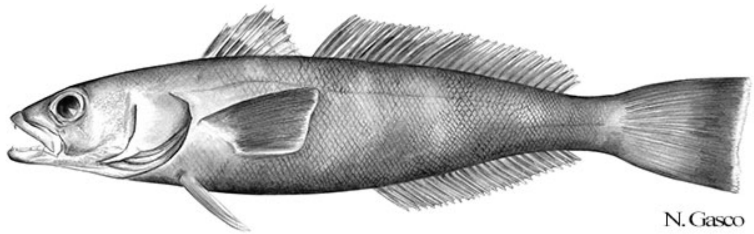
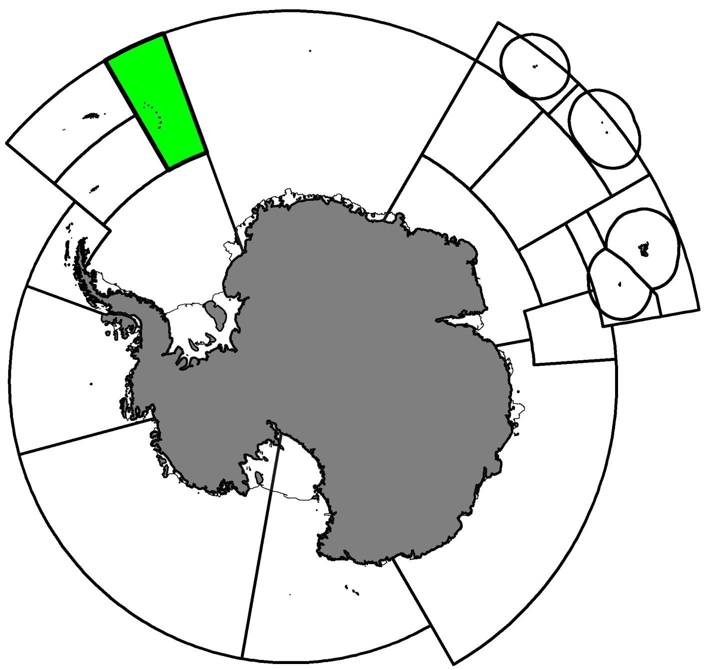
Stock Annex 2024: *Dissostichus eleginoides* in Subarea 48.4

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 48.4 Patagonian toothfish (*Dissostichus eleginoides*)

Species: Patagonian toothfish (*Dissostichus eleginoides*)

Area: CCAMLR Subarea 48.4

Created: September 2023

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1. GENERAL INFORMATION

1.1 Stock structure and definition

Patagonian toothfish in CCAMLR Subareas 48.3 and 48.4 (Figure 1.1) are considered an isolated population (Canales-Aguirre *et al*. 2012; Collins *et al*. 2010), 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 48.4, with Subarea 48.4 hypothesised to be an overflow area from Subarea 48.3 when large recruitment events occur (Soeffker *et al*. 2022).

Tag recapture data have shown that a high proportion of the long-distance movement of Patagonian toothfish is from Subarea 48.4 to Subarea 48.3, with around 20% of Subarea 48.4 releases being recaptured in Subarea 48.3, with no information on the regularity of 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*. 2002) of fish increases, marking a change in habitat use and food source availability.

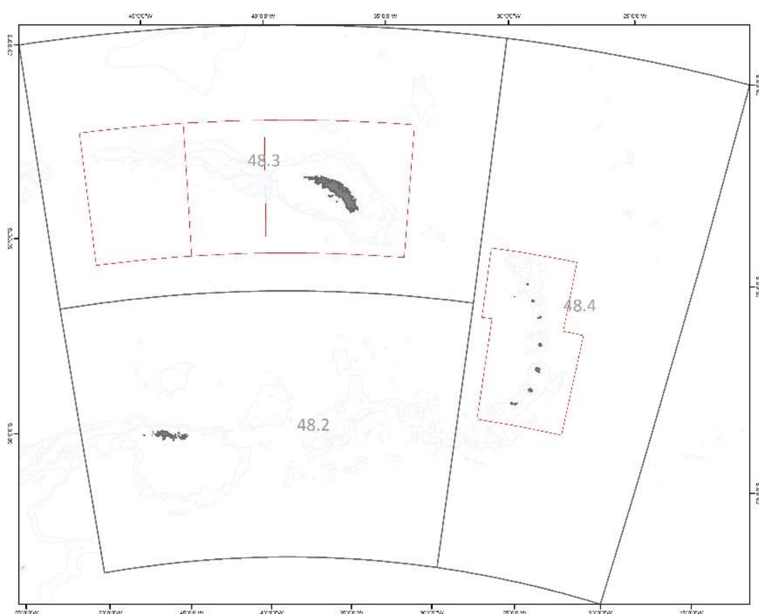

Figure 1.1. Conservation of Antarctic Marine Living Resources (CCAMLR) Subareas 48.2, 3 and 4, red line delineates the management areas.

1.2 Fishery

The CCAMLR Subareas 48.3 and 48.4 fisheries which catch Patagonian toothfish (*Dissostichus eleginoides*) have been in operation for around 40 years (Agnew, 2004). Catches of 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). Fishing for Patagonian toothfish, as a target species caught in longline fisheries, did not occur until the 1988/89 season where the fishery operated in Subarea 48.3. Targeted fishing of Patagonian toothfish in Subarea 48.4 did not occur until the 1992/93 season and paused until the 2004/05 season when a catch of 27 tonnes was taken (CCAMLR, 2002). During 2005, a three-year mark-recapture survey was proposed and commenced in the following year around the Northern end of the island chain (Delegation of the UK, 2005).

Both Patagonian and Antarctic toothfish are found in Subarea 48.4 and are distributed across the area with a higher proportion of Patagonian toothfish found in the north, and a higher proportion of Antarctic toothfish found in the South (Soffker *et al*. 2021). Further details of the fishery characteristics for Subarea 48.4 are available in Marsh *et al*. (2023).

1.3 Fishery management

CCAMLR catch limits were first introduced for statistical Subarea 48.4 in 1992/93 (CCAMLR CM 44/XI) when Chile notified to commence an Exploratory fishery. In response to the notification a catch limit of 240 tonnes for Patagonian toothfish was set. Following the results of the Exploratory fishery a catch limit was set at 28 tonnes for the following seasons. A prohibition on catches of Antarctic toothfish (*Dissostichus mawsoni*) was subsequently introduced in 1997. With the agreement of the initiation of the new Subarea 48.4 North survey (Figure 1.2) in the 2005/06 season the catch limit was increased to 100 tonnes so as not to limit the survey and allow for a target of 500 toothfish to be tagged. A Subarea 48.4 South survey commenced in the 2008/09 season with a catch limit of 75 tonnes for the two species of toothfish combined (CCAMLR CM 41-03). Separate catch limits for the Northern and Southern areas, delineated by a boundary line of 57º 20′S, continued until the 2013/14 season. Thereafter either the North or South area was closed if Patagonian or Antarctic toothfish catch limits were reached, respectively, prior to the season closure of the fishery. Since 2012/13 the two species have been assessed separately and species-specific catch limits are for the whole Subarea 48.4.

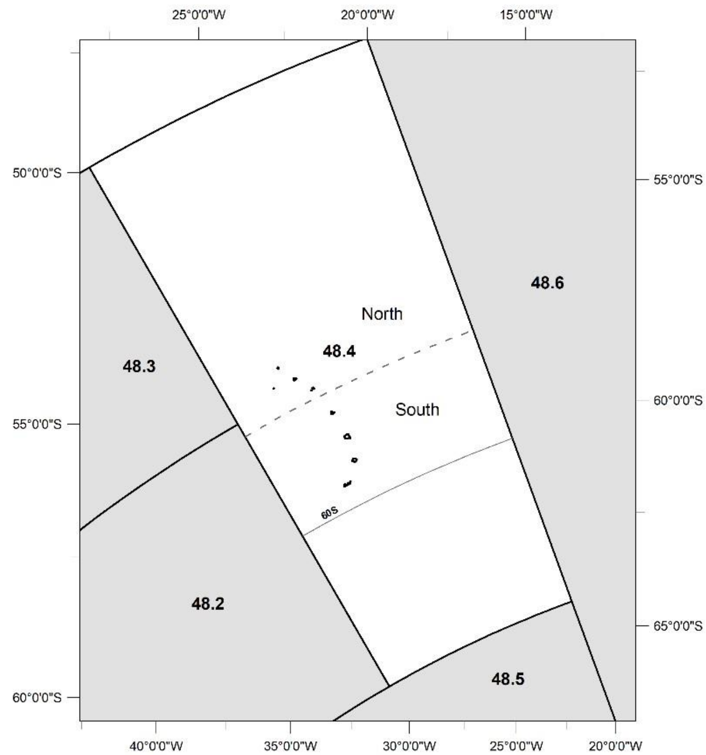

Figure 1.2. Map of area 48.4. Dashed line at 57º 20′S indicates previous North and South rectangles, which have been combined into a single assessment since 2012.

2. CATCH DATA

2.1 Commercial catch

Commercial catch data (retained and discarded fish) 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 from the CCAMLR *Dissostichus* Catch Documentation (DCD) scheme (CM 1005). Catch data from 2004/05 are included in the Patagonian toothfish assessment with associated size and age distributions available since 2010/11.

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 in the stock assessment.

2.3 Illegal, Unreported and Unregulated (IUU) removals

There has been no recorded evidence of IUU fishing in Subarea 48.4.

2.4 Other sources of mortality

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.

Estimates produced from the 2018/19 season, show that the number of hooks that were attached to lines and subsequently lost represented less than 2% of all hooks set (unpublished). If these hooks caught toothfish at the same rate as those retrieved, and if all the toothfish caught on lost lines died as a result of being caught, it would amount to < 0.5t of fishing related mortality unaccounted for annually. Thus, the additional mortality associated with lost lines is assumed to be negligible.

3. BIOLOGICAL INFORMATION

Patagonian toothfish can reach a total length of at least 253 cm (Soeffker *et al*. 2022). The largest recorded toothfish in Subarea 48.4 was 181 cm caught during fishing operations in the 2021/22 season. It has been noted that females grow much larger than males with a higher recorded length for similar age ranges (Collins *et al*. 2010).

Patagonian toothfish are a long-lived species and in CCAMLR Subareas 48.3 and 48.4 the oldest ages have been estimated at around 50 years based on age determination of otoliths collected during fishing and research survey operations (Belchier 2004). 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 not fully known, but have been attributed to either environmental differences or sampling effects (Collins *et al*. 2010, Soeffker *et al*. 2022).

The juvenile and sub-adult period of Patagonian toothfish is relatively long. During this period, they can be found in the shallow waters of the upper slope and remain there until maturation around the age of 7-10 years (Laptikhovsky *et al*. 2006). The steep slopes of the archipelago islands in 48.4, however, provide limited habitat for juvenile Patagonian toothfish. Topographical features such as these steep slopes further limit fishing, and therefore restrict sample collection to depths greater than 700 m, thus no information on juveniles and nursery grounds is available for this Subarea.

3.1 Length-weight relationship

Length-weight parameters were first reported by Roberts and Agnew (2009) and later updated for the biennial assessment updates run in 2015, and again in 2017 (FSA-15/28, WG-FSA-17). For the most recent analysis, data from 2005 up to 2023 (n ≈ 14,908) were checked for errors, outliers were removed and estimates of the length weight relationship were made using the equation,

$$\text{Mean weight} = \alpha(\text{length})^{\beta}.$$

The estimated length-weight parameters used in the assessment model are given in Table 5.2.

3.2 Growth relationship

The von Bertalanffy growth model (VBGM) parameter estimates (von Bertalanffy 1938) for Subarea

48.4 Patagonian toothfish were first described by Roberts and Agnew (2009). They were later updated by Scott (2012) using age-length observations from 2009 to 2011 and are used in the model as initial values to estimate *k* and L_{inf} internally. Owing to the lack of data on small individuals, t_0 of the VBGM is assumed to be zero and fixed in the integrated modelling framework. The fixed growth parameters are given in Table 5.2 with Table 5.3 providing details of the estimated parameters and initial starting values.

3.3 Stock recruitment relationship

In the Subarea 48.4 Patagonian toothfish assessment model, recruitment is estimated 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

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

The value of h is fixed at 0.75 as recommended by CCAMLR (2006; para 2.41) and based on the work conducted 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 48.4. Natural mortality input parameter of $M=0.13\ y^{-1}$ is fixed for all ages and all years.

3.5 Maturity

In Subarea 48.4, maturation parameters from gonad development are highly variable between seasons fished, due in part to the variable timing of the fishery. Therefore, it was not possible to estimate maturation proportions at length or age (Roberts and Agnew, 2009) and maturation proportions at age estimated for Subarea 48.3 are used instead. In Subarea 48.3, the proportion of mature individuals (across both sexes and all years) are estimated as a function of age class in a binomial regression and further details can be found in Earl *et al*. (2023). This is repeated annually, incorporating the latest fishing season data to update the maturity parameters and assess any temporal trends. 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 Tag release and recapture data

The tagging programme for Patagonian toothfish in the Subarea 48.4 fishery was first initiated in the 2004/05 fishing season. All vessels participating in the fishery have been requested to tag and release toothfish at a rate of no more than five fish per tonne of retained greenweight catch. Between 2004/05 and 2018/19, more than 4,250 Patagonian toothfish have been tagged and released in Subarea 48.4 and over 560 have been recaptured (Readdy and Earl, 2023).

Tagging survival is assumed to be 90%, the upper limit of the estimates calculated for Patagonian toothfish in Subarea 48.3, because of the larger size ranges available to the fishery in 48.4 (Roberts and Agnew, 2009). The effective tag detection rate is assumed to be 100% given observer coverage is 100% on all vessels that fish in Subarea 48.4.

4.1.1 Tagging parameters

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 48.4 Patagonian toothfish stock assessment.

Owing to relatively few tag recapture data, tag loss statistics estimated for Patagonian toothfish in Subarea 48.3 are used as input parameters in the Subarea 48.4 stock assessment. 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.* 2022). 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.* 2022). 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.* (2022) calculated this single tag loss rate as 0.0061y^{-1}, which was comparable to a previous estimate in 2011 of 0.0064 y^{-1} (Peatman *et al.* 2011).

4.2 Length and age data

Annual catch-scaled proportions at age frequencies from the commercial fleet are calculated from approximately 35 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 obtained from otoliths collected by the fishery during each season.

5. ASSESSMENT

5.1 Assessment development

Although Patagonian toothfish in Subareas 48.3 and 48.4 are considered as potentially being a single population, owing to the development of the fisheries by Subarea the two areas are assessed and managed as separate stock units.

The assessment in Subarea 48.4 was first developed with preliminary biomass estimates for the Northern area (Figure 1.2) in 2008, using a depletion method based on CPUE and the Petersen method using mark-recapture data (WG-FSA-08/46). In 2009, a CASAL model was developed using four years of data, 2005-2008, (WG-FSA-09/17) which provided stock status and catch advice for the Northern area of Subarea 48.4. For the Southern area, only one year of data was available and catch advice was based on CPUE x fishable area for both species of toothfish combined. From 2011, CPUE trends and the Peterson method were then used to provide combined catch advice. Since 2013, the Northern and Southern areas were combined, and a CASAL assessment and Petersen method was developed for the Patagonian and Antarctic toothfish, respectively. In 2023, a Casal2 assessment has been developed using the same structure as the previous CASAL model.

Table 5.1 Development of the integrated stock assessment for Patagonian toothfish in Subarea 48.4.

Year	**Stock assessment changes**	**Reference**
2013	First CASAL assessment of TOP in Subarea 48.4.	WG-SAM-13/24, WG-FSA-13/31
2014	Comparison of maturity ogives.	WG-FSA-14/29 Rev. 1, WG-FSA-09/17
2015	Updated maturity ogive and length-weight. Changes to mortality post tagging. Francis weighting introduced.	WG-FSA-15/28
2017	Update of length-weight parameters (not mentioned). Change to number of years of recaptures post-tagging reduced from 6 to 4.	WG-SAM-17/35
2019	No changes except for two additional years of data.	WG-FSA-2019/29
2021	No changes except for two additional years of data.	WG-FSA-2021/61, WG-FSA-2021/62
2022	Pre-initial run to update starting values for L_∞ and k of the growth function to address conversion issues.	WG-SAM-2022/19, WG-SAM-2022/21
2023	Addition of two years of data, migration to Casal2 from CASAL, update of length-weight and tag loss rate parameters and maturity ogive.	WG-FSA-2023/17, WG-FSA-2023/18

5.2 Method

Stock assessments have been carried out for the Patagonian toothfish population for the combined northern and southern area of Subarea 48.4 since 2013 (WG-FSA-13/31). The combined Subarea 48.4 integrated assessment model implemented in CASAL (Bull *et al.* 2012) was used prior to 2023. From 2023, an integrated assessment model in Casal2 has been implemented with the primary abundance information determined from tag release and recapture data conducted by the fishery. 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 the models applied assumptions in the stock assessments in a precautionary manner and noted that assessments were appropriate and consistent with CCAMLR's approach to management (Anon, 2018; SC-CAMLR-XXXVII 2018).

The model is structured with ages from 1–50, whereby the number of toothfish of each age is tracked through time, with the last age group being 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 1990 to the current year, and the annual cycle is broken into five discrete time steps, nominally, recruitment, fishing (February-May) and spawning, tag loss and an age-incrementation step.

Recruitment is assumed to occur at the beginning of the first-time step, to be the mean (unfished) recruitment (R_0) multiplied by the spawning stock-recruitment relationship and annual recruitment strength. Recruitment year strengths are assumed constant (equal to 1) for cohorts where adequate age frequency data were not available. Past recruitment is estimated assuming a lognormally distributed prior with variability $\sigma_R = 0.658$.

The model structure, described above, is replicated for each annual set of releases of tagged fish, with the numbers at age in the tag component defined by the year of tag-release. Tag releases are assumed to occur at the end of the second time-step. Numbers of fish tagged are then modified by initial tagrelated 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 relevant tagged component of the population.

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.

The toothfish fishery only operates only during the Summer-Autumn months (typically February–May), and therefore fishing mortality is only applied 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, then the instantaneous mortality from the fishery, and, finally, the remaining half of the natural mortality for the time step.

The selectivity parameters are estimated by the assessment model, and the catch-scaled proportions at age data are fitted in the model. The maturation process is applied in the second time step (Fishing). Maturation is specified as the time-invariant proportion of fish at age that are mature. In the second time step, a third 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 et 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 2×10^5 iterations, with every 1,000th sample taken from the next 9×10^5 iterations (i.e., a final sample of length 900 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).

Table 5.2. Fixed parameters assumed in the assessment model of the Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4. CV = coefficient of variation.

Relationship	Parameter (units)	Value	Reference
Natural mortality	M (y^{-1})	0.13	WG-FSA-09/17
Von Bertalanffy growth	t_o (y)	0	WG-SAM-13/24
	CV	0.08	
Ageing error	CV	0.1	
Length-weight	a ($t.cm^{-1}$)	3.44e-09	WG-FSA-2023/31
	b	3.237	
Beverton-Holt stock recruitment steepness	h	0.75	WG-SAM-06/08, WG-FSA-09/17
Maturity vector	0 to fully mature	Between 0-1	WG-FSA-23/31
Initial tag mortality		0.1	WG-FSA-05/18
Instantaneous tag loss (per tag)		0.0061 y^{-1}	WG-SAM-22/17

Tag detection rate	1.0	WG-FSA-09/17
Tag related growth retardation	0.75 year	WG-SAM-14/35, WG-FSA-14/49, WG-FSA-14/50

Table 5.3. Parameters estimated by the Casal2 integrated assessment model of the Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4. CV = coefficient of variation.

Relationship	Parameter (units)	Distribution	Initial value	Range	Reference
B_0	tonnes	Uniform-log	1,000	500 – 5,000	
Von Bertalanffy growth	*k* (y^{-1})	Uniform	0.092	0.03 - 0.2	WG-SAM-13/24
	L_∞ (cm)	Uniform	153.0	110 - 250	
Fishery selectivity	*Age @ 50% selected*	Uniform	8	1 - 50	WG-FSA-13/31
	Selectivity range (y)	Uniform	4	1 - 50	
Year class strength	*YCS* (1989present)	Lognormal	1	with mean 1 and CV 0.658 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 5.3 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