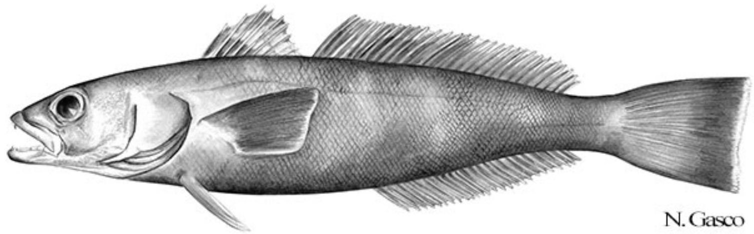
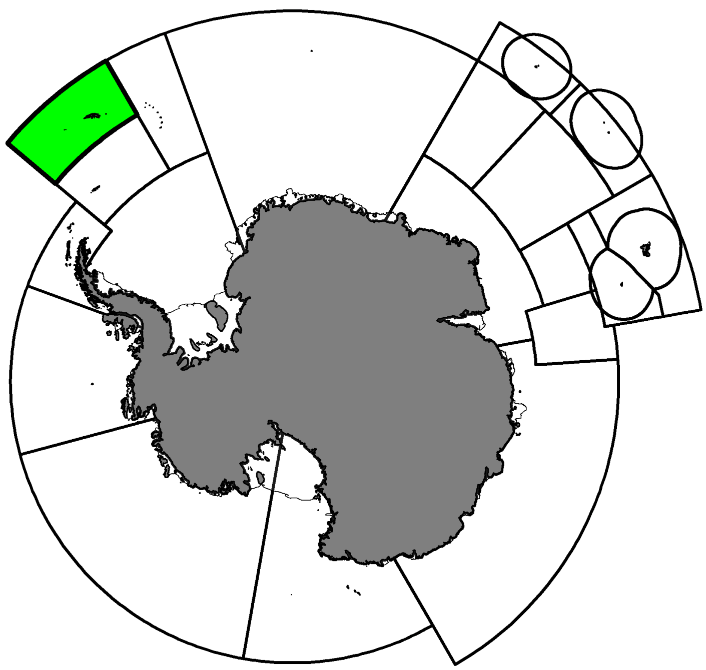
Stock Annex 2024: *Dissostichus eleginoides* in Subarea 48.3

CCAMLR Secretariat

20 December 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.

Stock Annex for the 2023 assessment of Subarea 48.3 Patagonian toothfish (*Dissostichus eleginoides*)

Species: Patagonian toothfish (*Dissostichus eleginoides*)

Area: CCAMLR Subarea 48.3

Created: September 2023

Authors: T. Earl, L. Readdy, J. Marsh

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1. GENERAL INFORMATION

1.1 Stock structure and definition

Patagonian toothfish in CCAMLR Subarea 48.3 and 48.4 (Figure 1) are considered an isolated population (Collins *et al.*, 2010; Canales-Aguirre *et al.*, 2012), shown through genetic, parasite and tagging studies. Separation of this population from other Patagonian shelf toothfish populations could be a consequence of the Polar and Subantarctic Fronts (Rogers *et al.*, 2006). Tagging studies have shown some degree of movement and connectivity between Subarea 48.3 and Subarea 48.4, which is hypothesised to be an overflow area when large recruitment events occur in 48.3 (Soeffker *et al.*, 2022).

Patagonian toothfish tag recapture data have shown that a higher proportion of the long-distance movement is from Subarea 48.4 to Subarea 48.3, around 20% of Subarea 48.4 releases are recaptured in Subarea 48.3, with no information on the regularity to the migration patterns (Soeffker *et al.*, 2022). Péron *et al.* (2016) showed that the size and sex compositions are strongly linked to topography and spatial location (latitude) as well as a gradual migration from shallow to deeper areas (ontogenetic movement) as the length, age and buoyancy control (Near *et al.*, 2003) of fish increases, marking a change in habitat use and food source availability.

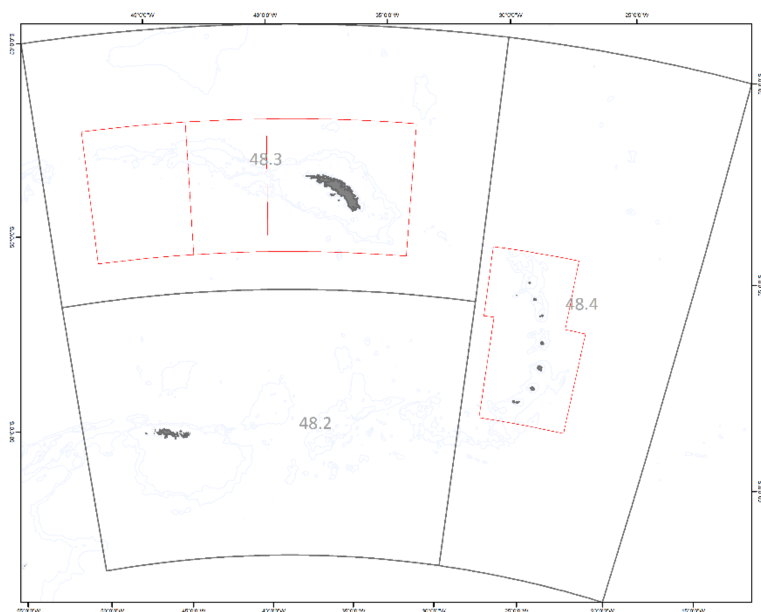

Figure 1. Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas 48.2, 3 and 4, red line delineates the management areas.

1.2 Fishery

The CCAMLR Subarea 48.3 and 48.4 fisheries which catch Patagonian toothfish (*Dissostichus eleginoides*) have been in operation for around 40 years (Agnew, 2004). Patagonian toothfish were first recorded in the catch in Subarea 48.3 in 1977, caught using otter trawls by the Soviet Union and Poland in mixed fisheries mainly targeted at rockcods (*Nototheniidae*) and icefish (*Channichthyidae*) (CCAMLR, 1990a, b). Patagonian toothfish, as a target species, caught in longline fisheries in Subarea 48.3 did not occur until the 1988/89 season, where 4,138 tonnes was taken (CCAMLR, 2002). Catch of toothfish rapidly increased from below 1,000 tonnes, as a bycaught species, prior to the 1986/87 season, up to a maximum recorded catch of 8,311 tonnes in the 1989/90 season (CCAMLR, 1990a, b and CCAMLR, 2000) the highest recorded catch of the timeseries. The increase was mainly driven by an increase in market demands for the highly sought after fish (Agnew, 2000). The high demand for toothfish is thought to have contributed to the increase in illegal fishing, estimated to be around four times that of the reported catch in 1997 (Agnew, 2000) in Subarea 48.3.

1.3 Fishery management

CCAMLR catch limits were first introduced for statistical Subarea 48.3 in 1990/91 (CCAMLR CM 24/IX) and limited to 2,500 tonnes, and updated annually or biennially in subsequent years. Since the 2004/05 season, management has been divided into three areas, 48.3A, B and C from West to East, with a zero catch limit applied to area 48.3A. No catch limit has been agreed by the CAMLR Commission since the 2021/22 season.

2. CATCH DATA

2.1 Commercial catch

Commercial catch (retained and discarded) data are reported by CCAMLR Members as both estimated catch on a set-by-set basis (C2 data, CM 41-01 and SISO observer forms) and landings by vessel and Subarea on the CCAMLR *Dissostichus* Catch Documentation (DCD) and part of the catch documentation scheme (CM 10-05). Observers are present on all vessels and collect biological data on target and non-target species, as well as information on fishing operations.

2.2 Discards

There have been no reports of discarding of dead toothfish, however some are occasionally lost from the line near the surface and are recorded as lost. The amount lost is negligible and is not included within the stock assessment.

2.3 Illegal, Unreported and Unregulated removals

Illegal, unreported, and unregulated (IUU) catch was first estimated in Subarea 48.3 in 1992, based on sightings of IUU vessels and estimates of the likely fishing effort of these vessels (Agnew and Kirkwood, 2005). Between 1992 to 1995, IUU catch was relatively high, ranging between 1,674 to 4,780 tonnes (Table 2.1), and commencing in 1995, attempts were made to incorporate estimates of IUU removals into the stock assessment following concerns that these removals would inhibit reliable stock assessments in Subarea 48.3 (CCAMLR-XIV, 1995). Estimates of IUU catch declined post-1995, ranging from 146 to 1,015 tonnes between 1998 and 2001 (Table 2.1). With the exception of 2005, in which 23 tonnes of IUU catch by a single IUU vessel was reported by the UK prior to the fishery (CCAMLR-XXIV, 2005), IUU catch has been estimated as zero since 2003 to the present (Table 2.1).

Table 2.1. Summary of estimates of illegal, unreported and unregulated removals in Subarea 48.3 since 1992 (from CCAMLR Fishery Reports)

Season	Estimated IUU catch (tonnes)
1992	3,066
1993	4,019
1994	4,780
1995	1,674

1996	- (not enough evidence to estimate, CCAMLR-XV, 1996)
1997	0
1998	146
1999	667
2000	1015
2001	196
2002	3
2003	0
2004	0
2005	23
2006	0
2007	0
2008	0
2009	0
2010	0
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0

2.4 Whale depredation

Orca and sperm whale are known to remove toothfish from the line during hauling, resulting in a drop in catch rates on lines where these species are observed to be interacting with the line (Koch, 2006). Estimates of depredation are derived from the CPUE standardisation (Earl *et al.*, 2021) described in Section 4.1, and included in the stock assessment and forecast.

2.5 Other sources of mortality

The longline gear that is baited and set but not successfully retrieved, due to sea ice, tidal currents submerging floats or gear failure during line retrieval, may result in unaccounted mortality of Patagonian toothfish or other species, known as ghost fishing.

Recent estimates, from the 2021-2022 season, show that the number of hooks that were attached to lines that were lost represented less than 2% of all hooks set (unpublished). Longlines only have the potential to catch once, as when the bait is gone, they do not continue to catch fish. If these hooks caught toothfish at the same rate as those on lines retrieved and were all the toothfish caught on lost lines to die as a result of being caught, then an additional 18 tonnes of Patagonian toothfish fishing related mortality may be unaccounted for annually.

A small quantity of Patagonian toothfish, is taken by scientific research programmes (i.e., the biennial groundfish survey), typically a total of less than a few tonnes in years when such research has been undertaken. The additional mortality from other scientific research programmes is likely to be negligible and has, therefore, not been included within the stock assessment.

3. BIOLOGICAL INFORMATION

Patagonian toothfish can reach a total length of up to 253 cm, the largest recorded in Subarea 48.3 during fishing operations, and females generally attain larger sizes at age relative to males (Collins *et al*., 2010, Söffker *et al*., 2022; Marsh *et al*., 2023). Patagonian toothfish are a long-lived species and in Subareas 48.3 and 48.4 the oldest ages have been estimated at around 50 years based on the age determination of otoliths collected during fishing and research survey operations (Belchier 2004).

Toothfish exhibit an ontogenetic shift to deeper water as they grow (Agnew *et al.*, 1999; Collins *et al.*, 2010; Söffker, Darby and Scott, 2014). Juvenile toothfish are found in shallow waters around islands and seamounts outside of the fishing depths, in particular, around the shelf of the seamount to the west of the islands (Collins *et al.*, 2021). As toothfish increase in size (and age), they move into deeper waters to occupy depths to 2,000 m+ but return to shallower waters to spawn (Collins *et al.*, 2010). Spawning is thought to occur all around the shelf edges of the islands and seamounts (Agnew *et al.*, 1999; Brigden *et al.*, 2017), with Shag Rocks in particular considered to be a spawning hotspot, owing to an overlap of reproductively active female and male toothfish found here (Brigden *et al.*, 2017). Spawning is thought to occur mostly during late July/August, with a potential smaller spawning event earlier in April/May (Agnew *et al.*, 1999).

Data on otolith analysis and length distributions have shown some differences between length at age in Subarea 48.3 compared to those caught in Subarea 48.4. The cause of these differences is unknown, but they have been attributed to either environmental differences or sampling effects (Collins *et al.*, 2010). Evidence from tagging studies have shown that Patagonian toothfish move between Subareas 48.3 and 48.4 (Söffker *et al.*, 2018, 2022). In particular, the movement of smaller (< 80 cm) individuals from Subarea 48.3 to Subarea 48.4 until maturity, corresponded to peaks in the length distribution of catch in Subarea 48.4, and peaks in recruitment of toothfish in Subarea 48.3 in preceding years (Söffker *et al.*, 2022), suggesting that Subarea 48.4 may provide an area of “overspill” habitat for toothfish, following years of higher recruitment in Subarea 48.3.

3.1 Length weight relationship

A length-weight relationship of the form

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

is estimated from observer sampling records, and updated as new data become available. The most recent update was in Earl and Readdy (2022), and the estimated length-weight parameters are given in Table 5.3.

3.2 Growth relationship

The von Bertalanffy growth parameter estimates (von Bertalanffy, 1938) for Patagonian toothfish were initially described by Belchier (2004) using >800 otolith samples collected in both the commercial longline fishery and groundfish survey in Subarea 48.3. Growth parameters were continually updated with additional data up until 2011 (e.g. Agnew and Belchier, 2009; Peatman *et al.*, 2011), after which fixed values were used in stock assessments from 2011 to 2022. In 2019, a study exploring the potential influence of long-term environmental change or shifting fishery dynamics on toothfish growth found no systematic temporal trends in sex-specific growth parameters between 1998 to 2018 (MacLeod *et al.*, 2019).

Historically, in Subarea 48.3, otoliths were sampled randomly which led to low sample numbers from length-classes that are proportionally less frequent in the catch, predominately, larger (older) individuals. Following a review of the sampling, a random stratified otolith sampling approach was initiated to ensure a more even selection of otoliths for ageing across the catch length-classes. During 2021 to 2023, unread otoliths from the UK library samples from 1998 to 2016 were resampled for reading using the stratified approach applied since 2017. A number of works explored the influence of incorporating these additional otoliths and appropriate analytical methods, in growth parameter estimation (Marsh *et al.*, 2022a, b; Marsh *et al.*, 2023). The current estimation method fits the growth model in a Bayesian framework, allowing for additional uncertainty in the linear predictor for older ages, and incorporates survey data, with the exception of age 2-3 fish, as they had potentially biased model estimates (Marsh *et al.*, 2023). These current growth parameters used in Earl and Readdy (2023) are shown in Table 5.3.

3.3 Stock recruitment relationship

In the Subarea 48.3 Patagonian toothfish assessment model, recruitment is estimated within the assessment using the 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

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

The value of h is fixed at 0.75 as recommended by CCAMLR (2006; para 2.41) and based on the work by Dunn *et al*. (2006) for Antarctic toothfish.

3.4 Natural mortality

The natural mortality rate (M) proposed by Dunn *et al.* (2006), applying the methods of Chapman and Robson (1960), Hoenig (1983), and Punt *et al.* (2005), is used for stock modelling in Subarea 48.3. A natural mortality input parameter of M=0.13 y^{-1} is fixed for all ages and all years.

3.5 Maturity

The maturity ogive used in Subarea 48.3 was originally calculated as a length based ogive (Hillary *et al.,* 2006), and in subsequent assessments converted to an age-based ogive. Estimates of maturity at length and age were reviewed in 2019 to explore any temporal changes in maturity parameters, which could be due to long-term environmental change or shifting fishery dynamics (MacLeod *et al.,* 2019). Across all time periods between 1996 to 2018, the proportion of mature toothfish was higher in larger length-classes, greater water depths, and for male toothfish, with females maturing at slightly larger length-classes relative to males (MacLeod *et al.,* 2019). Similarly, the proportion of mature fish was higher in older age-classes and in males, with males generally maturing at younger ages relative to females (MacLeod et al., 2019). Depth was found to be an influential factor in maturity at length but not maturity at age (MacLeod *et al.,* 2019). Between 1996 to 2018, the mean estimated length at 50% maturity ranged from 96.7 to 110 cm for females and from 68.8 to 78.8cm for males, and between 1998 to 2017, the mean estimated age at 50% maturity ranged from 15.4 to 17.1 years for females, and from 8.0 to 14.1 years for males (MacLeod *et al.,* 2019).

In 2022, following the revision of the procedure to select otoliths for age reading and resampling of historic otolith samples (Section 3.1), maturity at age was re-estimated to determine any influence of these additional otolith samples on maturity parameters (Marsh *et al.*, 2022b). Between 2009 to 2021, the mean estimated age at 50% maturity ranged from 8.5 to 11.5 years for females, and from 7.0 to 8.2 years for males, and there was no significant influence of the additional otoliths on maturity parameter estimation (Marsh *et al.*, 2022b).

The proportion of mature individuals (across both sexes and all years) used in the assessment are estimated as a function of age class in a binomial regression. Survey data for immature toothfish (stage 1 maturity) are also included to account for few immature records in the C2 dataset. The most recently updated maturity parameters estimated using data collected between 1998 to 2022 are shown in Table 3.1:

Table 3.1. The proportion of mature Patagonian toothfish at age in Subarea 48.3.

Age	1	2	3	4	5	6	7	8	9	10	11
Maturity prop	0	0	0	0	0	0	0	0.465	0.524	0.582	0.638
Age	12	13	14	15	16	17	18	19	20	21	22
Maturity prop	0.691	0.739	0.782	0.82	0.852	0.879	0.902	0.921	0.937	0.949	0.96
Age	23	24	25	26	27	28	29	30	31	32	33
Maturity prop	0.968	0.974	0.98	0.984	0.987	0.99	0.992	0.994	0.995	0.996	0.997
Age	34	35	36	37	38	39	40	41			
Maturity prop	0.998	0.998	0.998	0.999	0.999	0.999	0.999	1			

4. ABUNDANCE AND AGE INFORMATION

4.1 Catch-per-unit-effort (CPUE)

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 and was updated for each assessment. In 2023, the method was changed to use a GAMM following the method of Berg et al. (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. Depredation rates are calculated by estimating the reduction in catch associated with whale abundance.

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.

4.2 Tag release and recapture data

The tagging programme for Patagonian toothfish in the Subarea 48.3 fishery was first initiated in the 2002-03 fishing season. All vessels participating in the fishery have been requested to tag and release toothfish at a rate of at least 1.3 fish per tonne of retained greenweight catch. Between 2003 and 2022, more than 66,000 Patagonian toothfish have been tagged and released in the Subarea and over 12,500 have been recaptured Marsh and Earl, 2023).

4.2.1 Tagging parameters

Following methods presented in Dunn *et al.* (2011), 10,968 double-tagged toothfish that were recaptured between 2004 and 2021 were used to estimate initial and ongoing tag-loss rates (Marsh *et al.*, 2022c). Initial tag loss rate was estimated to be 2.8% (95% confidence interval: 2.0% - 3.6%) and the ongoing single tag loss rate was estimated as 0.037 y^{-1} (95% confidence interval: 0.035 - 0.041 y^{-1}) (Marsh *et al.*, 2022c). As the CASAL assessment incorporates a single tag loss rate parameter, a single tag loss rate parameter was derived that best approximated the double tag model, when considering recaptures between one to four seasons at liberty (i.e. excluding in-year recaptures, and covering the period where the majority of tagged fish are recaptured, Peatman *et al.*, 2011). Marsh *et al.* (2022c) calculated this single tag loss rate as $0.0061 y^{-1}$, which was comparable to a previous estimate in 2011 of 0.0064 y^{-1} (Peatman *et al.*, 2011).

Based on studies by Agnew and Belchier (2009) using length data of Patagonian 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 0.75 years, followed by normal growth. Therefore, growth retardation is assumed to be 0.75 years for tagged fish in the Subarea 48.3 Patagonian toothfish stock assessment.

Initial tag mortality vector is applied outside the model to tag releases based on their length, using values from Agnew *et al.* (2007) shown in Table 4.1.

Table 4.1. The tag survival proportions by length bin used in the assessment (Agnew et *al.* 2007)

Length bin (cm)	30, 40	50	60	70	80	90	100+
Tag survival	1	0.96	0.95	0.95	0.94	0.83	0.80

4.3 Length and age data

Annual catch-scaled proportions at age frequencies from the commercial fleet are calculated from toothfish that are randomly selected from each line hauled and measured for length. Catch-scaled length frequencies are then calculated. Annual age-length keys are then applied to generate annual age frequencies where age-length keys are generated from otoliths collected by the fishery during each season.

5. ASSESSMENT

5.1 Assessment development

Patagonian toothfish from Subareas 48.3 and 48.4 have been found to be genetically separate to toothfish found on the Patagonian shelf. Although Patagonian toothfish in Subareas 48.3 and 48.4 are considered as potentially one population, owing to the development of the fisheries by Subarea, the two areas are assessed and managed as separate stock units. Assessments for each of the Subareas were developed at different rates with Subarea 48.3 being developed first aiding in the monitoring and management of the already established fishery.

The first assessments for toothfish in Subarea 48.3 made use of surveys to estimate total biomass (CCAMLR, 1998) but were considered uncertain given the limited spatial coverage. This led to the exploration of simple length-based cohort analysis and extrapolation analysis of single year classes (CCAMLR, 1990c) but these methods were considered questionable. The establishment of a data collection programme prompted further development of CPUE indices and short-term projections using the Generalized Yield Model (GYM; Constable and de la Mare, 1996). During the 2004 CCAMLR meeting (CCAMLR, 2004) there was agreement to develop assessments using integrated assessment frameworks which saw the development of assessments within the CASAL framework (C++ Algorithmic Stock Assessment Laboratory, https://www.niwa.co.nz/fisheries/tools-resources/casal). Age-structured production (ASPM; CCAMLR, 2005) and CASAL models were first presented during the 2005 CCAMLR meetings with agreement to continue the development of the Subarea 48.3 CASAL model as the accepted assessment method. Since 2007 the stock has been assessed biannually based on the recommendation of WG-FSA (CCAMLR, 2006). In 2023, the assessment developments were carried out in Casal2, as described in Earl and Readdy (2023). A history of key developments is provided in Table 5.1.

Table 5.1. Model time steps, and the model processes that occur within them.

Year	**Changes from previous assessment**
1985	Start of catch time series.
1997	Observers on all vessels.
2005	Preliminary presentation of CASAL assessment (Agnew *et al.*, 2005, Hillary *et al.*, 2005).
2006	First CASAL assessment (Agnew *et al.*, 2006).
2009	Catch at age data included. Total catch corrected for depredation.
2011	Inclusion of 0.006377 tag loss factor, depredation corrected CPUE included. Sensitivity testing of 2 vs 3 fleet model.
2013	Investigation of 2 fleet vs 3 fleet representation of catch data. Use of two fleet model was preferred.
2015	Francis weighting introduced.
2017	No changes. Two additional years of data added.
2019	No changes. Two additional years of data added.
2021	No changes. Two additional years of data added.
2022	Recruitment assumptions, survey uncertainty, growth and age compositions updated.
2023	Model run in Casal2, updates to historic tag and ageing data, recruitment parameterisation, growth and maturity.

5.2 Method

Since 2005, the CASAL assessment has been refined periodically. In 2009 the assessment moved from using catch-at-length proportions to using catch-at-age proportions, derived from random otolith sampling of the catch. Data from the UK groundfish survey (e.g. Collins *et al.,* 2021) was included to estimate juvenile toothfish abundance, and cetacean depredation corrections to CPUE were incorporated for catches from 2003 onwards (Agnew and Peatman, 2009). In 2011 the use of a ‘three-fleet model’ in addition to the established ‘two-fleet-model’ was explored to account for changing fishing behaviour, which was continued until and including 2013 (Peatman *et al.,* 2011, Scott, 2013), and in addition the tag loss rate was revised (Peatman *et* *al.,* 2011). The assessment in 2013 made no further changes to the biological parameters but investigated the two- vs three-fleet model scenarios, following which WG-FSA recommended the use of the two-fleet model for future assessments (CCAMLR, 2013) WG-FSA-13 § 4.19).

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 management approach (Anon, 2018; SC-CAMLR-XXXVII 2018).

The model annual cycle is described in Table 5.2. The model represents the population as an untagged part, and a part for each year of tag releases. Recruitment occurs in the untagged part of the population. Tag releases move fish from the untagged part of the population into a separate tagged component for each year of tag release. The numbers at age of recaptured fish with a tag are also removed from the appropriate tagged component of the population. The population processes (natural mortality, fishing mortality, ageing, etc.) are then applied collectively over the tagged and untagged components of the model.

Table 5.2. Model time steps, and the model processes that occur within them.

Time-step	Processes (type)
Summer (Dec-Apr)	Recruitment (Beverton-Holt stock-recruit relationship), Natural mortality Ongoing tag loss
Fishing (May-Aug)	Natural mortality Fishing mortality Tag releases SSB (50% of the way through the time-step)
FishingTagLoss (instantaneous)	Ongoing tag loss during the fishing season
Spring (Sep-Nov)	Natural mortality Ongoing tag loss
AgeIncrement (instantaneous)	Ageing

As tag-release data are only available as numbers at length (and not age), the proportions of tagged fish at age are determined within the model by multiplying the observed proportions of fish tagged at length by the proportions of fish at age 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 only operates during the autumn-winter months (typically May–August), fishing mortality is applied only in the second (Fishing) time step in the 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 fisheries separately; split temporally between 1997 and 1998, with each split into catch and depredation. The two time periods are: (1) the historical longline fishery in the early period (1988-1997); and (2) the recent longline fishery (1998-present). The selectivities assumed for the depredation are the same as those estimated for the respective catch.

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. Priors and parameter ranges are shown in Table 5.4. 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. 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 2×10^5 iterations, with every 1000^{th} 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 and Welch (1983).

Table 5.3. Biological parameters assumed in the assessment model of the Patagonian toothfish (*Dissostichus eleginoides*) population of Subarea 48.3. CV = coefficient of variation.

Relationship	Parameter (units)	Value
Natural mortality	$M\ (y^{-1})$	0.13
Von Bertalanffy growth	$t_o\ (y)$	-1.4869
	k (y^{-1})	0.0653
	L_∞ (cm)	154.1977
	CV	0.08
Length-weight	$a\ (t.cm^{-1})$	6.760e-09
	b	3.085
Stock-recruit steepness	h	0.75
Ageing error	CV	0.1
Initial tag mortality		0
Initial tag loss (per tag)		
Instantaneous tag loss (per tag)		0.0061 y^{-1}
Tag detection rate		1.0
Tag related growth retardation		0.75 year

Table 5.4. Model estimated parameters in the assessment model of the Patagonian toothfish (*Dissostichus eleginoides*) population of Subarea 48.3. CV = coefficient of variation.

Relationship	Parameter (units)	Distribution	Initial value	Range
B_0	tonnes	Uniform-log	70,000	20,000 – 1,000,000
Early fishery selectivity		Uniform	12	1 - 50
(Double normal)		Uniform	2.95	0.05 - 50
		Uniform	14.22	0.05 - 500
Late fishery selectivity		Uniform	8.63	1 - 50
(Double normal)		Uniform	1.17	0.05 - 50
		Uniform	9.79	0.05 - 500
Survey selectivity		Uniform	2	1 - 50
(Double normal)		Uniform	1.17	0.05 - 50
		Uniform	9.79	0.05 - 500
CV process error	*CPUESG2*	Uniform		0.001 - 5
	CPUESG3			
	Survey			
Q	*CPUESG2*	Uniform-log		1e-8 – 1e-1
	CPUESG3			

	Survey			
Year class strength	*YCS* (1985-present)	Lognormal	1	with mean 1 and CV 0.8 bound between 0.001 and 20

5.3 Projection method

Stock abundance is estimated using a constant catch forward projection from the joint posterior distribution for 35 years within the integrated stock assessment model. Estimates of the CCAMLR precautionary yield are based on the target and threshold reference points summarised in Section 5.4 below.

Recruitment is assumed to follow a Beverton-Holt stock-recruit curve with steepness h = 0.75. Expected recruitment for recent years for which age data are not available (i.e., recruitments for the most recent seven years) and future recruitment are calculated from the stock recruit curve. Recruitment strengths are randomly drawn from a lognormal distribution with standard deviation estimated from historic recruitment.

5.4 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