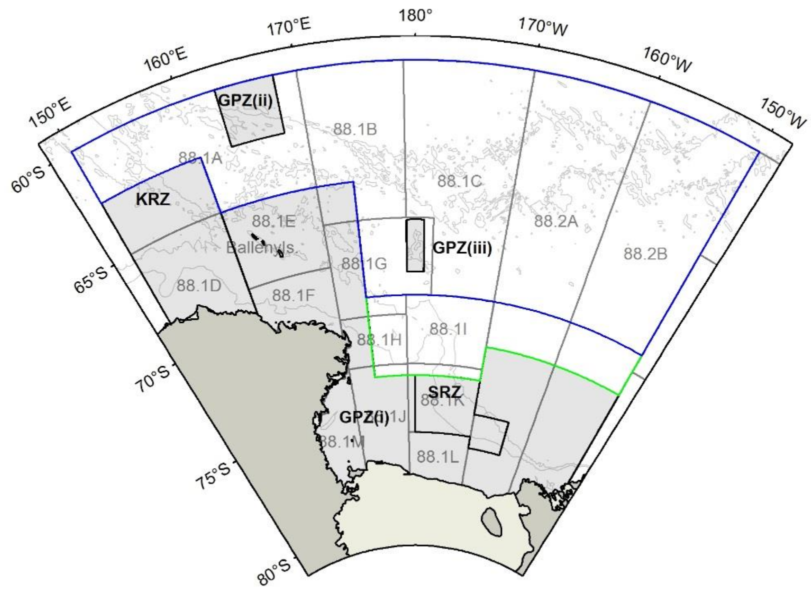

Figure 1. Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas 88.1 and 88.2, Small-Scale Research Units (SSRUs), the Ross Sea region Marine Protected Area (General Protection Zones (GPZ) (i)–(iii), the Krill Research Zone (KRZ), and the Special Research Zone (SRZ); in dark grey shade), and the Ross Sea region (bounded region). The blue polygon delineates the N70 management area, while the green polygon delineates the S70 management area. Depth contours (light grey) are plotted at 1000 and 3000 m.

2. METHODS

The 2021 assessment model of RSR Antarctic toothfish is a Bayesian sex- and age- structured population model, following the structure detailed by Mormede et al. (2014), Dunn (2019) and Grüss et al. (2021d). Previous assessment models were described by Dunn et al. (2005), Dunn & Hanchet (2007, 2009), Mormede et al. (2011, 2013, 2015), and Mormede (2017). The 2021 assessment model was implemented using the general stock assessment package CASAL (Bull et al. 2012) version v2.30-2012-03-21 rev 4648 (CCAMLR-38, Annex 5). A detailed description of the stock area, stock assessment methods, and the stock assessment model parameters are given in the Stock Annex (Grüss et al. 2021c).

The following data were updated in the 2021 assessment model from that used in the 2019 assessment model:

- Annual catch for the 2020 and 2021 fishing seasons and catch by local area (N70, S70, SRZ, and Other areas) were added with minor revisions to the previous catch history (Grüss et al. 2021a).
- Catch from the RSSS was updated and added for 2020 and 2021 (Devine et al. 2021). Reported catches outside the CCAMLR Convention area (SPRFMO) were updated and added for 2020 (Fenaughty 2020) and 2021 (Fenaughty 2021). IUU catch for 2020 and 2021 were assumed to be 0 t.

- Scaled catch-at-age frequencies from the commercial fishery for 2019 and 2020 were added, and historical catch-at-age frequencies (1998–2018) were updated as described in Grüss et al. (2021a).
- Tag-release data for 2019 and 2020 and associated recapture data for 2020 and 2021 (see Grüss et al. (2021a)) were added, and the tag-recapture time series data for 2001–2019 were revised, including correction of vessel specific tagged fish survival and vessel specific tag detection rates (Grüss et al. (2021a).
- Tag-release, tag-recapture, and length frequency data for vessel trips that had been quarantined since the 2019 assessment were removed (Grüss et al. 2021a).
- RSSS standardised abundance series were updated to 2021, and RSSS catch-at-age frequencies for 2020 and 2021 were added (Devine & Prasad 2021).
- Year class strength (YCS) was estimated for the period 2003–2015, and the estimates of YCS were assumed to have an average of one over that period.

We refer to the updated 2021 assessment model as R1.1 and use this model as a base to conduct sensitivity analyses to address the following issue:

Each year that the assessment model is updated, the addition of new tag-release years creates additional partitions within the model and increases the computer memory allocation required to evaluate the model. Given the memory constraints inherent in the software (defined by the 32-bit memory address allocation limit used for CASAL's auto-differentiation based minimiser), the continued addition of the tag data may not be computationally feasible without substantial modification to the software. The removal of data is generally not recommended unless a clear data quality problem is evident. However, in this case it may be a pragmatic solution to get the model to run.

(i) *R1.2. Evaluation of the impact of removing the initial three years of tag-release data (2001–2003) and associated tag-recapture data*. The initial three years of tag-release and associated tag-recapture data (3.9% of all available tag data) were identified as potentially different in quality to the tag data since 2004. Tagging in 2001-2003 was initiated by New Zealand vessels as a pilot project targeting small fish to understand whether Antarctic toothfish tagging was feasible and to learn more about toothfish movement. Tagging was introduced as a requirement in 2004 (under CM41-01/C), extending the pilot scheme to all vessels, as a means to estimate abundance.

(ii) *R1.3. Evaluation of the impact of removing the initial six years of tag-release data (2001–2006) and associated tag-recapture data (19.1% of all tag data)*. After the requirement for all vessels to tag toothfish was introduced in 2004, tagging continued to occur predominantly on smaller toothfish. In 2007, CCAMLR introduced the requirement to tag fish in proportion to the length frequency of the retained catch (under CM 41-01/C). This improved the distribution of tagged fish, and this continued to improve until it stabilised when achieving a high tag-overlap statistic (60%) was introduced as a requirement in CM 41-01/C in 2011.

As in previous assessments, catch per unit effort (CPUE) indices were not included in the 2021 assessment model because CPUE was not likely to reflect changes in abundance (Parker & Mormede 2017; Dunn 2019).

3. RESULTS

3.1 Analysis of maximum posterior density (MPD) results

Diagnostic plots for the 2021 base case assessment model (R1.1) are given by Grüss et al. (2021b). The estimated maximum posterior density (MPD) initial biomass (B_0) for the 2021 assessment model was 78 892 t, and the current biomass (B_{2021}) was estimated to be at 62.7% of B_0. The start values and prior assumptions used are given in Table A1, relative data weightings are summarised in Table A2, and the total objective function is detailed in Table A3.

Likelihood profiles were carried out by fixing B_0 over a range of plausible values, and the remaining parameters (e.g., selectivity parameters) were estimated (Figure 2). The tag-recaptures of fish released in 2001, 2003, 2008, 2009, 2012 and 2017, RSSS abundances, and the age frequencies from the "Other" fisheries suggested that estimates of lower initial biomass (< 50 000 t) were less likely, whereas the tag recaptures of fish released in 2002, 2004, 2006, 2018, 2019 and 2020, and the age frequencies from the RSSS, N70, S70, and SRZ fisheries suggested that estimates of higher initial biomass (> 100 000 t) were less likely (Figure 2).

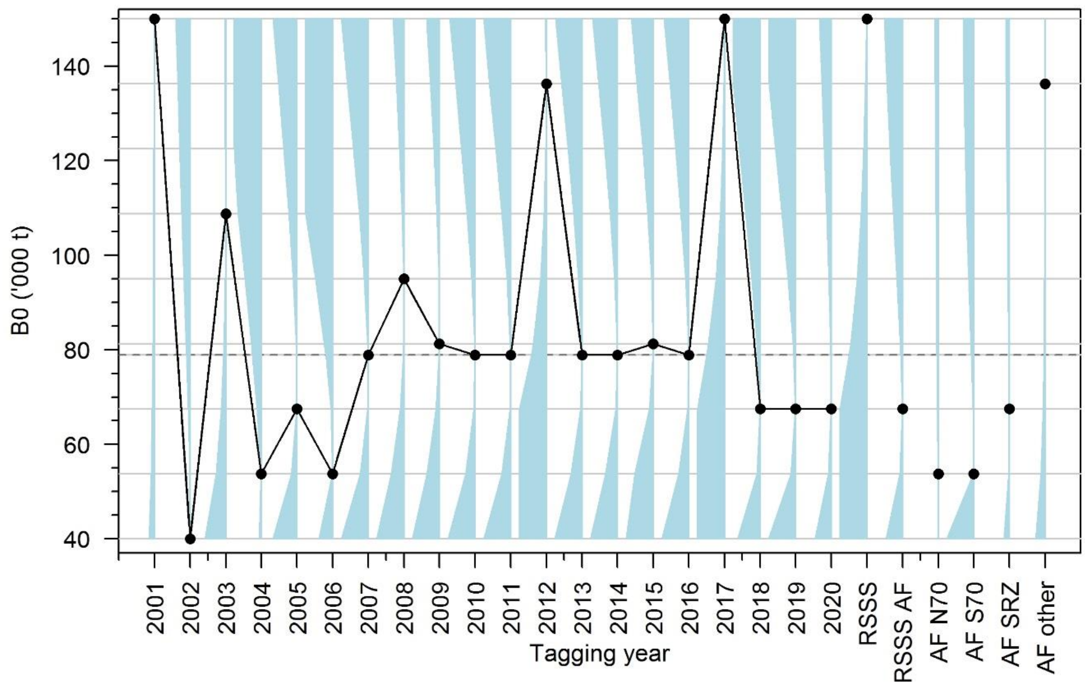

Figure 2. Likelihood profiles for pre-exploitation biomass B_0 for the 2021 base case assessment model of Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*). Negative log likelihood values were rescaled to have a minimum of 0 for each dataset. The dashed horizontal line indicates the maximum posterior density (MPD) value for B_0.

Plots of the observed proportions-at-age of the catch versus the MPD expected values suggested that there was some evidence of inadequate fit for commercial catch-at-age data and some RSSS age frequencies, specifically to the very youngest (< 5 years) and the oldest (≥ 35 years) aged fish. While the residuals for the most common ages were generally adequate, there was a residual pattern suggesting evidence for either changing selectivity through time and/or YCS progression that was not well accounted for (Figure 3). Fits to the RSSS local abundance series were within the confidence intervals and followed the overall trend (Figure 4).

Plots of the observed number of tagged fish recaptured versus MPD expected values suggested adequate fits in most of the tag-release data, and there was no evidence of systematic bias in the expected tag detection rate (see the diagnostic plots in Grüss et al. (2021b)). The residuals for the number of tags recaptured from each tag-release cohort suggest positive or negative bias correlated with the year of recapture, rather than the year of release (Figure 5). This finding was similar to the findings in previous assessments of RSR Antarctic toothfish (e.g., Dunn 2019).

Year classes estimated in the 2021 base case assessment model (R1.1) were consistent with those estimated in the previous stock assessment (Dunn, 2019) and showed a pattern of year classes fluctuating above and below average since 2003, with strong 2005, 2013, and 2014 year classes and weak 2003 and 2008 year classes.

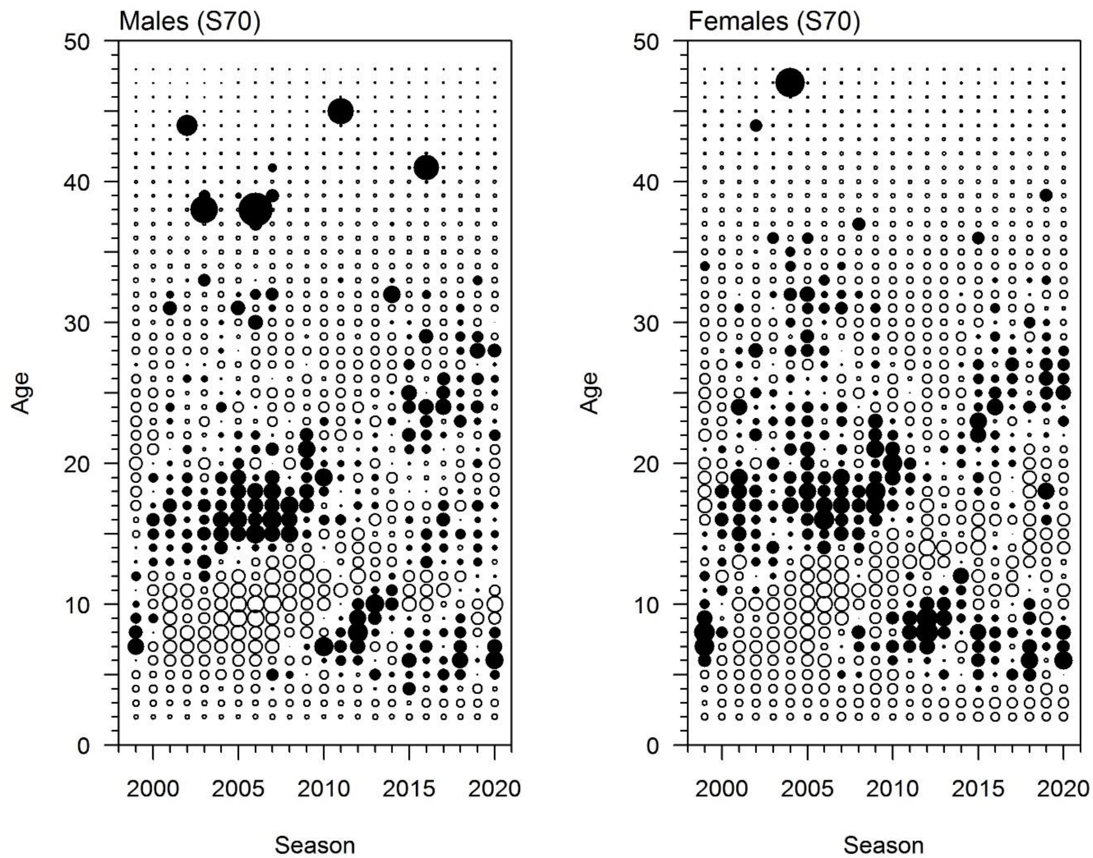

Figure 3. Pearson residuals of the catch-at-age data for males and females of the Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*) in the S70 fishery, for the 2021 base case assessment model. Black circles are for positive Pearson residuals, and empty circles are for negative Pearson residuals.

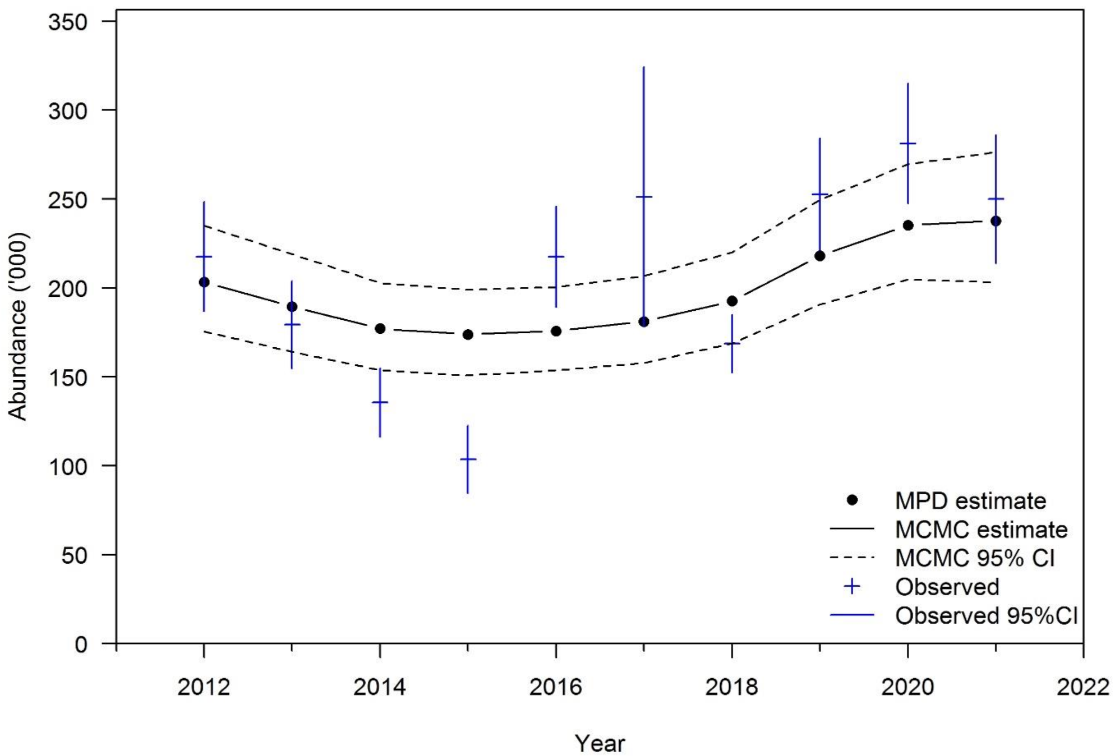

Figure 4. Maximum posterior density (MPD) and Markov chain Monte Carlo (MCMC) fits to the survey local abundance series for the 2021 base case assessment model of the Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*).

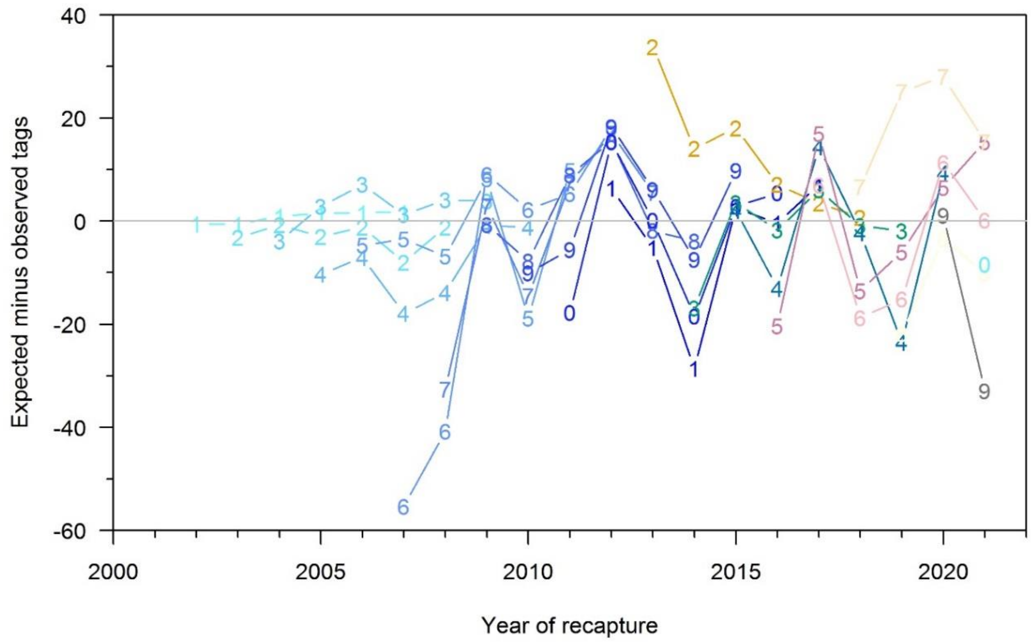

Figure 5. Expected minus observed number of tagged fish recaptured each year of recapture per year of release for the 2021 base case assessment model of Ross Sea Region Antarctic toothfish (*Dissostichus mawsoni*), with each year of release indicated by the plot character (e.g., 1 = 2001 or 2011).

3.2 Audit trail from the 2019 assessment model

Incremental changes from the 2019 base case assessment model (R0.0) to the 2021 base case assessment model (R1.1) were made and are given below as an audit trail describing the effect of each step change. Revised and additional observations and data were added incrementally, without changing the 2019 data weightings. Finally, the data weightings were re-estimated using the methods of Francis (2011) to obtain the 2021 model. Details of each of the steps are given in Table 1.

The audit trail suggests that revising catch history and age frequencies had very little impact on the assessment outcomes (Table 1). In contrast, revising tag releases and tag recaptures led to a small increase in the estimated initial biomass (B_0); this small increase in B_0 is due to the “select” calibration of vessel tag-release mortality and tag detection and, to a lesser extent, to the exclusion of quarantined vessel trips since the previous assessment. Updating the assessment model to include data up to and including the 2021 season instead of the 2019 season had very little effect on assessment model outcomes. Adding the 2019 and 2020 tag releases and the corresponding 2020 and 2021 tag-recapture observations led to an increase in initial biomass. Adding the 2019-2021 age frequencies and estimating YCS for the period 2003–2015 resulted in an increase. The addition of the RSSS standardised abundance series updated to 2021 also led to an increase in initial biomass. Finally, updating the data weightings (i.e., considering the re-estimation of the effective sample sizes of age frequency data and the tag dispersion parameters) led to a very slight increase in initial biomass (Table 1).

Overall, the MPD estimates of B_0 from the R0.0 model increased from 72 314 t to 78 892 t. B_{2019} increased from 47 753 t to 52 339 t. B_{2019} as a percent of B_0 was almost the same, at 66.0% in the 2019 model compared with 66.3% in this model.

Table 1. Audit trail of maximum posterior density (MPD) estimates of B_0 (t), B_{2019} (t), and B_{2019} as a percent of B_0 for Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*), describing the stepwise incremental changes from the 2019 base case assessment model (R0.0) to the 2021 base case assessment model (R1.1).

Run	Description	B_0 (t)	B_{2019} (t)	B_{2019} (% B_0)
R0.0	2019 base case assessment model	72 314	47 753	66.0
R0.1	Revising catch history	72 326	47 718	66.0
R0.2	Revising age frequencies	72 451	47 819	66.0
R0.3	Revising tag releases	76 865	52 181	67.9
R0.4	Revising tag-recapture observations	74 710	50 028	67.0
R0.5	Updating assessment model to 2021	74 707	50 024	67.0
R0.6	Adding 2019 and 2020 tag releases and 2020 and 2021 tag-recapture observations	75 803	51 438	67.9
R0.7	Adding age frequencies for 2019-2021 and estimating year class strength over the period 2003–2015	76 426	51 823	67.8
R0.8	Adding Ross Sea Shelf Survey abundances	78 865	52 332	66.4
R0.9	Updating and recalculating the relative data weightings	78 892	52 339	66.3
R1.1	2021 base case assessment model	78 892	52 339	66.3

3.3 Sensitivity analyses

In the first sensitivity analysis (R1.2), the initial three years of tag-release data (2001–2003) and associated tag-recapture data were removed. The sensitivity run showed little differences between R1.2 model runs and the 2021 model (R1.1), either in terms of the initial or the current biomass estimates (Tables 2 and 3). However, although there was a slight improvement in the overall likelihood (the negative log likelihood improved by 37 points), there was no significant improvement in Pearson residuals of the catch-at-age data (Figure 6) and the negative log likelihood for S70 catch-at-age data was decreased by only 0.1%. The R1.2 model slightly improved the negative log likelihood for the remaining tag-recapture observations (by about 11 to 12%)

In model R1.3, the initial six years of tag-release data (2001–2006) and associated tag-recapture data were removed. The sensitivity runs showed differences between R1.3 and R1.1 in terms of both initial or current biomass estimates (Table 2) and showed an increase in both initial and current biomass estimates. Moreover, the R1.3 model resulted in almost no change in the overall likelihood (the negative log likelihood decreased by 2 points) and did not lead to any improvement in Pearson residuals of the catch-at-age data.

Table 2. Sensitivity maximum posterior density (MPD) estimates of B_0, B_{2019}, and B_{2021} as a percent of B_0 for Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*).

Run	Description	B_0 (t)	B_{2019} (t)	B_{2021} (t)	B_{2021} (% B_0)
R0.0	2019 base case assessment model	72 314	47 753	–	–
R1.1	2021 base case assessment model	78 892	52 339	49 480	62.7
R1.2	2021 model using 2004+ tagging data	78 870	52 353	49 513	62.8
R1.3	2021 model using 2007+ tagging data	83 073	56 141	53 198	64.0

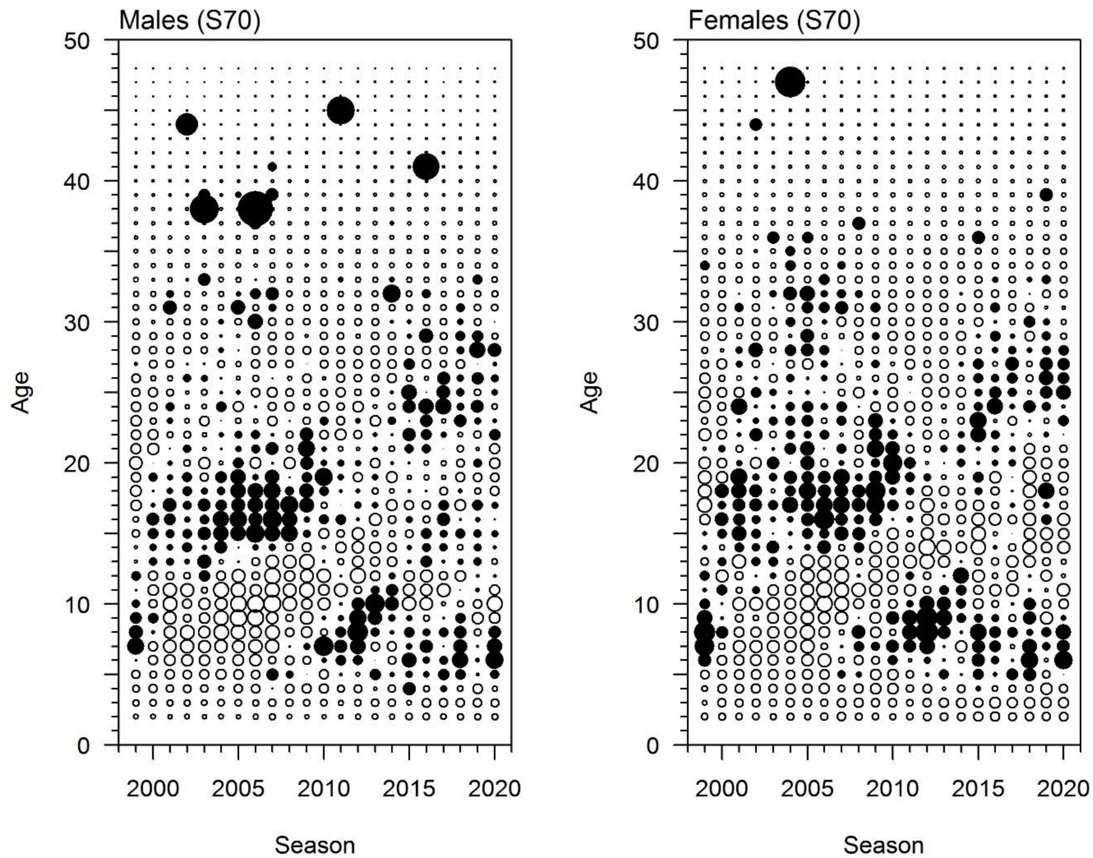

Figure 6. Pearson residuals of the catch-at-age data for males and females of Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*) in the S70 fishery, for the R1.2 sensitivity model. In the R1.2 sensitivity analysis, the first three years of tag-release data (2001–2003) and associated tag-recapture data were removed. Black circles are for positive Pearson residuals, and empty circles are for negative Pearson residuals.

3.4 Markov chain Monte Carlo (MCMC) results

Markov chain Monte Carlo (MCMC) trace plots showed no evidence of lack of convergence in the key biomass parameters and most of the estimated parameters, but there was weak evidence of non-convergence in the right-hand declining limb of both the male and female selectivities for the N70, S70, and SRZ fisheries. Between-sample autocorrelations were low and the median jump size as a proportion of the range of each parameter suggested no evidence of non-convergence, except for the right-hand limb of the female selectivity for the SRZ fishery. The convergence test of Geweke (1992) and the stationarity and half-width tests of Heidelberger & Welch (1983) also suggested some evidence of failure to converge in the right-hand limb parameter of the female selectivity for the N70 fishery. Model estimates using a logistic selectivity for the N70 have previously showed almost no difference in the resulting outcomes of the model (Dunn 2019, Grüss et al. 2021d), and the lack of convergence in the right-hand limb N70 selectivity parameter was unlikely to have any influence on the model conclusions.

Fits to the catch-at-age data suggest some evidence of poor fit, especially in the earlier years of the fishery. However, sensitivity analyses using different fishery definitions and year class estimates gave similar estimates of absolute current biomass (see Dunn (2019) and Grüss et al. (2021d)). While preliminary investigations (Dunn 2019, Grüss et al. 2021d) indicate that some improvement could be obtained by considering the estimation of earlier year class strengths and/or allowing for changing selectivity, these were not fully developed in time for this assessment. Further consideration of these issues should be investigated in future assessments.

YCS was estimated for the years 2003–2015 for the 2021 base case assessment model. Stronger than average recruitment in 2005, 2013 and 2014 was estimated, and weaker than average recruitment in 2003 and 2008 (Figure 7). MCMC estimates of YCS suggested that recruitment variability over this period was about $\sigma_R = 0.37$ (95% CIs 0.28–0.47) and that autocorrelation was between -0.33 and 0.47.

Fits to the survey local abundance series are shown in Figure 4. Fits were within the confidence interval of the RSSS. Fluctuations in the survey abundance trend were likely representative of variability in local abundance, with the overall pattern consistent with the assessment model. The patterns of estimated YCS's were consistent with the patterns in the RSSS age frequencies, suggesting that the RSSS was monitoring the relative recruitment of the population. The RSSS was noted by the independent review of the integrated modelling methods used to assess toothfish (Anon 2018; SC-CAMLR-XXXVII 2018) as an important index for the assessment, and as a means to employ a fishery independent method to monitor recruitment.

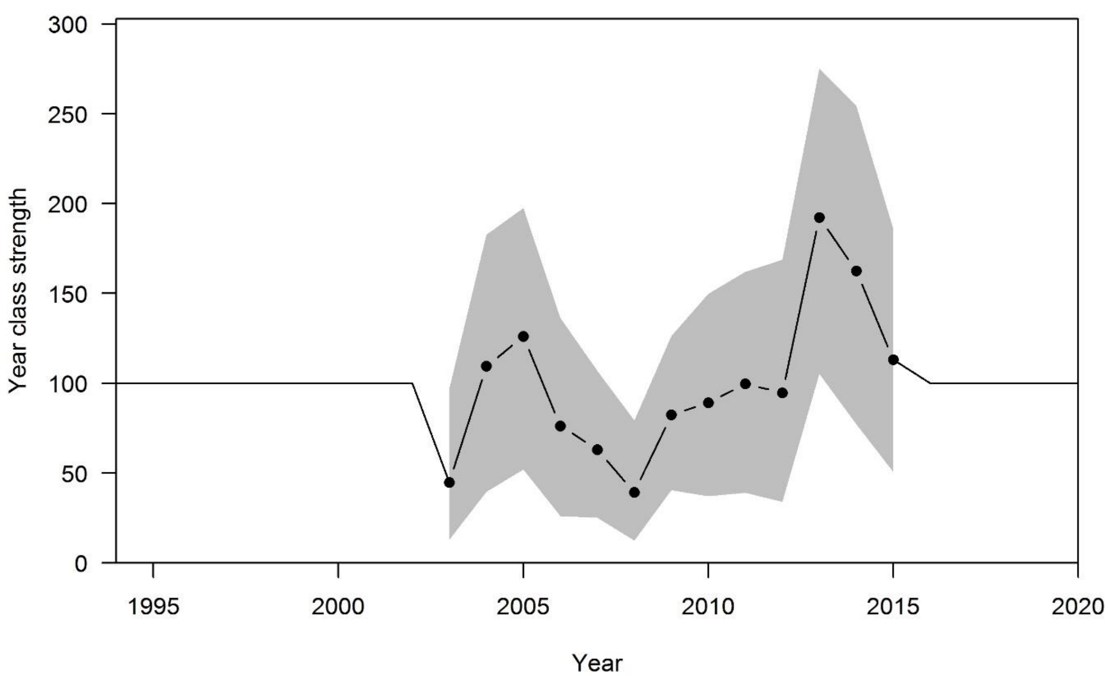

Figure 7. Markov chain Monte Carlo (MCMC) predicted distribution of year class strengths for the 2021 base case assessment of Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*), with the median (black line and points) and 95% credible intervals (grey area).

3.5 Estimates of biomass and yield

Estimates of the initial biomass and current biomass are given in
Table 1 below and in Figure 8. The MPD for the base case model (R1.1) estimated the equilibrium pre-exploitation spawning stock biomass, B_0, as 78 892 t and the current stock status (B_{2021}) as 62.7%. MCMC estimated B_0 as 78 373 t (95% CIs 71 999–85 663 t) and the current stock status as 62.7% B_0 (95% CIs 59.9–65.6% B_0).

Projected biomass trajectories are shown in Figures 9 and 10. Precautionary yields using the CCAMLR decision rules are given in Table 2 and in Figure 11 using a future catch split of 19% for N70, 66% for S70 and 15% for the SRZ. Comparison of biomass trajectories with model runs used for management advice in previous years are shown in Figure 12.

The precautionary yield calculated using the CCAMLR decision rules was 3495 t.

Table 1. Median Markov chain Monte Carlo (MCMC) estimates (and 95% credible intervals) of B_0, B_{2021}, and B_{2021} as %B_0 for the 2019 base case assessment model (R0.0), the 2021 base case assessment model (R1.1), and model R1.2.

Model	B_0	B_{2021}	B_{2021} (%B_0)
R0.0	71 730 (65 890–78 730)	–	–
R1.1	78 373 (71 999–85 663)	49 034 (43 463–55 882)	62.7 (59.9–65.6)
R1.2	78 065 (71 729– 86 362)	48 875 (43 229– 56 554)	62.7 (59.8– 65.9)

Table 2. Estimated risks of the 2019 catch limit (3140 t) using the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas decision rules for the 2019 base case assessment model (R0.0) and the 2021 base assessment model (R1.1), and the estimated precautionary yield for the 2021 base case assessment model (R1.1).

Model	Pr(SSB < 50% B_0)	Pr(SSB < 20% B_0)	Catch limit (t)
R0.0	0.50	<0.01	3140
R1.1 assuming 2019 catch limit in projections	0.32	<0.01	3140
R1.1 estimated precautionary yield	0.50	<0.01	3495

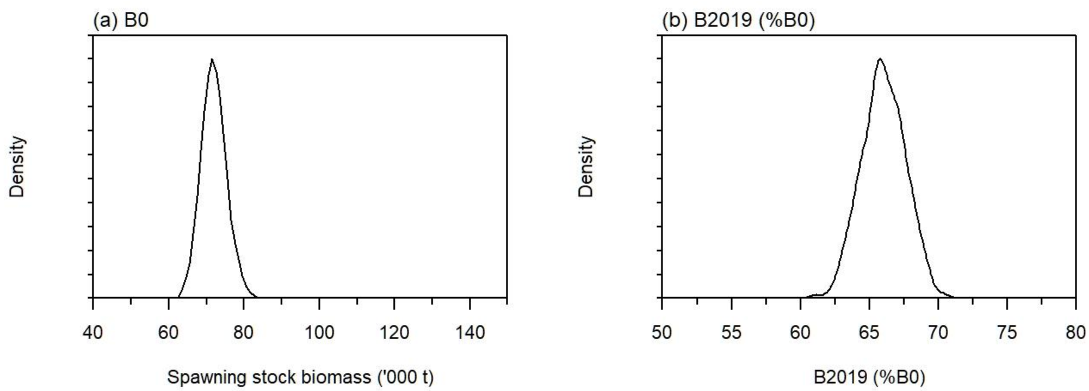

Figure 8. Markov chain Monte Carlo (MCMC) posterior distributions of (a) B_0 and (b) current biomass (%B_{2021}/B_0) for the base case assessment model (R1.1).

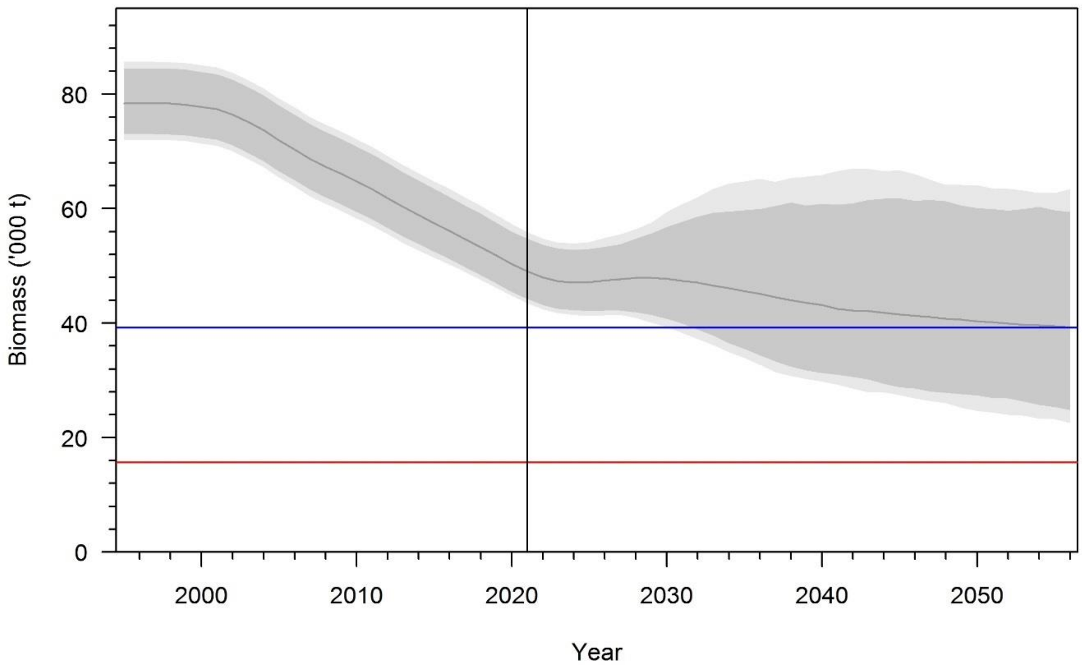

Figure 9. Markov chain Monte Carlo (MCMC) estimates of the trajectory of Antarctic toothfish (*Dissostichus mawsoni*) spawning stock biomass (black line) with the 90% and 95% (dark and light grey shading respectively), projected out to 2056, for the base case assessment model (R1.1). The horizontal blue and red lines correspond to 50% median B_0 and 20% median B_0, respectively.

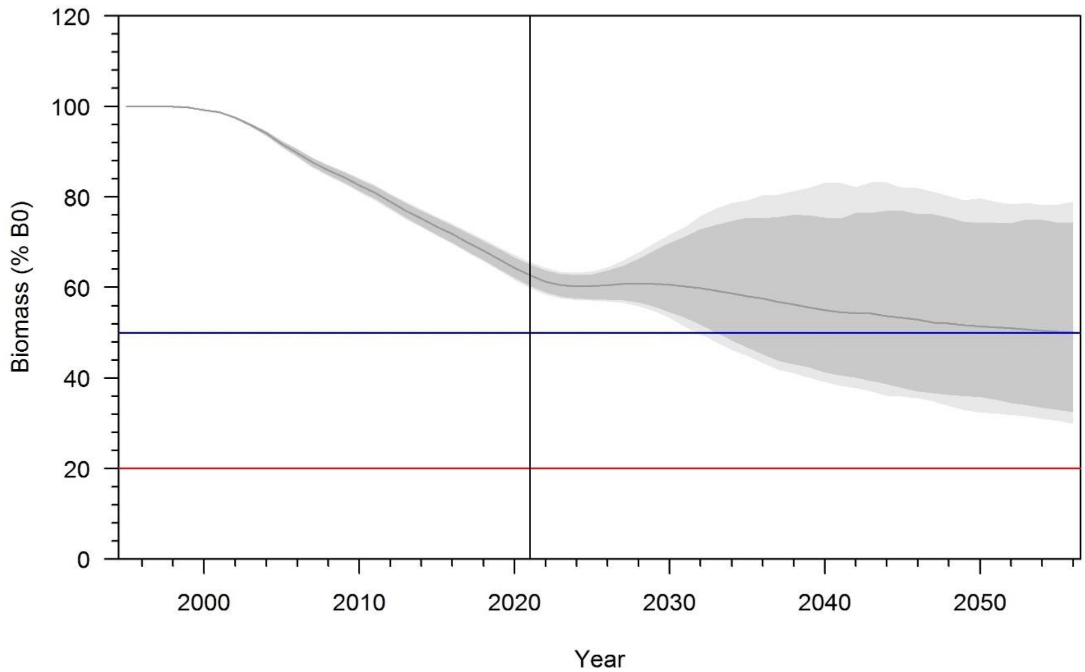

Figure 10. Markov chain Monte Carlo (MCMC) estimates of the trajectory of Antarctic toothfish (*Dissostichus mawsoni*) spawning stock biomass as a percentage of initial biomass (black line) with the 90% and 95% (dark and light grey shading respectively), projected out to 2056, for the base case assessment model (R1.1). The horizontal blue and red lines correspond to 50% median B_0 and 20% median B_0, respectively.

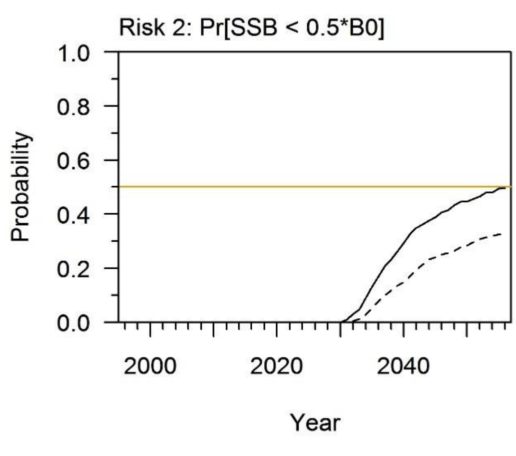

Figure 11. Estimated risk for the base case assessment model (R1.1) under the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas decision rules with the Pr(SSB < 0.5B_0) ≥ 0.5 with the current catch limit (3140 t) (dashed lines) and maximum catch that meets the decision rule criteria for each model (3495 t, solid line).

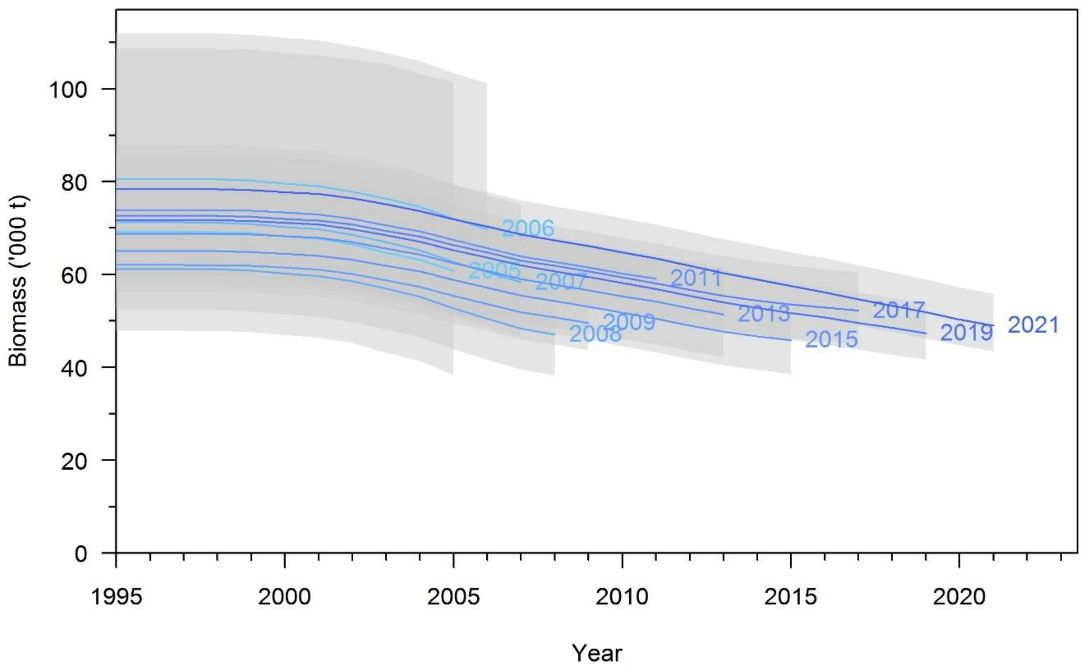

Figure 12. Markov chain Monte Carlo (MCMC) estimates of the trajectory of Antarctic toothfish (*Dissostichus mawsoni*) spawning stock biomass for the base case assessment model (R1.1) (black line) and previous models used for management advice (years of management in the figure). The 95% confidence intervals are shown as grey shading for each model.

4. DISCUSSION

This paper updates the assessment model for Antarctic toothfish (*Dissostichus mawsoni*) in the RSR (Subareas 88.1 and SSRUs 88.2A-B), including data up to and including 2021.

The inclusion of the recent years of tag-release data and associated tag-recapture data were the most influential of the changes in the model since 2019. Fits to the tag data and catch-at-age data were adequate and had a similar pattern to previous assessments. There was a correlation in the tag-recapture residuals based on year of recapture but not year of release, likely a reflection of spatial changes and variability in fishing effort when tags are detected, through time. The fit to the rate of the number of tags recovered through time showed no evidence of systematic departure from the observed rate — suggesting that the model assumptions of rates of ongoing tag mortality, tag loss rate, and tag detection rate were adequate.

The 2021 model showed that the information from the RSSS informed the estimation of recruitment strength. Over the period covered by the RSSS, three strong recruitment years were recorded (2005, 2013 and 2014), as well as two weak recruitment years (2003 and 2008). The RSSS abundance trends for the survey were fitted reasonably, albeit with interannual variability. Although local abundance trends may fluctuate due to local abundance variation, the overall pattern of a decrease and increase is consistent with the assessment model. The regular monitoring of recruitment also acts as an important safeguard to detect any unusual recruitment patterns that may occur in the future. For example, if there was a series of poor recruitments detected in the survey then the projected catch limits could be revised accordingly. This highlights the importance of established long time series of standardised abundance surveys to provide fishery-independent information on stock abundance and on recruitment.

A key outcome of the sensitivity analyses was that the exclusion of the initial three years of tag-release data (2001–2003) and associated tag-recapture data (R1.2) resulted in almost no difference in initial or the current biomass estimates and slightly improved the overall likelihood of the model. Although R1.2 did not improve the patterns in the Pearson residuals of the catch-at-age data, it decreased the negative log likelihood for the remaining tag-recapture observations. The main advantage of employing R1.2 would be to reduce the number of partitions used to model the population, thereby decreasing the CASAL computer memory allocation needed to evaluate the assessment model. We also found that exclusion of the initial six years of tag-release data (2001–2006) and associated tag-recapture data (R1.3) led to an increase in both initial or current biomass estimates and no improvement in overall model likelihood.

The sensitivity analyses conducted by Grüss et al. (2021d) also included analyses that split the fisheries into pre-2012 and 2012–2021 fisheries and/or estimating YCS for the period 1975–2014. While these resulted in a better overall model fit and suggested some improvement in Pearson residuals of the catch-at-age data, they did not fully resolve the patterns in the age data residuals. Therefore, we recommend that future studies carry out additional analyses, including considering alternative fishery temporal splits and/or YCS estimation to attempt to reduce the residual patterns in the age frequency data.

In addition, the model diagnostics reported in Grüss et al. (2021d) suggested that the youngest ages (< five year-old fish) and the oldest ages (≥ 35 year-old fish) were not well fitted in the model. Sensitivity analyses on the 2019 model that aggregated the older (> 35 years) fish did not affect the model outcomes but did significantly reduce the intermittent large residuals in the catch-at-age observations (see Table 2 and Figure 10 of Dunn (2019)). The residual pattern in younger ages is more difficult to resolve. This pattern is likely to arise from insufficient flexibility in the selectivity function used to model the catch-at-age at very young ages. Given the negligible numbers of fish observed at these ages, an alternative is to exclude fish of these ages from the model and instead recruit the fish into the modelled population at age four or five instead. Thus, we recommend that future development should consider aggregating the very old fish (> 35 years) in the observations as a plus group and recruit fish into the model at age four or five instead of age one. These changes are unlikely to change the estimated stock status but may improve model fits to age data.

The catch that could be taken under a constant exploitation rate harvest strategy (CAY) meeting the CCAMLR decision rule target and threshold criteria was calculated as CAY = 0.044, resulting in a yield of 3517 t for 2022.

The model estimates of biomass and yield were slightly higher than those from the 2019 assessment. The CCAMLR precautionary yield for the Ross Sea region (i.e., Pr(SSB > 50% B_0) > 50% and Pr(SSB < 20% B_0) < 10%) was calculated as 3495 t. We recommend that the catch limit be set at a total 3495 t for RSR Antarctic toothfish in the 2021/22 and 2022/23 fishing seasons.

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APPENDIX – SUPPLEMENTARY INFORMATION

Table A1. Starting values, priors, number of parameters (*N*), and bounds for the free parameters for the 2021 base case assessment model (R1.1) for Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*) (R1.1). B_0 = pre-exploitation biomass; YCS = year class strength; RSSS = Ross Sea Shelf Survey.

Parameter		*N*	Start value	Prior	Bounds	
					Lower	Upper
B_0 (t)		1	70 000	Uniform-log	1 x 10^4	1 x 10^6
Fishing selectivities (male)	a_1		8.0	Uniform	1.0	50.0
	s_L		4.0	Uniform	1.0	50.0
	s_R	12	10.0	Uniform	1.0	500.0
Fishing selectivities (female)	a_{max}		1.0	Uniform	0.01	10.0
	a_1		8.0	Uniform	1.0	50.0
	s_L		4.0	Uniform	1.0	50.0
	s_R	16	10.0	Uniform	1.0	500.0
YCS	*YCS*	13	1.0	Lognormal	0.001	100.0
RSSS abundance	*cv*	1	0.0	Uniform	0	10.0
RSSS selectivities (male)	a_1		8.0	Uniform	1.0	50.0
	s_L		4.0	Uniform	1.0	50.0
	s_R	3	10.0	Uniform	1.0	500.0
RSSS selectivities (female)	a_{max}		1.0	Uniform	0.01	10.0
	a_1		8.0	Uniform	1.0	50.0
	s_L		4.0	Uniform	1.0	50.0
	s_R	4	10.0	Uniform	1.0	500.0

Table A2. Francis (2011) weighting factor for catch-at-age weight for the N70, S70, SRZ, and Other areas (w_{N70}, w_{S70}, w_{SRZ}, w_{Other}) and the RSSS (w_B), survey biomass *c.v.*, and tag-recapture (*ø*) observations for the 2019 base case assessment model (R0.0) and the 2021 base case assessment model (R1.1) for Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*).

Run	Model	w_{N70}	w_{S70}	w_{SRZ}	W_{Other}	w_B	*c.v.*	*ø*
R0.0	2019 base case assessment model	0.05	0.04	0.03	0.02	0.24	0.0	6.03
R1.1	2021 base case assessment model	0.06	0.03	0.04	0.02	0.23	0.0	6.22

Table A3. Maximum posterior density (MPD) objective function values and number of estimated parameters for the 2019 base case assessment model (R0.0) and 2021 base case assessment model (R1.1) for Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*). The two models have similar, but not identical, data weightings and amounts of observational data, so values are not strictly comparable. RSSS = Ross Sea Shelf Survey; B_0 = pre-exploitation biomass; q = catchability; YCS = year class strength.

Objective function		Model run
Component	R0.0 (2019)	R1.1 (2021)
2001 tags recaptured	1.9	1.8
2002 tags recaptured	14.0	11.1
2003 tags recaptured	14.9	12.8
2004 tags recaptured	21.8	22.8
2005 tags recaptured	20.8	21.0
2006 tags recaptured	31.1	30.9
2007 tags recaptured	25.1	24.5
2008 tags recaptured	17.5	16.8
2009 tags recaptured	16.9	16.2
2010 tags recaptured	21.6	20.6
2011 tags recaptured	19.6	18.7
2012 tags recaptured	20.7	19.5
2013 tags recaptured	18.5	17.1
2014 tags recaptured	20.4	21.4
2015 tags recaptured	19.1	24.4
2016 tags recaptured	13.7	18.8
2017 tags recaptured	7.7	15.6
2018 tags recaptured	5.0	14.0
2019 tags recaptured	–	11.9
2020 tags recaptured	–	4.0
Catch-at-age (N70)	289.1	320.2
Catch-at-age (S70)	486.4	536.0
Catch-at-age (SRZ)	388.1	435.9
Catch-at-age (Other)	301.3	332.5
Sub-total	1774.9	1968.4
Age frequency (RSSS)	423.6	539.5
Abundance trajectory (RSSS)	11.3	14.7
Sub-total (observations)	2209.8	2522.6
Penalties	0.0	0.0
B_0 prior	11.2	12.3
q prior (survey abundance)	-3.2	-3.2
YCS prior	-6.3	-7.5
All other priors	0.0	0.0
Total objective function	2211.5	2523.2
No. of free parameters	48	50

Additional Resources

- Fishery Summary: pdf, html
- Fishery Report: pdf, html
- Species Description: pdf, html
- Stock Annex: pdf
- Fisheries Documents Browser