Stock Annex 2021: *Dissostichus eleginoides* at Kerguelen Islands French EEZ (Division 58.5.1)

CCAMLR Secretariat

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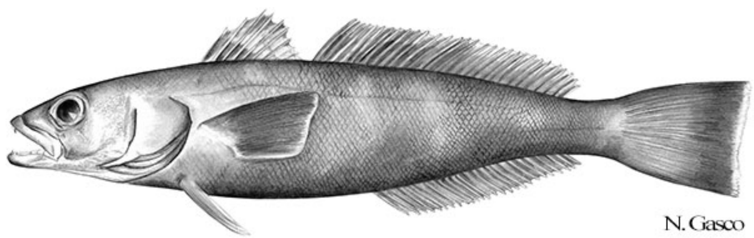
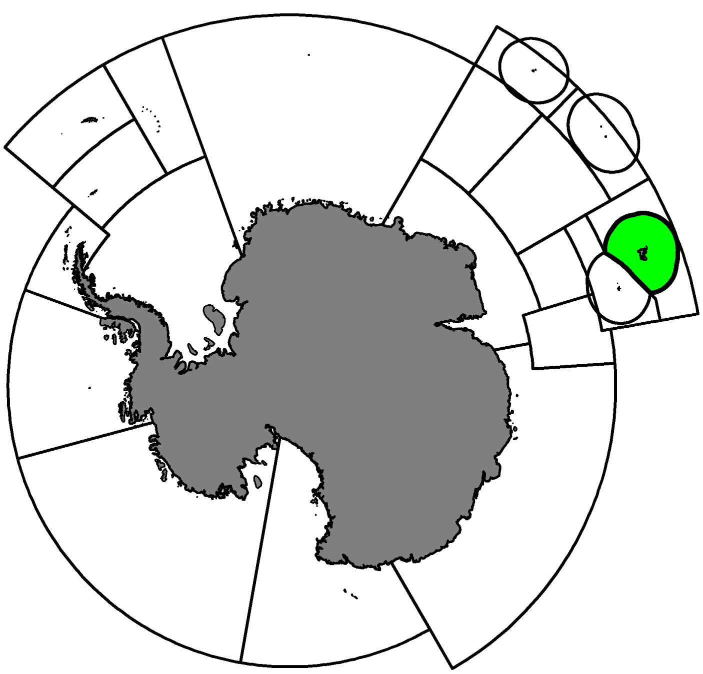


Patagonian toothfish *Dissostichus eleginoides* Smitt, 1898.



Map of the management areas within the CAMLR Convention Area. The region discussed in this report is shaded in green.

Commission for the Conservation of Antarctic Marine Living Resources
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Stock Annex for the 2021 assessment of the Patagonian toothfish (Dissostichus eleginoides) population of Kerguelen

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EN

Stock Annex for the 2021 assessment of the Patagonian toothfish (Dissostichus elegenoides) population of the Kerguelen Island EEZ in Division 58.5.1

Species: Antarctic toothfish (Dissostichus elegenoides)

Area: EEZ of Kerguelen (CCAMLR Subareas 58.5.1)

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1 GENERAL INFORMATION

1.1 Stock structure and definition

Dissostichus eleginoides (Patagonian toothfish) is a large long-lived species belonging to the family Nototheniidae, or Antarctic cods. It is characterised by slow growth, low fecundity and late maturity. They are associated with cold water and are found around the sub-Antarctic and South America, as far north as Equador in the cold Humboldt current. *Dissostichus eleginoides* appears to have protracted spawning periods, taking place mainly in winter, but which may start as early as late autumn and extend into spring. *Dissostichus eleginoides* are thought to spawn in deep water around sub-Antarctic islands, around South Georgia Island (Subarea 48.3), Bouvet Island (Subarea 48.6), Prince Edward Islands (Subarea 58.7) and on the Kerguelen Plateau (Divisions 58.5.1 and 58.5.2), but data in Crozet Islands (Subarea 58.6) are still not available. Patagonian toothfish show distinct depth preferences with age, with juveniles (500 m) as they reach maturity (~90 cm). They are important predators, feeding primarily on fish, cephalopods and crustaceans; they also scavenge (Duhamel et al. 1987, Collins et al. 2007).

The Kerguelen Plateau is located in the Southern Indian Ocean and stretches from around 45°S to over 60°S. Two large fisheries for Patagonian toothfish operates on the northern part of the plateau. They are located in CCAMLR Division 58.5.1 which covers the French Exclusive Economic Zones (EEZ) around Kerguelen Islands, and Division 58.5.2 which covers the Australian EEZ around Heard Island and McDonald Islands (HIMI).

Based on available genetic information (Toomey et al. 2016), catch composition (Péron et al. 2016) and tag-recapture data from survey and the commercial toothfish fishery (Burch et al. 2017, Ziegler 2019), Patagonian toothfish are continuously distributed on the northern part of the Kerguelen Plateau and populations are linked. Within this area, the populations are likely structured with juveniles settling in shallow waters around the islands and potential exchange between Kerguelen Islands and HIMI. As fish grow larger and older, they move to deeper waters, and major spawning grounds are located on the western and southern side of the plateau (Péron et al. 2016, Ziegler et al. 2021).

1.2 Fishery

In the French EEZ of the Kerguelen Island located in the CCAMLR Division 58.5.1., Patagonian toothfish (*Dissostichus eleginoides*) was targeted occasionally by commercial trawlers in the 90's (CCAMLR fishery report, 2020). Longliners have progressively replaced the trawlers and for the last 20 years, 7 French longliners have been operating in the area using automatic weighted bottom longlines. During the early stage of the fishery, between 1997 and 2004, illegal, unregulated and unreported (IUU) fishing occurred together with legal fishing (Duhamel, 2003).

Fishery observers are on board of all vessels to collect biological and statistical data and complete logbooks. They monitor the catch data and the biological data collected on board and transmit them every week to fishery manager at TAAF (Terres Australes et Antarctiques Françaises, French Overseas Territories), and to the Muséum national d'Histoire Naturelle (MNHN). Landings are controlled by an independent company and are matched with the observer data.

Several measures of fishery management have been taken to ensure a sustainable exploitation of the stock and protect the ecosystem (birds mitigation devices, vulnerable marine ecosystem (VME) exclusion area, skate cut-off method and move-on rule, depredation mitigation…). Areas where depth is lower than 500 meters and territorial waters (12 NM) are prohibited from fishing. Fishing is also prohibited within the strict protection areas of the Marine Reserve since 2006. There is a size limitation of the targeted species (>60 cm). To ensure a good representation of the stock and recaptures of tagged fish, fishing effort is limited to no more than one longliner in a statistical sector (0.5°lat x 1°long) at a time. The vessel can also stay for a limited period of time only in each statistical sector (10 days). The fishery is active throughout the year with the exception of a summer closure period (1 February to either 1 or 15 March) which has been in place since 2004.

Within the French EEZs, fishing seasons, catch limits for target species, as well as vessel licensing, are allocated by France. A six-year management plan was adopted in 2019 with the overall objective of ensuring conditions for a sustainable and optimal exploitation of Patagonian toothfish. It also sets catch limits for a period of 3 years. The season extends from 1 September to 31 August. Management measures are annually established by TAAF and specific to the EEZ

The main management measure concerning Patagonian toothfish is to limit the removals by ensuring that their level does not lead to (1) a probability higher than 10% of the spawning biomass dropping below 20% of its median pre-exploitation level over a 35-year harvesting period (i.e. depletion probability) and (2) a median escapement of the spawning biomass at the end of a 35-year period smaller than 60% of the median pre-exploitation level.

In the EEZ of Kerguelen, various national conservation and fisheries enforcement measures are applicable, such as:

- Annual catch limit set triennially since 2019
- Limitation on the number of longline vessels authorized to operate in the fishery
- Demersal longlines and pots are the only authorized fishing gears
- Fishing season extends from 1 September to 31 August of the following year with an annual closure from 1 February to mid-March, which differs from the CCAMLR fishing season
- One vessel at a time fishing per 0.5◦ latitude x 1◦ longitude rectangle for a maximum period of 10 days
- Fishing is prohibited within the strict protection areas of the Marine Reserve and in areas not exceeding 500m in depth
- Move-on rule to limit catches of *D. eleginoides* of 60cm and less
- Cut-off procedure and move-on rules for skates to reduce fishing mortality
- Mitigation measures to reduce bird mortality
- Move-on rule on VME
- One French scientific observer on board each licensed vessel
- Mandatory vessel logbooks
- A single catch landings site at Réunion Island
- Mandatory port inspection

2 CATCH DATA

2.1 Commercial catch

Data from commercial fisheries in French EEZ are available for the period from 1980-2020. Before 2000, trawl was the main fishing gear and French vessels operated in Kerguelen area. The longline fisheries started in 1991 with foreign longliners in Kerguelen before French vessels took over in 2000 (Duhamel & Williams, 2011; Duhamel et al., 2011). Substantial IUU longline fishing occurred in the Kerguelen EEZ (1996-2004) and also in its whereabouts (2010) with an overall catch of 40 000 tons over the IUU period. Annual estimations of illegal catches are partially available and are implemented in the models.

The haul-by-haul data from longline and trawl include information on the fishing operations as fishing date, haul latitude and longitude, fishing depth, gear type, number of hooks and total catches in numbers and weight.

Killer and sperm whale are responsible for catch removals during the fishing operations. To account for this extra mortality, catch data is revised with a depredation rate and are included in the overall fish removal in the model (Tixier et al., 2020).

2.2 Illegal Unreported and unregulated removals

Illegal, unreported and unregulated (IUU) fishing was first detected in this region in 1996 and in some years IUU catches have exceeded legal catches, resulting in total removals exceeding 10,000 tonnes in some seasons.

IUU fishing activity were once again detected in Division 58.5.1 (Kerguelen EEZ) in 2006, with one IUU-listed fishing vessel observed in the division. Two IUU-listed vessels were sighted during 2007 and three IUU-listed vessels were sighted during 2008 in the EEZ. Other IUU fishing vessel was observed on the boundary of the Kerguelen EEZ during winter 2007, and reports from France indicate that IUU activities sometimes occurred here during each year from 2008 to 2012. One IUU-listed fishing vessel was sighted in Division 58.5.1 during 2010, two during 2012 and one during the 2013. While no IUU-listed vessel was observed during 2014, 2015 and 2016, however, IUU fishing gear was recovered from the region during all three years. Following the recognition of methodological issues in its assessment, no estimates of the IUU catch of *Dissostichus* spp. have been provided since 2011 (SC CAMLR-XXIX, paragraph 6.5).

2.3 Other sources of mortality

Since 2007, observers systematically note the presence of killer and sperm whale during the hauling of the line and with a depredation rate estimated. While depredation by killer whale has been extremely seldom, the recent occurrence of killer whale in the area suggests that it might become a significant issue in the future.

Depredation by sperm whale has been pretty stable over the estimated period and is around 4-5%.

To account for this extra mortality, catch data is revised with a depredation rate and is included as the overall fish removal in the model (Tixier et al, 2020, Gasco et al.,2016).

3 BIOLOGICAL INFORMATION

At first, only removals data were collected, but after 1983, the sampling program evolved to collect haul-by-haul biological data. It includes data such as total length and weight of all sampled fish and late on, otoliths. A subsample offish are sexed and have their maturity stage assessed. When quality of the biological data is considered poor, the data is flagged and not used.

3.1 Length weight relationship

Length-weight parameters were estimated with the following equation (Sinègre et al., 2017).

$$weight = a(length)^b .$$

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

3.2 Growth relationship

The otoliths reading program started in 2014. It involves three specialized laboratories: the laboratory of sclerochronology of Ifremer (Boulogne/mer, France), the CEFAS (Lowestoft, UK) and the Australian Antarctic Division (Kingston, Australia). Results obtained in collaboration are now available and included in our approaches to estimate the growth curve and will be part of future assessment of the stock to inform on the annual age structure of the catches and the population. A 4-year program, aiming to read 12 000 otoliths has started in 2020 and will allow to base assessment model primarily on age frequency data. The first two years of the program will ensure that 5 fish will be aged per 5 cm class and the second two years will allow to get 5 fish per 1 cm class.

Year-specific ALKs, grouped by 5 cm length bins from 15 to 220 cm for the scientific surveys (POKER) and the commercial catch were calculated from age-length samples.

A Bayesian hierarchical modelling was developed in 2019 in order to propose a unified framework to estimate Patagonian toothfish growth curves. We built the model with the r package NIMBLE that compiles models and algorithms using C++ for speed. It includes three components:

1. A system for using models written in the BUGS model language as programmable objects in R.
2. An initial library of algorithms for models written in BUGS, including basic MCMC, which can be used directly or can be customized from R before being compiled and run.
3. A language embedded in R for programming algorithms for models, both of which are compiled through C++ code and loaded into R.

This statistical model includes multiple levels and estimates the posterior distributions of the parameters using the Bayesian method. It combines sub-models to form a hierarchical structure allowing the estimation per year, sex and stock while providing a global estimate of parameters. This framework is also suitable to produce adequate prior distribution that could be used for other modeling approach (e.g. CASAL stock assessment) or data poor situations.

The updated growth parameters estimated with this model and more than 500 newly-aged fish can be found in Table 1.

3.3 Stock recruitment relationship

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 $h = SR(0{,}2B_0)$

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

3.4 Natural mortality

Based on Candy et al. (2011), the natural mortality is estimated to be 0.155 and constant for all age classes.

3.5 Maturity

The maturity parameters used in this stock assessment are the same than the one used in Sinègre et al, 2017 (Table 1).

4 ABUNDANCE INFORMATION

4.1 Catch-per-unit-effort (CPUE)

In more recent years, four bottom trawl biomass surveys named *POKER* (2006, 2010, 2013 and 2017) have been conducted in the bathymetric range 100 - 1000 m and provide insights on the juvenile phase of the population (Duhamel et al. 2014, Duhamel et al. 2019).

The length distribution and the biomass estimates are used to update the CASAL model, keeping in mind that these biomass estimates represent only a subset of the Patagonian toothfish biomass in the division 58.5.1 given its wide distribution encompassing waters from 10 m to 2500 m.

4.2 Tag-release and recapture data

Within the French EEZ, vessels are required to tag and release toothfish at a rate of 1 fish per tonne of green weight caught throughout the season.

The tagging program undertaken by France in its EEZ in Division 58.5.1 has achieved a similar tag-recapture rate to the tagging program undertaken by Australia in Division 58.5.2, which indicates that tagged fish move mainly short distances, but some fish make longer forays around the slope, as well as long-distance movements outside the division (Ziegler et al. 2020). Fish from the tagging program at Heard Island (Division 58.5.2) have also shown movement of sub adult/adult fish between zones (Heard to Kerguelen and also Crozet), but the proportion of exchange between stocks is relatively small (Williams et al., 2002; WG-FSA-07/48 Rev. 1, Ziegler et al. 2020). Movement of adult Patagonian toothfish from HIMI to Kerguelen EEZ is accounted for by increasing slightly to tag shedding parameter in the HIMI stock assessment (Ziegler et al. 2019).

Table 1. Biological parameters assumed in the assessment model of the Patagonian toothfish (*Dissostichus elegenoides*) population of the Kerguelen island region.

Stock recruitment	Beverton-Holt
Steepness h	H= 0.75
σ_R	0.89
Size-at-age	*Von Bertalanffy*
Linf	170 cm
K	0.0662
t0	-1.12
CV	0.072
Weight at length L	a: $9.61\ 10^{-9}$ b: 3.02
Maturity	a50: 9.25 ato95: 8.07
Natural Mortality M	0.155
Tagging data	
Tag detection	0.999
Tag-release M	0.1
Tag related growth retardation	0.5 year
Tag shedding	0.004

Table 2: Estimated parameters of the Crozet fishing selectivity function and their numbers, priors, starting values, and lower and upper bounds. DNC stands for double-normal capped.

Parameters			Number	Starting values	Prior	Lower bound	Upper Bound
SSB0			1	200 000	Uniform-log	50 000	400 000
Selectivities	DNC	a_1	1	8	Uniform	0.1	50
		s_L	1	4	Uniform	0.01	50
		s_R	1	10	Uniform	0.1	500
		a_{max}		1	Uniform	1	1

5 ASSESSMENT

5.1 Method

At Kerguelen, the stock assessment is based on single-sex CASAL models; the Patagonian toothfish population is modelled in 35 age classes, from age 1 to age 35, with a plus class. They are run for the period 1980 – 2019 with fishing seasons starting the 1rst of September and ending the 31rst of August. The population parameters are summarized in the Table 1.

The annual cycle is divided into three time-steps or seasons during which (1) fish recruitment and fishing, (2) spawning, and (3) ageing occurred.

5.1.1 Model estimation procedure

The models estimate unfished spawning biomass *SSB0,* survey catchability *q*, annual year class strength (YCS) and the parameters of the selectivity functions for the survey and sub-fisheries (see 5.1.2). Initially, free parameters and their covariance are estimated by maximum posterior density (MPD). These estimates are used as starting point for Monte Carlo Markov Chains (MCMCs) sampling. For the MCMCs, the first 500 000 iterations were dismissed (burn-in), and every 1000th sample taken from the 1 million iterations (thin). MCMC produce posterior distribution for the free parameters and state-space. It also includes uncertainty. Convergence of the chains can be tested to confirm estimations.

All model runs are conducted with the CASAL version 2.30-2012-03-21 rev. 4648 that was agreed on WG SAM 14.

5.1.1.1 Penalties

The models include penalties for catches and tagging data. A penalty for YCS is set to force the average of estimated YCS towards 1. Catch penalties prohibit the model from returning an estimated fishable biomass for which the catch in any given year would exceed the maximum exploitation rate set at U = 0.995 for each sub-fishery (see 5.1.2).

5.1.1.2 Process error and data weighting

In order to adjust observation data weights in the model, an additional variance, named process error, is applied for each set of observation (length frequencies and tag data). The iterative method used in this assessment method is based on the observed vs. expected mean length of each distribution as described by Francis (2011a, 2011b). A factor is applied to the initial effective sample size for each catch at length dataset and an over-dispersion parameter for the recapture data as is described in Mormède et al. (2013).

5.1.2 Commercial fishery and fleet structure

Fishing hauls may show similarities that are caused by gear specificities, seabed structure, depth and fish availability. Hauls with analogous distribution of catch-at-age and length distributions are pooled together into groups defined as sub-fisheries (Sinègre & Duhamel, 2015). Each group is modeled with a specific selectivity function. The sub-fishery structure consists of (1) a trawl shallow group for fishing grounds shallower than 500m depth, (2) a trawl deep group for those deeper than 500m, (3) a longline shallow group for fishing area with depth between 500 and 1250m and a (4) longline deep group for those deeper than 1250m. A shallow area that has the particularity to have similar length distribution in the catches to deeper area has been pooled with the latter sub-fishery.

5.1.3 Selectivity function

The selectivity function used in the last assessment is a double-normal capped (DNC) fitted for each sub-fishery and the survey (Table 1). The DNC function is calculated as f(x) for age x (Bull et al. 2012):

$$f(x) = \begin{cases} a_{max} 2^{-[(x-a_1)/\sigma_L]^2} & x \le a_1 \\ a_{max} & a_1 < x < a_1 + a_2 \\ a_{max} 2^{-[(x-(a_1+a_2))/\sigma_U]^2} & x > a_1 + a_2 \end{cases} \qquad (1)$$

where a1 and a1+ a2 define the age range at which the ogive takes the value a_{max}, and σ_L and σ_R define the shape of the left-hand and right-hand side of the DNC function such that the ogive takes the value 0.5 a_{max} at *(a = a1 -* σ_L *and a = a1 + a2 +* σ_R*)*. In all cases, a_{max} is not estimated but set to 1, i.e. only four parameters are estimated for all DNCs.

Priors used are detailed in Table 2.

5.1.4 Tagging data

The tagging program started in 2006/07. The fishery observers set two tags per fish with a ratio of one tagged fish per ton of fish caught. Since the catches have been pretty stable since 2009, the number of fish tagged stabilized around 5 000 fish every year.

In 2019, a new R routine that identifies misreporting and tag loss has been developed to maximize tag matching (>95% of the tag recaptures could be matched to their release information). In the assessment, the tag-recaptured data used is capped at 6 years at liberty and fish recaptured the same season of their tagging are excluded as they are not likely to provide insights on the growth of fish and biomass of the population. Also, we assume a no growth period of half a year following the tagging.

To account for fish migrations between Kerguelen Islands area (Division 58.5.1) and HIMI area (Division 58.5.2), the tag-shedding parameter is fixed with an annual migration rates of 0.004 (Burch et al. 2017).

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 parameterized as a lognormal distribution with mean R0 modified by the stock recruit curve and standard deviation $\sigma_R = 0.89$. 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 $\sigma_R = 0.89$. The future selectivities assumed are those for the subfisheries, and the catch split between the fisheries is assumed consistent with the last 5 years catch proportions. No allowance is made for potential IUU, but depredation is accounted for and considered constant and equal to the average depredation rate of the last 5 years in projections.

5.3 Reference points and calculation of catch limits

Catch limits are estimated through a catch projection procedure within the stock assessment model that accounts for the uncertainty of the parameters. The catch projection procedure assumes constant annual catches scenarios that include catches and depredation. The decision rules specify that the lower yield between $\gamma 1$ and $\gamma 2$ should be taken as reference.

.with γ_1 ensuring that the probability of the spawning biomass dropping below 20% of its median pre-exploitation level over a 35-year harvesting period is <10% (depletion probability).

.with γ_2, so that the median escapement of the spawning biomass at the end of a 35-year period is 60% of the median pre-exploitation level.

The depletion probability is calculated as the proportion of samples from the Bayesian posterior where the predicted future spawning biomass was below 20% of B_0 in the respective sample at any time over the 35-year projected period.

The level of escapement is calculated as the proportion of samples from the Bayesian posterior where the projected future status of the spawning biomass was below 60% of B_0 in the respective sample at the end of the 35-year projection period.

Also, while the CCAMLR decision rules set the target spawning stock biomass for toothfish at 50% B0, with no more than a 50% probability of being below 50% B0, and no more than a 10% probability of being below 20% B0 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), the decision rules in the French EEZ are even more precautionary by setting the target spawning stock biomass for toothfish at 60% B0 and not 50%.

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Additional Resources

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