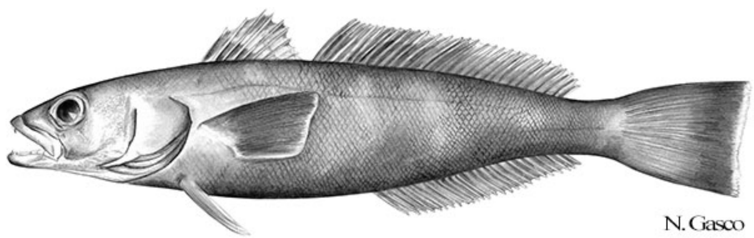
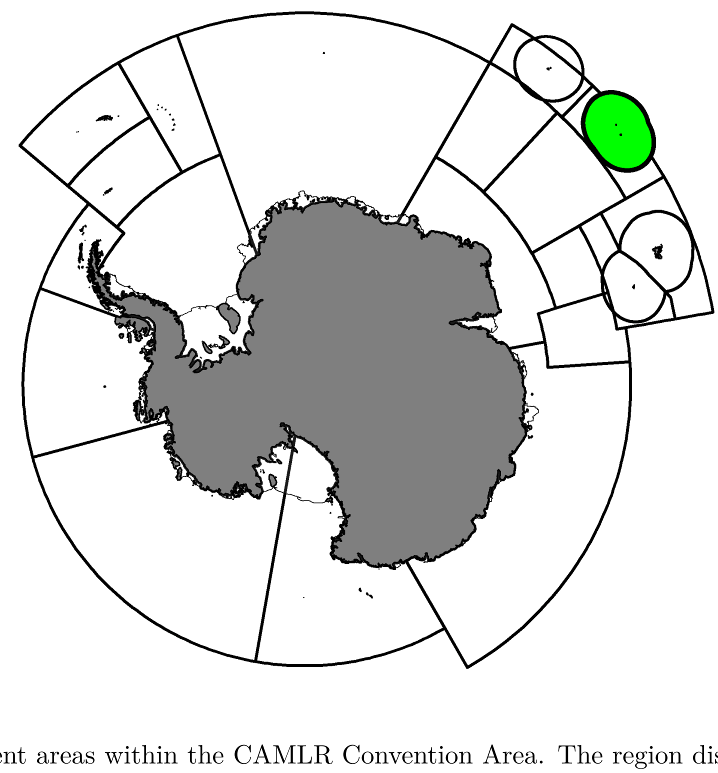
Stock Annex 2023: *Dissostichus eleginoides* at Crozet Island French EEZ (Subarea 58.6)

CCAMLR Secretariat

16 February 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.

CCAMLR

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Commission pour la conservation de la faune et la flore marines de l'Antarctique
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Stock Annex for the 2023 assessment of the Patagonian toothfish (Dissostichus elegenoides) population of the Crozet Islands EEZ in Division 58.6.

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Stock Annex for the 2023 assessment of the Patagonian toothfish (*Dissostichus elegenoides*) population of the Crozet Islands EEZ in Division 58.6.

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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 Crozet islands are located in the Southern Indian Ocean. They are located in CCAMLR Division 58.6 which covers the French Exclusive Economic Zones (EEZ) around Crozet islands.

1.2 Fishery

The licensed longline fishery for Patagonian toothfish (Dissostichus eleginoides) in the French exclusive economic zone (EEZ) was established in 1978 around the Crozet Island, which includes a portion of Subarea 58.6 and extends into FAO Area 51 (north of 45∘∘S), outside the CAMLR Convention Area.

Trawl fishing was conducted by Japanese vessels prior to 1979 and by French vessels from 1983 to 1996 and in 2000. It has since been discontinued. A joint survey between France and Japan first conducted longline fishing in Subarea 58.6 in 1997, and this method has been used in the fishery since then.

The fishery is open year-round, but most fishing effort takes place in February and March when the fishery in the French EEZ at the Kerguelen Islands (Division 58.5.1) is closed. Fishing effort in this area concentrates on the Crozet shelf slope and on the eastern part of the del Cano Rise. The fishery is also characterized by a high level of catch depredation (Tixier et al., 2010) by killer whales (Orcinus orca).

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 two longliner in a statistical sector (0.5°lat x 1°long) at a time.

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 1st of September to 31st of 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 Crozet, various national conservation and fisheries enforcement measures are applicable, such as:

- Annual catch limit set triennially since 2019
- 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 1977-2022.

Before 1997, the French trawler "Austral" operated occasionally in the Crozet area. The overall catch of the trawler during the entire period sums up to 1 137 tons. The longline fishery started in 1996/97 with a foreign longliner "Anyo-Maru 22" during a joint Japanese/French survey. A national longline fishery has been operating every year since 1997. A trap experiment (ORCASAV program) was conducted in 2010 with a chartered vessel "Austral Leader 2".

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

Killer and sperm whale are responsible for catch removals during the fishing operations. To account for this extra mortality, catch data are 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

However, substantial IUU longline fishing occurred in the French EEZ (1996-2004) (Duhamel, 2003) and also in its whereabouts. There hasn't been IUU fishing since 2004. Yearly estimations of related catches are partially available and allow implementing illegal catches in the models.

2.3 Other sources of mortality

Since 2007, observers systematically note the presence and numbers of killer and sperm whale during the hauling of the line.

With a depredation rate estimated between 50% and 30% during the period 2003 - 2020 (see CCAMLR fishery report 2018), they are responsible for important catch removals during the fishing operations. To account for this extra mortality, catch data is revised with a depredation rate and are included as the overall fish removal in the model (Gasco et al.,2016).

The depredation rate used in projection is the average of the five most recent years estimates, i.e. 36% of the catches (Figure 1).

The methodology used is described in Tixier et al, 2020 and is based on generalized additive model.

$$CPUE_i = \exp(Year_{fi} + Vessel_{fi} + s(Depth_i) + s(lat_i, lon_i) + s(Month_i) + s(Soaking\ time_i) + s(NKillerWhales_i) + s(NSpermWhales_i)) + \varepsilon_i$$

$\varepsilon_i \sim N(0, \sigma^2)$

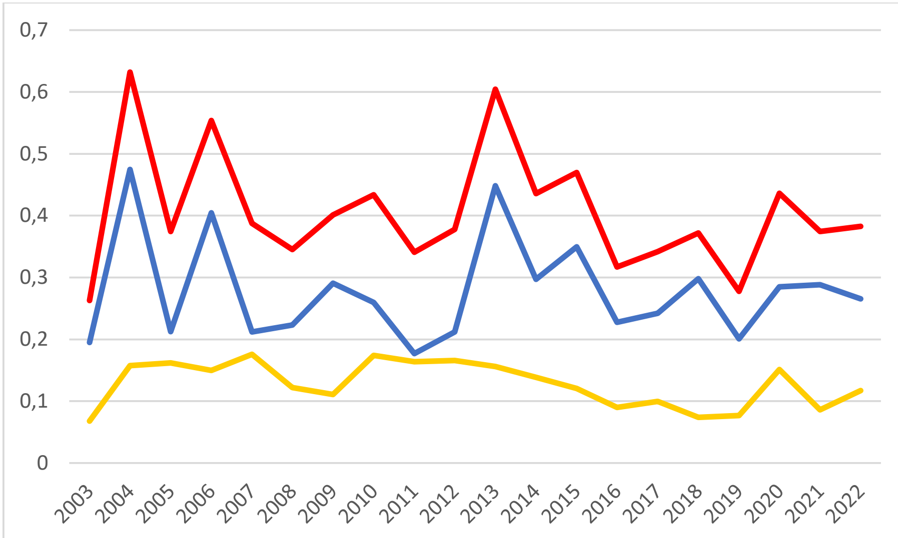

Figure 1: Time series of depredation rate (killer whales (blue line), sperm whales (yellow) and the overall in red) estimated in Crozet EEZ

The depredation by lice represents only 4;3 tons a year (figure 2). Even though it is negligible in this fishery, catches of fish unfit for consumption due to lice contamination have always been accounted for in the catches input of models. However, they were not accounted for in the catch limit (CL) calculation in the past. They are now integrated to the CL estimation process by removing the average of 3 last years from the CL.

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

The growth parameters used in this stock are the same than the one used in Massiot-Granier et al. (2019) (Table 1).

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

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 ensure that 5 fish will be aged per 5 cm class and the second two years 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 commercial catch were calculated from age-length samples (Figures 3 and 4).

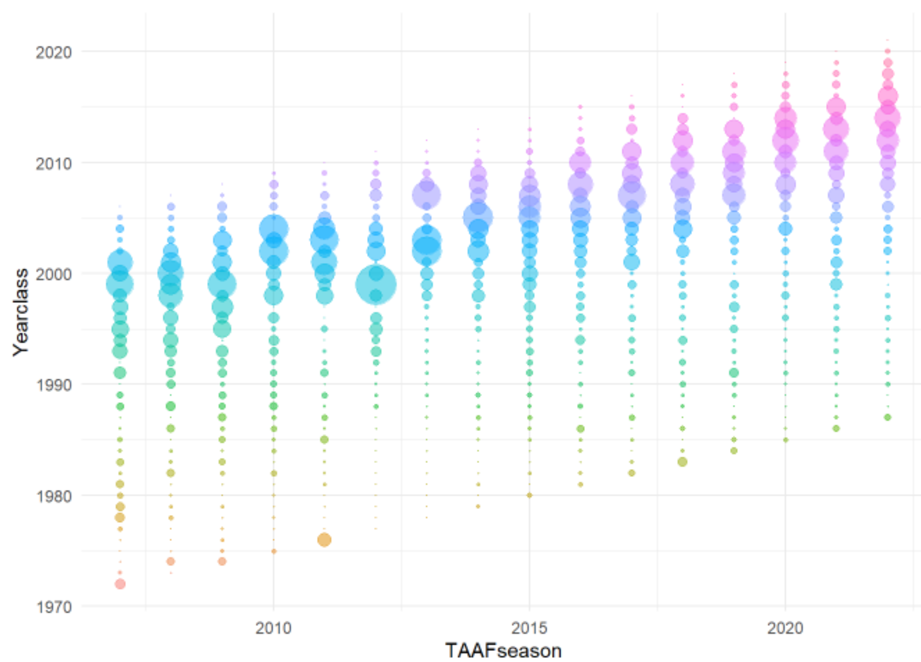

Figure 2: Bubble Plot of Yearclass of West catch

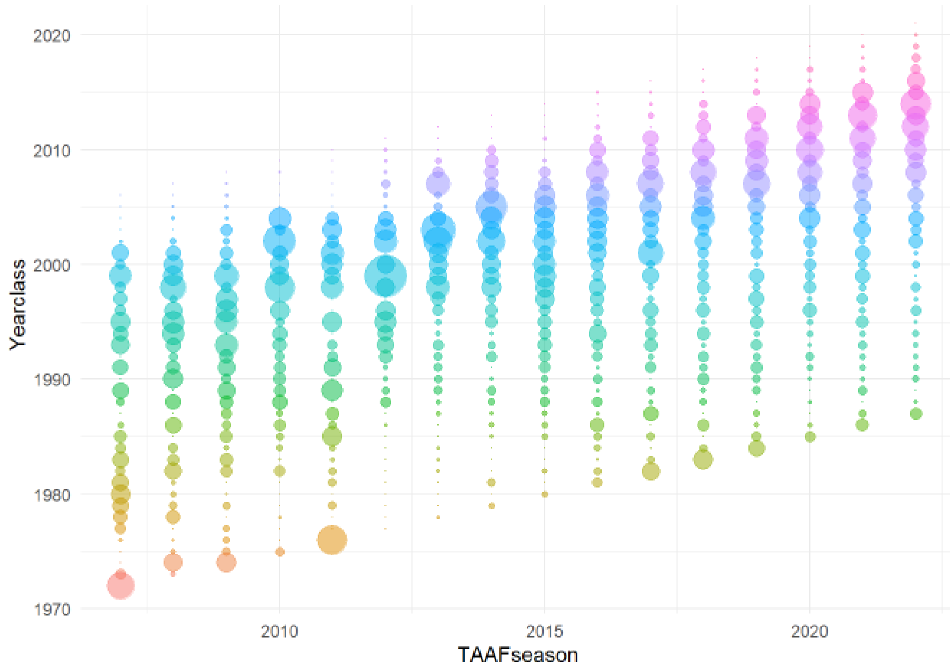

Figure 3: Bubble Plot of Yearclass of East catch

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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).

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

Stock recruitment	Beverton-Holt
Steepness h	H= 0.75
σ_R	0.89
Size-at-age	*Von Bertalanffy*
Linf	197 cm
K	0.039
t0	-2.3
CV	0.1
Weight at length L	a: $6.699e^{-9}$ b: 3.095
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

4 ASSESSMENT

4.1 Method

At Crozet, 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 1978 – 2022 with fishing seasons starting the 1rt of September and ending the 31st 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.

4.1.1 Model estimation procedure

The models estimate unfished spawning biomass SSB_0, annual year class strength (YCS) and the parameters of the selectivity functions for sub-fisheries. 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.

4.1.1.1 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.

4.1.1.2 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).

4.1.2 Commercial fishery and fleet structure

Fishing hauls may show similarities that are caused by gear specifities, seabed structure, depth and fish availability. Hauls with analogous distribution of catch-at-age and length distributions were 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 group, (2) a longliner group for the Del Cano rise area (western part of the EEZ) and (3) a longliner group for the Crozet plateau (eastern part of the EEZ).

4.1.3 Selectivity function

The selectivity function used in the last assessment is a double-normal capped (DNC) fitted for each sub-fishery (Table 2). The DNC function is calculated as f(x) for age x (Bull et al. 2012):

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

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 $(a = a1 - \sigma_L$ *and* $a = a1 + a2 + \sigma_R)$. 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.

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	55000	Uniform-log	35000	75000
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

4.2 Tag-release and recapture 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 ranged from 433 to 1 389 fish every year (Table 3). A new R routine that identifies misreporting and tag loss was developed to ensure an improved match of released and recaptured fish. >95% of the tags recaptured could be matched to their released 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.

Table 3 : Numbers of longline tag-release and tag recaptured Patagonian toothfish in division 58.5.1 from 2007 and 2022.

Releases		Recaptures																
Years	**Numbers**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
2006	1252	14	5	17	14	8	12	2	0	0	0	0	0	0	0	0	0	72
2007	433		7	8	3	3	1	0	2	0	0	0	0	0	0	0	0	24
2008	589			21	8	7	1	7	3	2	2	0	0	0	0	0	0	51
2009	622				18	11	6	10	7	3	1	4	0	0	0	0	0	60
2010	617					6	3	5	3	4	3	4	1	0	0	0	0	29
2011	697						14	7	3	2	3	3	0	1	0	0	0	33
2012	649							18	8	10	4	0	0	0	1	0	0	41
2013	704								24	13	10	9	1	3	1	1	0	62
2014	744									21	21	11	9	3	0	1	1	67
2015	920										21	19	3	9	7	3	2	64
2016	1082											32	34	19	5	8	4	102
2017	1389												29	32	14	16	5	96
2018	1143													24	18	22	9	73
2019	969														15	15	11	41
2020	861															22	20	42
2021	851																25	25
Total	13522	14	12	46	43	35	37	49	50	55	65	82	77	91	61	88	77	**882**

4.3 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. 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.

4.4 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% SSB_0, with no more than a 50% probability of being below 50% SSB_0, and no more than a 10% probability of being below 20% SSB_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), the decision rules in the French EEZ are even more precautionary by setting the target spawning stock biomass for toothfish at 60% SSB_0 and not 50%.

5 REFERENCES

Bull B., Francis R.I.C.C., Dunn A., McKenzie A., Gilbert D.J., Smith M.H. & Bian R. (2008). CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.20 - 2008/02/14. NIWA Technical Report 130.275 pp.

Burch P., Ziegler P.E., Welsford D.C. and C. Péron (2017) Estimation and correction of bias caused by fish immigration and emigration in a tag-based stock assessment. Document WG-SAM-17/11, CCAMLR, Hobart, Australia.

Candy S.G., Welford D.C., Lamb T., Verdouw J.J. & Hutchins J.J. (2011). Estimation of natural mortality for the Patagonian toothfish at Heard and McDonald islands using catch-at-age and aged mark-recapture data from the main trawl ground. CCAMLR Science 18: 29-46.

CCAMLR 2020. *Dissostichus eleginoides* Crozet Island French EEZ (Subarea 58.6), Fishery Report.

Constable, A.J.;DeLaMare, W.K.;Agnew, D.J.;Everson, I.;Miller ,D.,2000. Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). ICES Journal of Marine Science 57,778–791.

Collins, M.A., Ross, K.A., Belchier, M., Reid, K., 2007. Distribution and diet of juvenile Patagonian toothfish on the South Georgia and Shag Rocks shelves (SouthernOcean).

Duhamel G. (1987). Ichtyofaune des secteurs indien occidental et atlantique oriental de l'océan austral : biogéographie, cycles biologiques et dynamique des populations. Thèse de doctorat d'Etat ès Sciences Naturelles. Université Pierre et Marie Curie (Paris 6).

Duhamel, G. (2003). La Légine, pêcherie conflictuelle. Pêche légale et braconnage organisé. Cas du secteur indien de l'océan Austral : 177-187. *In :* Exploitation et surexploitation des ressources marines vivantes. Rapport sur la Science et la Technologie n°17. Académie des Sciences éditions Tec & Doc Lavoisier Paris : 503 pp.

Duhamel G., Pruvost P., Bertignac M., Gasco N. & Hautecoeur M. 2011. **-** Major fisheries events in the Kerguelen Islands: *Notothenia rossii*, *Champsocephalus gunnari*, *Dissostichus eleginoides*. Current distribution and status of stocks: 275-286. *in*: The Kerguelen Plateau: marine ecosystem and fisheries. (Duhamel G. & Welsford D. eds). Paris, Société française d'ichtyologie: 304 pp.

Duhamel G**.** & Williams R. 2011. **-** History of whaling, sealing, fishery and aquaculture trials in the area of the Kerguelen Plateau: 15-28. *in*: The Kerguelen Plateau: marine ecosystem and fisheries. (Duhamel G. & Welsford D. eds). Paris, Société française d'ichtyologie: 304 pp.

Duhamel, G., Péron, C., Sinègre, R., Chazeau, C., and Gasco, N. (2019). "Important readjustments in the biomass and distribution of groundfish species in the northern part of the Kerguelen plateau and skiff bank," in Proceedings of the Second Symposium on The Kerguelen Plateau: Marine Ecosystem and Fisheries, eds D. Welsford, J. Dell, and G. Duhamel (Hobart, TAS: CCAMLR), 135–184.

Gasco N., Tixier P., Duhamel G. and Guinet C. (2016). Update on Patagonian toothfish (Dissostichus eleginoides) losses in the bottom longline fishery due to the depredation by killer whales and sperm whales off the Kerguelen and Crozet Islands. CCAMLR, WG-FSA Meeting, Hobart, Australia, WG-FSA-16/10.

Péron, C., Welsford, D.C., Ziegler, P., Lamb, T.D., Gasco, N., Chazeau, C., Sinègre, R., Duhamel, G., 2016. Modelling spatial distribution of Patagonian toothfish through life-stages and sex and its implications for the fishery on the Kerguelen Plateau. Prog. Oceanogr. 141, 81–95. https://doi.org/10.1016/j.pocean.2015.12.003

Sinègre R. & Duhamel G., (2015). Updated Stock assessment of Patagonian toothfish (*Dissostichus eleginoides*) in the vicinity of the Crozet Islands (sub-area 58.6). CCAMLR, WG-FSA Meeting, Hobart, Australia, WG-FSA-15/69.

Sinègre R., Lecomte J.B. & Duhamel G., (2017). Updated stock assessment of Patagonian toothfish (*Dissostichus eleginoides*) in the vicinity of Kerguelen Islands (sub-area 58.6).CCAMLR, WG-FSA Meeting, Hobart, Australia, WG-FSA-17/60.

Tixier, P., Burch, P., Massiot-Granier, F., Ziegler, P., Welsford, D., Lea, M.-A., Hindell, M.A., Guinet, C., Wotherspoon, S., Gasco, N., Péron, C., Duhamel, G., Arangio, R., Tascheri, R., Somhlaba, S., Arnould, J.P.Y., 2020. Assessing the impact of toothed whale depredation on socio-ecosystems and fishery management in wide-ranging subantarctic fisheries. Rev. Fish Biol. Fish. 30, 203–217.

Toomey L, Welsford D, Appleyard SA, Polanowski A, Faux C, Deagle BE, Belchier M, Marthick J, Jarman S. 2016. Genetic structure of Patagonian toothfish populations from otolith DNA. Antarctic Science 28:347–360 DOI 10.1017/S0954102016000183.

Ziegler P. (2019) Population structure of Patagonian toothfish (Dissostichus eleginoides) on the Kerguelen Plateau and consequences for the fishery in SIOFA Statistical Area 7. Document SERAWG-01/08, Southern Indian Ocean Fisheries Agreement (SIOFA/APSOI), La Réunion.

Ziegler, P., Burch, P., Péron, C., Welsford, D., Farmer, B., Yates, P., Potts, J., Woodcock, E., Barnes, T., Duhamel, G., 2021. Development of robust assessment methods and harvest strategies for spatially complex, multi-jurisdictional Toothfish fisheries in the Southern Ocean. Fisheries Research and Development Corporation Project No 2013/013

Additional Resources

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