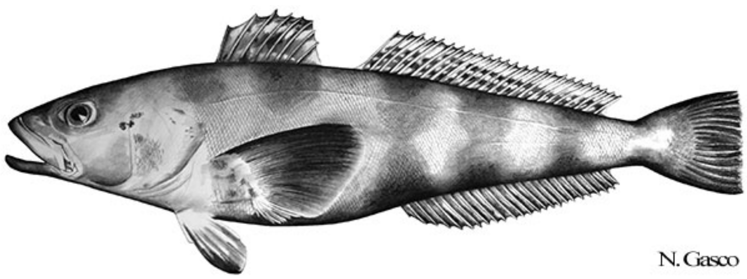
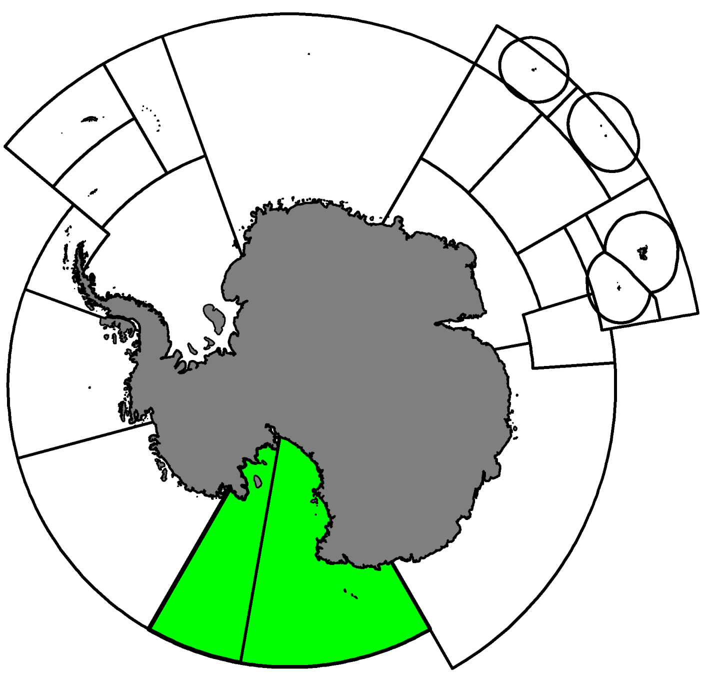
Stock Annex 2021: *Dissostichus mawsoni* in Subarea 88.1

CCAMLR Secretariat

26 April 2022



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, "2021" refers to the 2020/21 CCAMLR fishing season (from 1 December 2020 to 30 November 2021).

Commission for the Conservation of Antarctic Marine Living Resources
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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Stock Annex for the 2021 assessment of Ross Sea region Antarctic toothfish (Dissostichus mawsoni)

WG-FSA

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EN

Stock Annex for the 2021 assessment of Ross Sea region Antarctic toothfish (*Dissostichus mawsoni*)

Species: Antarctic toothfish (*Dissostichus mawsoni*)

Area: Ross Sea (CCAMLR Subareas 88.1 and 88.2A-B)

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1. GENERAL INFORMATION

1.1 Stock structure and definition

The areas included within the assessment of Antarctic toothfish (*Dissostichus mawsoni*) are the Ross Sea region (RSR), defined as Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Subarea 88.1 and Small-Scale Research Units (SSRUs) 88.2A–B; these areas encompass the CCAMLR region south of 60° S and between 150° E and 150° W (Figure 1. Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas 88.1 and 88.2, small scale statistical areas (SSRUs), the Ross Sea region Marine Protected Area (General protection Zones (GPZ) (i)–(iii) in light grey shade and the Special Research Zone (SRZ) in dark grey shade) and the Ross Sea region (bounded region). The light blue line delineates the N70 management area from the S70 management area. Depth contours (light grey) are plotted at 1000 m and 3000 m.).

Toothfish are large nototheniids endemic to Antarctic and sub-Antarctic waters. There are two main species of toothfish, Antarctic toothfish (*D. mawsoni*) and Patagonian toothfish (*D. eleginoides*). Their distribution is circumpolar, although *D. mawsoni* have a more southern distribution and are found in latitudes south of the Antarctic Convergence (Gon & Heemstra 1990). *D. eleginoides* are typically only found in the north-west of the RSR, while *D. mawsoni* is the dominant species in the rest of the region. Hanchet et al. (2008) described the life history of Antarctic toothfish in the RSR. They hypothesised that Antarctic toothfish spawn to the north of the Antarctic continental slope, and mainly on the ridges and banks of the Pacific-Antarctic Ridge during winter or spring. Parker et al. (2019) found evidence of spawning in the northern part of the RSR and concluded that spawning in this area likely occurs from mid-July through August.

Analysis of genetic data has shown that fish within the Pacific sector of the Southern Ocean are weakly genetically differentiated from those in the Atlantic and Indian sectors (Kuhn & Gaffney 2008), with weak evidence for genetic separation of Antarctic toothfish between the RSR and the neighbouring Amundsen Sea region (Kuhn & Gaffney 2008). The life history of Antarctic toothfish proposed for the RSR by Hanchet et al. (2008) based on tag movements and ocean circulation and hydrography (Rickard et al. 2010) suggested that Antarctic toothfish in the RSR should be treated as a separate stock. Parker (2014) reviewed the stock structure of Antarctic toothfish in Area 88 including information from genetic studies, otolith microchemistry, stable isotopes, tagging, size and age structure, growth dynamics, and egg and larval dispersal simulations, and concluded that there was no evidence to change the existing stock boundaries for Antarctic toothfish in the RSR.

Length and age data from the RSR show that smaller and younger Antarctic toothfish are dominant in the southern latitudes and ontogenetically move north as they age. Adolescent and mature sized fish are found along the continental slope, while the oldest and most reproductively advanced fish are typically found at the most northern extent of the slope, and in the northern seamounts, ridges, and hills.

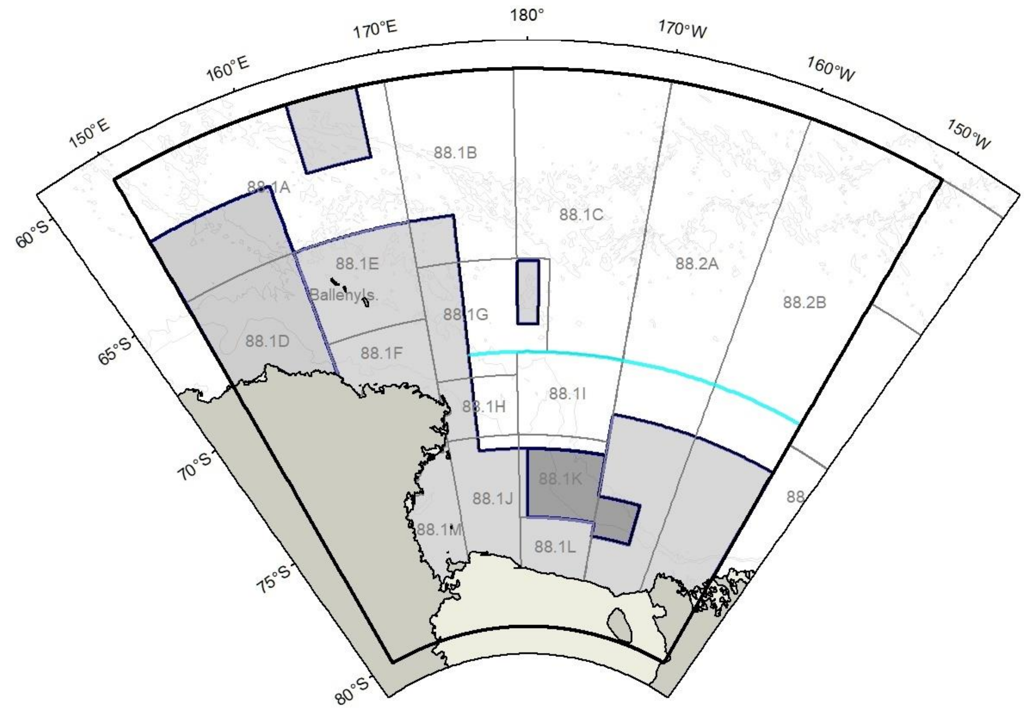

Figure 1. Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas 88.1 and 88.2, small scale statistical areas (SSRUs), the Ross Sea region Marine Protected Area (General protection Zones (GPZ) (i)–(iii) in light grey shade and the Special Research Zone (SRZ) in dark grey shade) and the Ross Sea region (bounded region). The light blue line delineates the N70 management area from the S70 management area. Depth contours (light grey) are plotted at 1000 m and 3000 m.

1.2 Fishery

The only fishery that has operated in the RSR is the target toothfish bottom longline fishery. The fishery was initiated in 1997 and now comprises a fleet of about 15 to 25 vessels from six to ten Member nations annually. Fishing takes place from 1st December each year in the northern regions of the Ross Sea and progresses south as ice recedes over the austral summer. Typically, the catch limit for the region is fully caught by January–February, and the fishery is then closed for the remainder of the season (with the season defined as the period 1st December to 30th August and labelled using the calendar year of the period from 1st January).

In 2016, CCAMLR adopted the Ross Sea region Marine Protected Area (RSrMPA) (CM 91-05, CCAMLR-XXXVI 2017), which came into effect on 1st December 2017 (i.e., in the 2017/18 fishing season). The RSrMPA defines three General Protection Zones (GPZ (i), (ii), and (iii)) that exclude fishing, a Special Research Zone (SRZ) that allows for fishing at a lower exploitation rate, and an open area outside the MPA. A Krill Research Zone (KRZ) is also defined that does not permit Antarctic toothfish targeted fishing.

The target toothfish bottom longline fishery is currently managed within four separate management areas. Within the RSrMPA GPZ, the catch limit for the exploratory fishery is zero tonne. Within the 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 of the RSrMPA, with those proportions based on advice from the Scientific Committee of CCAMLR (CM 41-09 paragraph 2). From 2009–2017, the fishery was spatially managed with SSRU catch limits. SSRUs 881.A, 88.1D, 88.1E, 88.1F, 88.1M, 88.2A, and 88.2B had zero catch limits. Catch limits were set for (1) SSRUs 881.B, 88.1C, and 88.1G combined; (2) SSRUs 88.1H, 88.1I, and 88.1K combined; and (3) SSRUs 88.1J and 88.1L combined. In addition, in the RSR, targeted longline fishing in areas with depths less than 550 m is also prohibited in exploratory fisheries (see CM 22-08).

The target toothfish bottom longline fishery concentrates its efforts in depths from 800–1800 m. Fishing takes place predominantly in SSRUs 88.1C, 88.1H, 88.1I, and 88.1K, in areas outside the RSrMPA. Longliners use either autolines (Fenaughty 2008), Spanish lines (Kokorin & Istomin 2006; Jung & Choi 2011), or trotlines (Delegation of Japan 2006).

The fishery is 100% observed by observers from the CCAMLR Scheme of Scientific Observation (SISO), with every vessel carrying both a national and an international observer, and standardised biological and catch sampling on each line.

2. CATCH DATA

2.1 Commercial catch

Commercial catch data are reported by CCAMLR Members as both estimated catch on a set-by-set basis (C2 data, CM 41-01) and landings by vessel and Subarea from the CCAMLR Dissostichus Catch Documentation (DCD) scheme (CM 10-05).

2.2 Discards

Discards of Antarctic toothfish (or any fish bycatch or offal products) are not permitted south of 60° S. In addition, observers monitor for discards or discarded offal, with up to 40% of all hooks hauled being directly observed. No discarding of dead toothfish has been reported. Fish are occasionally lost from the line near the surface and are recorded as lost. The amount discarded or lost is negligible and is not included within the stock assessment.

2.3 Illegal, Unreported and Unregulated removals

Based on aerial surveillance and other sources of intelligence, the level of illegal, unreported, and unregulated (IUU) catch was estimated to be a total of 632 t between the years 1997 and 2011. The IUU catch was 92 t in 2002, 240 t in 2004, 28 t in 2005, and 272 t in 2008.

Information of an unidentified longline fishing line in Subarea 88.1 in November 2017 was recorded and provided to CCAMLR by the Republic of Korea (CCAMLR-XXXVII 2018). The total line was not able to be retrieved and, therefore, the length of the line and any associated catch were not estimated.

After 2011, CCAMLR stopped estimating the amount of IUU catch and instead estimated the amount of IUU effort. Since 2011, IUU effort in the Convention Area has typically been comprised of vessels using gillnets. Gillnets are prohibited under CM 22-04, and there are few data to estimate gillnet sizes or the amount of associated catch. However, CCAMLR has estimated that there has been no IUU effort in Subareas 88.1 and 88.2 since the 2010–11 fishing season (CCAMLR-XXXVI 2017), except for the unidentified longline found in November 2017.

Estimated annual IUU catch is included within the RSR Antarctic toothfish stock assessment and is assumed to have the same selectivity as the fishing in the management area outside the MPA and south of 70° S.

2.4 Other sources of mortality

The longline gear that is baited and set but not successfully retrieved may result in unaccounted mortality of Antarctic toothfish or other species. The bottom longline gear is most often lost due to interactions of downlines with moving sea ice, but may also result from tidal currents submerging floats or gear failure during line retrieval.

Webber & Parker (2011) estimated that, between 2008 and 2011, the number of hooks that were attached to lines that were lost represented 3–8% of all hooks set. Longlines only have the potential to catch once, as when the bait is gone, they do not continue to catch fish. Webber & Parker (2011) reported that, if these hooks caught toothfish at the same rate as those on lines retrieved and that all the toothfish caught on lost lines died as a result of being caught, then an additional 175–244 t of Antarctic toothfish fishing related mortality may be unaccounted for annually.

Sensitivity analyses on the stock assessment have shown that addition of catch from lost lines results in higher estimates of pre-exploitation biomass and similar or higher stock status than when these are excluded from the assessment. Hence, due to the uncertainty of the exact amount of mortality from lost lines, a precautionary approach was used and additional mortality from this source was not included within the RSR Antarctic toothfish stock assessment.

A small quantity of Antarctic toothfish was taken by other scientific research programmes (i.e., research trawls and coastal ice-based line research), typically a total of less than a few tonnes in years when such research was undertaken. The additional mortality from other scientific research programmes was likely to be negligible and has, therefore, not been included within the RSR Antarctic toothfish stock assessment.

On 13th December 2010, the *Insung No.1* was tragically lost in the northern Ross Sea during fishing operations (Delegation of the Republic of Korea 2011). Catch, effort, tag release and recapture and SISO data from this vessel trip were not available, but the CCAMLR Secretariat (pers. comm) estimated from the submitted five-day catch summaries that it had caught about 37 t at the time of its loss.

Catches from areas outside the Convention area immediately adjacent to the RSR have occurred in recent years. These catches are regulated through the South Pacific Regional Fisheries Management Organisation (SPRFMO) and are reported to CCAMLR using the CCAMLR C2 and SISO observer forms. Catches of Antarctic toothfish from the SPRFMO region immediately adjacent to the northeast of the RSR were included within the RSR Antarctic toothfish stock assessment and are assumed to have the same selectivity as fish taken in the northern part (the N70 area) of the RSR. The reported catches for this area were 29 t in each of 2016 and 2017 (Cryer et al. 2017; Delegation of New Zealand 2018). In 2018, SPRFMO made an allocation of 140 t for each of the 2019 and 2020 calendar years from this region (Delegation of New Zealand 2018). Antarctic toothfish catch in the SPRFMO region immediately adjacent to the northeast of the RSR was 77.5 t in fishing year 2020 (Fenaughty 2020) and 24.1 t in fishing year 2021 (Fenaughty 2021). Catches from outside the Convention area where the fish are likely to be a part of the RSR Antarctic toothfish stock are included within the stock assessment. SPRFMO allocations that have been agreed, but not yet taken, are excluded from the stock assessment.

3. BIOLOGICAL INFORMATION

The Antarctic toothfish has a circumpolar distribution and typically though not exclusively south of the Antarctic convergence (~60° S). A summary of the biology of Antarctic toothfish is provided in Hanchet et al. (2015). Although Antarctic toothfish are primarily a demersal species, adults can be neutrally buoyant and some have been observed to inhabit the pelagic zone at times during their life cycle (Near et al. 2003). Juvenile growth has been well documented (Horn, 2002; Horn et al., 2003), with fish reaching about 60 cm total length (TL) after five years and about 100 cm TL after ten years. Growth slows as fish reach the adult stage from about 125 cm. The maximum length recorded is 250 cm, and less than 1% of observed Antarctic toothfish have been above 180 cm. The maximum recorded age of Antarctic toothfish is 48 years, but fewer than 1% of all Antarctic toothfish have been aged greater than 31 years. Ages have been validated by Horn (2003) for juvenile fish using tetracycline marking and for adult fish using two recaptured tagged fish, as well as by Brooks et al. (2011) for adult fish using lead-radium dating.

Hanchet et al. (2008) suggested that, depending on the exact location of spawning, eggs and larvae become entrained by the Ross Sea gyres (a small clockwise rotating western gyre located around the Balleny Islands, and a larger clockwise rotating eastern gyre covering the rest of Subareas 88.1 and 88.2), and move either west settling out around the Balleny Islands and adjacent Antarctic continental shelf, south onto the Ross Sea shelf, or eastwards with the eastern Ross Sea gyre settling along the continental slope and shelf to the east of the Ross Sea in Subarea 88.2.

As the juveniles in Subarea 88.2 grow, they likely move west with the Antarctic coastal counter current, towards the Ross Sea shelf and then to deeper water (>1000 m). They then move northwards as they mature, towards the continental slope, into depths of 1000–1500 m. Spawning and pre-spawning fish move onto the Pacific-Antarctic ridge to spawn and then likely return to the more productive slope area to feed and regain condition (Hanchet et al. 2008) or remain in the north (Parker et al. 2019). Tagging data suggest that spawning fish remain in the northern area for two or three years and this may be different by sex. A similar conclusion on the life history was reached in Ashford et al. (2012) using otolith chemistry, age data, and Lagrangian particle simulations.

3.1 Length weight relationship

Length-weight parameters were reported first by Hanchet et al. (2001), and then by Dunn et al. (2006). They were later updated by Dunn & Parker (2019). For the most recent analysis, data up to 2019 ($n \approx$ 527 000) were checked for errors, outliers were removed, and the data were log-transformed and estimates of the length weight relationship made using the equation,

$$\text{Mean weight} = a(\text{length})^b.$$

The estimated length-weight parameters are given in Table 1.

3.2 Growth relationship

The von Bertalanffy growth parameter estimates (von Bertalanffy 1938) for RSR Antarctic toothfish were first described by Horn (2002). They were later updated by Dunn (2006) using age-length observations from n = 4569 fish. Recently, Von Bertalanffy growth rates were revised by Dunn & Parker (2019), from n = 18 307 observations of age and length, assuming normally distributed errors with constant coefficient of variation for both sexes as a function of length. The estimated growth parameters are given in Table 1.

3.3 Stock recruitment relationship

In the RSR Antarctic toothfish assessment model, recruitment is assumed to follow a Beverton-Holt relationship, whereby the stock recruitment (SR) is a function of the spawning stock biomass (SSB), the pre-exploitation equilibrium unfished spawning stock biomass (B_0), and the parameter steepness h, defined as $h = SR(0.2B_0)$, where

$$SR(SSB) = \frac{SSB}{B_0} \Big/ \left(1 - \frac{5h-1}{4h}\left(1 - \frac{SSB}{B_0}\right)\right)$$

Table 1 in Myers et al. (1999) summarised estimates of *h* for a large range of species. These values were employed to derive plausible values of *h* for Antarctic toothfish by Dunn (2006). For species selected from the orders Gadiformes (including cods and hakes), Lophiiformes (monkfish), Ophidiiformes (lings), Scorpaeniformes (perch, rockfish) and *Anoplopoma fimbria* (sablefish), the *h* values had a median of 0.73, with an interquartile range of 0.46–0.83 and 90% percentile of 0.32–0.94. Punt et al. (2005) analysed stock and recruitment data to estimate priors for the steepness of the stock recruitment relationship. Their recommendations were based on the median posteriors of estimated values of steepness. They recommended that "… if a single default point estimate of steepness be used in a stock assessment, then the default should be *h* = 0.907 for Clupeiformes, Gadiformes, and Pleuronectiformes, and *h* = 0.757 for other species" (i.e., Aulopiformes, Perciformes, Salmoniformes and Scorpaeniformes). Based on this, and without empirical data for Antarctic toothfish, Dunn (2006) recommended Antarctic toothfish steepness be assumed to be *h* = 0.75.

3.4 Natural mortality

The natural mortality rate (*M*) of Antarctic toothfish was estimated by Dunn et al. (2006), using the methods of Chapman-Robson (1960), Hoenig (1983), and Punt et al. (2005). Estimates of *M* derived from these methods ranged from 0.11 to 0.17 y^{-1}. Catch-at-age data between 1998 and 2005 were employed to generate *M* estimates, as these catch-at-age data were from the early years of the fishery where data were from a population that had likely had very low exploitation rates. Data from the northern regions of the Ross Sea were used as they represented the oldest fish in the population (Dunn et al. 2006). After a consideration of possible assumptions and potential bias, Dunn et al. (2006) proposed that a value of 0.13 y^{-1} be employed for stock modelling with a range of 0.11–0.15 y^{-1} for sensitivity analyses (see Mormede et al. (2014)). Estimation within the stock assessment indicated a value of between 0.09–0.13 y^{-1} (Moore et al. 2019), using the 2017 assessment model of Mormede (2017).

3.5 Maturity

Estimates of maturity for RSR Antarctic toothfish were based on hindcasting from the presence of post-ovulatory follicles in the ovaries and forecasting from the assessment of oocyte developmental stage, using samples from about 1100 fish from the slope area of the RSR. Maturity was assumed to follow a logistic relationship;

$$f(x) = 1/\left(1 + 19^{(a_{50} - x)/a_{to95}}\right)$$

where the logistic function takes values 0.5 at $x = a_{50}$ and 0.95 at $x = a_{50} + a_{to95}$.

The estimated mean age and length at 50% spawning for females on the Ross Sea slope was 16.6 years and 133.2 cm, and the mean age and length at 50% maturity for males was 12.8 years and 120.4 cm (Parker & Grimes 2010). These estimates were updated in 2012 to 16.9 years (+7.7 years for 95% spawning) and 135 cm for females and 12.0 years (+5.2 years for 95% spawning) and 109 cm for males on the Ross Sea slope (Parker & Marriott 2012). Evidence of skip-spawning was likely only in adolescent females, and resulted in a flatter, right-shifted maturity ogive for females on the slope.

Table 1. Biological parameters assumed in the assessment model of the Antarctic toothfish (*Dissostichus mawsoni*) population of the Ross Sea region. CV = coefficient of variation.

Relationship	Parameter (units)	Value	
		Male	Female
Natural mortality	M (y^{-1})	0.13	0.13
Von Bertalanffy growth	t_0 (y)	-0.292	-0.712

	k (y^{-1})		0.101	0.082
	L_∞ (cm)		164.06	180.49
	CV		0.101	0.101
Length-weight	a ($t.cm^{-1}$)		$1.247.10^{-8}$	$7.361.10^{-9}$
	b		2.990	3.105
Maturity	a_{50} (± a_{to95})		11.99 (5.25)	16.92 (7.68)
Steepness	h	0.75		
Recruitment variability	σ_R	0.6		
Ageing error	CV	0.1		
Initial tag mortality		10%		
Initial tag loss (per tag)		3.3%		
Instantaneous tag loss (per tag)		0.062 y^{-1}		
Tag detection rate		99.3%		
Tag related growth retardation		0.5 year		

4. ABUNDANCE AND AGE INFORMATION

4.1 Catch-per-unit-effort (CPUE)

The CPUE indices estimated for the RSR Antarctic toothfish stock showed an increase for several years, followed by a decrease in the index with considerable interannual variability (Parker & Mormede 2017). The changes in CPUE were not consistent with likely "fish down" changes in abundance and appear to partially reflect spatial management boundary changes, ice-driven availability on an annual basis, and continuing improvement in skill and fishing strategy by the fishing fleet, rather than underlying abundance. Hence, the CPUE indices are not yet considered to be a reliable index of changes in abundance for the Antarctic toothfish population of the RSR.

4.2 Tag release and recapture data

The tagging programme for Antarctic toothfish in the RSR fishery was first initiated in the 2001 fishing season by New Zealand vessels. Since 2006, all vessels participating in the fishery have been required to tag and release toothfish at a rate of at least one fish per tonne of retained greenweight catch (although higher rates can be required for vessels undertaking specific research fishing under CM 24-01 or research plans under CM 21-02). Between 2001 and 2021, more than 58 000 Antarctic toothfish have been tagged and released in the RSR and almost 3600 have been recaptured (Grüss et al. 2021a).

The assessment model of the Antarctic toothfish population of the RSR applies numbers of tag releases and recaptures that are corrected for differences in vessel- specific survival rates of tagged fish and recapture detection rates using the methods of Mormede (2014). For the period 2001–2021, the fishing fleets average effective tagging survival was estimated at about 72% and the effective tag detection rate estimated at about 65%, although these values vary with the proportion of catch taken by vessels with different rates (Grüss et al. 2021a).

4.2.1 Tagging parameters

Each fishing vessel operating in the RSR is required to carry two scientific observers. Because 40% of every line hauled is observed by a scientific observer and each fish is handled individually when hauled, the tag-detection rate is assumed to be close to 100%, less the rate that tag recaptures cannot be linked to a release event (likely transcription errors) before adjusting for vessel specific detection rates. Because about 0.5% of recaptures could not be reliably linked (Grüss et al. 2021a), the tag-detection rate assumed was 99.5%. This was then adjusted using vessel specific detection rates estimated using the method of Mormede (2014).

Antarctic toothfish have been tagged since 2001 and routinely double-tagged since 2004. By 2010, a total of 64 fish which had been double-tagged were recaptured with a single tag, allowing for the calculation of initial and ongoing tag-loss rates. Initial tag loss rates were estimated to be 3.3% per tag and the instantaneous tag-loss rate was estimated as 0.062 y^{-1} per tag (Dunn et al. 2011). Tag loss rates are applied for single and double tagged fish in the RSR Antarctic toothfish assessment model.

Based on an at-sea experiment, Payne & Agnew (2006) estimated the initial mortality from tagging of Patagonian toothfish in Subarea 48.3 as 10% when accounting for all toothfish (including those that "froze" due to inadequate water circulation in the at-sea experimental tanks) or 5% when considering only toothfish that were in good condition. In the absence of information available for Antarctic toothfish, an initial tag-related mortality at release of 10% has been assumed. This was then adjusted using vessel specific survival rates estimated using the method of Mormede (2014).

Based on length data of Antarctic toothfish tagged and subsequently recaptured, tagging likely results in a temporary retardation of growth in individual fish. This was estimated as the equivalent to a period of zero growth immediately following tagging of approximately 0.5 years, followed with normal growth. Growth retardation is assumed to be 0.5 years for tagged fish in the RSR Antarctic toothfish stock assessment.

4.3 Age data

Annual catch-scaled proportions at age frequencies from the commercial fleet are calculated for each of the four area-based fisheries separately (i.e., the component of the fishery operating within the SRZ, outside the MPA and south of 70° S (S70), the area outside the MPA and north of 70° S (N70), and the areas designated as the GPZ (Other). Up to about 35 toothfish are randomly selected from each line hauled and measured for sex and length. Catch-scaled length frequencies for each fishery area are calculated, and variance estimated using bootstrapping. Annual age-length keys are then applied to generate annual age frequencies for each area. Age length keys are generated from otoliths collected during each season and area. The annual age length key used for the SRZ, S70, and other fisheries combined is derived from otoliths collected by the fishery in the SRZ, S70, and other areas including otoliths from the Ross Sea Shelf Survey (RSSS). The annual age length key for the N70 area is derived from otoliths collected in N70 only.

5. ASSESSMENT

5.1 Method

Stock assessments have been carried out for the Antarctic toothfish population of the RSR since 2005 (Dunn et al. 2005) using an integrated assessment model implemented in CASAL (Bull et al. 2012) with the primary abundance information determined from tag release and recapture data conducted by the exploratory fishery. The most recent assessment is the 2021 assessment (Grüss et al. 2021b). The stock assessment methodology was reviewed in 2018 by the CCAMLR independent review of integrated assessments for toothfish (Anon 2018; SC-CAMLR-XXXVII 2018). The review panel found that that the models applied assumptions in the stock assessments in a precautionary manner when there is uncertainty in parameters and assumptions, and noted that assessment was appropriate for the precautionary management of the stock and consistent with CCAMLR's approach to management (Anon 2018; SC-CAMLR-XXXVII 2018).

The stock assessment is undertaken using an integrated statistical catch-at-age model (Mormede et al. 2014) implemented in CASAL (Bull et al. 2012). The model is structured with ages from 1–50, whereby the number of male and female toothfish of each age from 1 to 50 is tracked through time, and the last age group was a plus group (i.e., an aggregate of all fish aged 50 and older). The population is initialised assuming an equilibrium age structure at an unfished equilibrium biomass, i.e., with constant recruitment. The initial biomass is estimated by the model. The model is run from 1995 to the current year, and the annual cycle is broken into three discrete time steps, nominally summer (November–April), winter (May–October), and an age-incrementation step.

Recruitment is assumed to occur at the beginning of the first (summer) time step, to be 50:50 male to female and to be the mean (unfished) recruitment (R_0) multiplied by the spawning stock-recruitment relationship. Recruitment is assumed constant (equal to 1 before applying the stock recruitment relationship) for years where adequate age frequency data were not available. Future recruitment is assumed to be lognormally distributed with variability $\sigma_R = 0.6$, where the value of σ_R was derived from a meta-analysis using data from Myers et al. (1999) by Dunn (2006).

The model structure, described above, is replicated for each annual set of releases of tagged fish, with the numbers at age and sex in the tag component defined by the year of tag-release. Tag releases are assumed to occur at the end of the first time-step. Numbers of fish tagged are then modified by initial tag-related mortality (a proportion) and then subsequent ongoing annual tag loss (a constant rate). The population processes (natural mortality, fishing mortality, ageing, etc.) are then applied collectively over the tagged and untagged components of the model. The numbers at age of recaptured fish with a tag are also removed from the appropriate tagged component of the population.

As tag-release data are only available as numbers at length (and not age or sex), the proportions of tagged fish at age and sex are determined within the model by multiplying the observed proportions of fish tagged at length by the proportions of fish at age/sex by length assumed by the model for the overall population at the time of tagging. The numbers of tagged fish at length recaptured each year for each tag-release event are provided to the assessment model as observations.

Because the toothfish fishery operates only during the summer months (typically December–March), fishing mortality is applied only in the first (summer) time step in the RSR Antarctic toothfish assessment model. Fishing mortality is applied by removing half of the natural mortality for the time step (a quarter of the total annual mortality), then the instantaneous mortality from the fisheries, and, finally, the remaining half of the natural mortality for the time step. Fishing mortality is applied for four area-based fisheries separately. The four main fisheries are: (1) the fishery operating within the SRZ; (2) the fishery operating in the area outside the MPA and south of 70° S (the S70 area); (3) the fishery operating in the area outside the MPA and north of 70° S (the N70 area); and (4) the historical fishery operating in areas now designated as the GPZ (referred to as the ’Other’ fishery).

IUU removals are also considered in the assessment model of the Antarctic toothfish population of the RSR, as a specific ‘IUU’ fishery. Catches outside the Convention area immediately adjacent to the RSR are considered in the assessment model of the Antarctic toothfish population of the RSR as a specific ‘SPRFMO’ fishery. Finally, catches from the RSSS, which has been carried out annually in the Ross Sea since 2012, are also considered in the assessment model. Each fishery considered in the assessment model employs different selectivity functions to reflect the different age distributions of fish in the catch (i.e., assuming a fleets-as-areas approach), except: (1) the IUU fishery, which is assumed to have the same selectivity as the S70 fishery; and (2) the SPRFMO fishery, which is assumed to have the same selectivity as the N70 fishery. For each of the fisheries considered in the assessment model, fishing selectivities are estimated assuming a domed shape ogive.

The selectivity parameters are estimated by the assessment model, and the catch-scaled proportions at age data are fitted in the model using time-invariant area specific selectivities. The maturation process is applied in the second time step (winter). Maturation is specified as the time-invariant proportion of male and female fish at age that are mature. In the second time step, the remaining half of annual natural mortality is also applied.

In the final time step, the age of all fish is incremented by one year, except for the fish in the 50-plus age group, which remain in that group. Biomass calculations at any point in the assessment model are made by multiplying the number of fish in each year class by the size-at-age relationship and the length–weight relationship for each sex separately.

Initial model parameters are estimated by minimising the total objective function, which is the sum of the negative log-likelihoods from the data, the negative-log priors and the penalty functions employed to apply model constraints. Penalties are applied to both catch and mark-recapture data. Initial fits are evaluated at the mode of the posterior distribution (MPD), and data weightings are determined by considering MPD fits and residual patterns and qualitative evaluation of MPD profile distributions (i.e., by evaluating the minimum objective function while fixing one parameter and allowing all other parameters to vary).

Assessment models are estimated using a Bayesian approach with Metropolis-Hastings sampling to evaluate the joint posterior distribution (Gelman et al. 1995; Gilks et al. 1998), as described by Mormede at al. (2014). Chains are initialised using a random starting point near the MPD (generated from a multivariate normal distribution, centred on the MPD, with covariance equal to the inverse Hessian matrix), with a correlation matrix derived from the inverse Hessian matrix. Markov chain Monte Carlo (MCMC) is run using a burn-in length of 5×10^5 iterations, with every 1000th sample taken from the next 1×10^6 iterations (i.e., a final sample of length 1000 is taken to estimate the Bayesian posterior distribution). Chains are investigated for evidence of non-convergence using multiple-chain comparisons, standard diagnostic plots, chain autocorrelation estimates, as well as the single-chain convergence tests of Geweke (1992) and the stationarity and half-width tests of Heidelberger & Welch (1983).

5.2 Projection method

Stock abundance is estimated using a constant catch forward projection from the joint posterior distribution for 35 years using the integrated stock assessment model. Estimates of the CCAMLR precautionary yield are based on the target and threshold reference points summarised in Section 5.3 below.

Recruitment is assumed to follow a Beverton-Holt stock recruit curve with steepness $h = 0.75$. Future recruitment is parameterised as a lognormal distribution with mean R_0 modified by the stock recruit curve and standard deviation $\sigma_R = 0.6$. Recruitment for recent years for which age data are not available (i.e., recruitments for the most recent six years) are assumed unknown and are replaced with random deviates from a lognormal distribution with mean R_0 modified by the stock recruit curve and standard deviation $\sigma_R = 0.6$.

The future selectivities assumed are those for the areas-as-fleets fisheries, and the catch split between the fisheries is assumed set equal to the allocation to those areas defined in CM 91-05 paragraph 8(i)-(iv), i.e., 15% in the SRZ, 66% for S70, and 19% for N70. No allowance is made for potential IUU or other sources of harvest mortality in projections.

5.3 Reference points

The CCAMLR decision rules set the target spawning stock biomass for toothfish at 50% B_0, with no more than a 50% probability of being below 50% B_0, and no more than a 10% probability of being below 20% B_0 when calculated under a constant catch scenario at the end of a projection period of 35 years from the most recent year of the assessment (Constable et al. 2000).

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Additional Resources

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