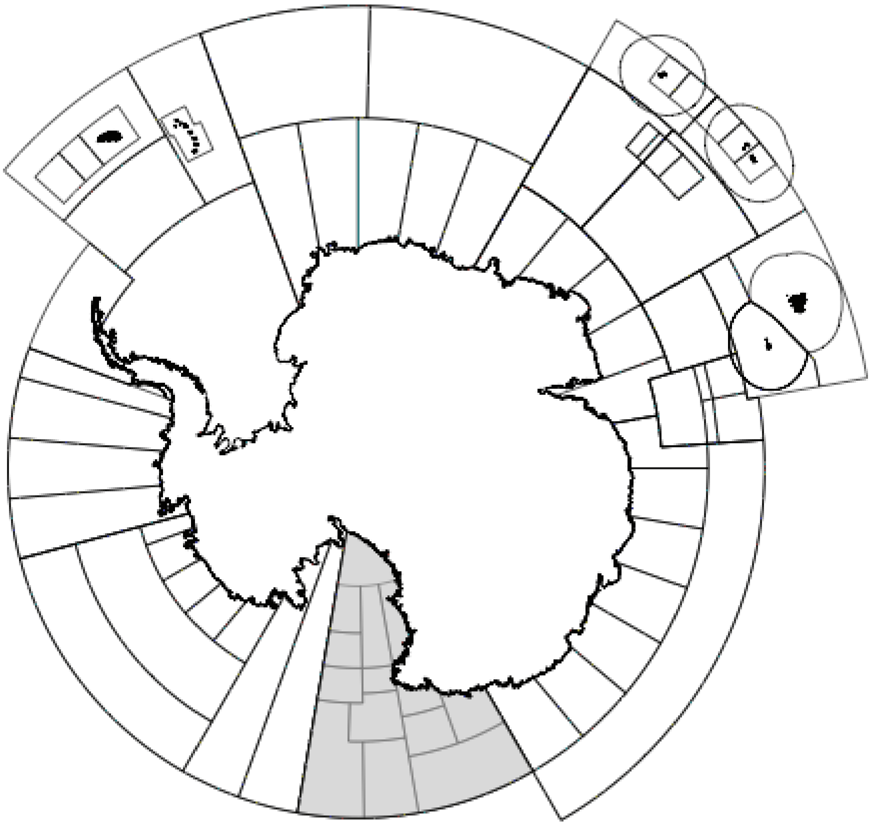
Commission for the Conservation of Antarctic Marine Living Resources
Commission pour la conservation de la faune et la flore marines de l'Antarctique
Комиссия по сохранению морских живых ресурсов Антарктики
Comisión para la Conservación de los Recursos Vivos Marinos Antárticos

FISHERY REPORT

Fishery Report 2018: Exploratory fishery for *Dissostichus mawsoni* in Subarea 88.1



The map above shows the management areas within the CAMLR Convention Area, the specific region related to this report is shaded.
Throughout this report the CCAMLR fishing season is represented by the year in which that season ended, e.g. 2015 represents the 2014/15 CCAMLR fishing season (from 1 December 2014 to 30 November 2015).

Fishery Report 2018: Exploratory fishery for *Dissostichus mawsoni* in Subarea 88.1

Introduction to the fishery

1. This report describes the exploratory longline fishery for Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 88.1. Prior to 2017, this fishery was an exploratory fishery for *Dissostichus* spp., however, in order to better align the target species with the assessment process, the target species was specified as *D. mawsoni*, with any Patagonian toothfish (*D. eleginoides*) caught counting towards the catch limit for *D. mawsoni.*

2. The distribution of catch limits to the small-scale research units (SSRUs) in Subareas 88.1 and 88.2 was part of an experiment starting in 2006 when the SSRUs between 150°E and 170°E (881A, D, E, F) and between 170°W and 150°W (882A–B) were closed to fishing to ensure that effort was retained in the area of the experiment (SC-CAMLR-XXIV, paragraphs 4.163 to 4.166). SSRU 881M was defined and closed to fishing in 2009 to protect the likely toothfish migration corridor in the western Ross Sea and Terra Nova Bay (SC-CAMLR-XXVII, paragraphs 4.160 and 4.161).

3. For the purposes of stock assessment, Subareas 88.1 and 88.2 are split into two areas: (i) Subarea 88.1 and SSRUs 882A–B (referred to as the Ross Sea region for the purpose of describing the assessment and the data used therein, this is also the area that is the subject of this report) and (ii) SSRUs 882C–H (referred to as Subarea 88.2).

4. The limits on the exploratory fishery for *D. mawsoni* in Subarea 88.1 in 2017 are described in Conservation Measure (CM) 41-09. To assist administration of the fishery, the catch limits for SSRUs 881B, C and G were combined into a 'north' region (881B, C, G), those for SSRUs 881H, I and K were combined into a 'slope' region (881H, I, K) and those for SSRUs 881J and L into a 'shelf' region (881J, L). After 1 December 2017, at which time the Ross Sea region marine protected area (MPA) came into force (see CM 91-05), the regions to which catch limits apply were modified to all areas outside the Ross Sea region MPA and north of 70°S (N70), all areas outside the Ross Sea region MPA and south of 70°S (S70), the Special Research Zone (SRZ). The MPA comprises General Protection Zones (GPZ) with three separate areas (i, ii, iii), the SRZ and a Krill Research Zone (KRZ) see (Figure 1).

5. These 'administrative' boundaries are used for the management of the fishery, however, the allocation of catches to these regions in the assessment process uses a tree-based regression based on the median length of fish in each longline set, and the explanatory variables SSRU and depth. The catch histories in Table 1 are based on subareas so that catches in SSRUs 882A−B are reported from that subarea, whereas in the catch history for the assessment, these catches are included in the Ross Sea region to better correspond to the presumed geographical distribution of the Ross Sea toothfish stock.

6. The precautionary catch limit in Subarea 88.1 in 2018 for *D. mawsoni* was 3 157 tonnes, and was allocated as follows: N70: 591 tonnes (19%), S70: 2 054 tonnes (65%); and SRZ: 467 tonnes and a research catch limit of 65 tonnes to enable the conduct of the Ross Sea shelf survey. The catch limits and regulation of by-catch were defined in CMs 33-03 and 41-09.

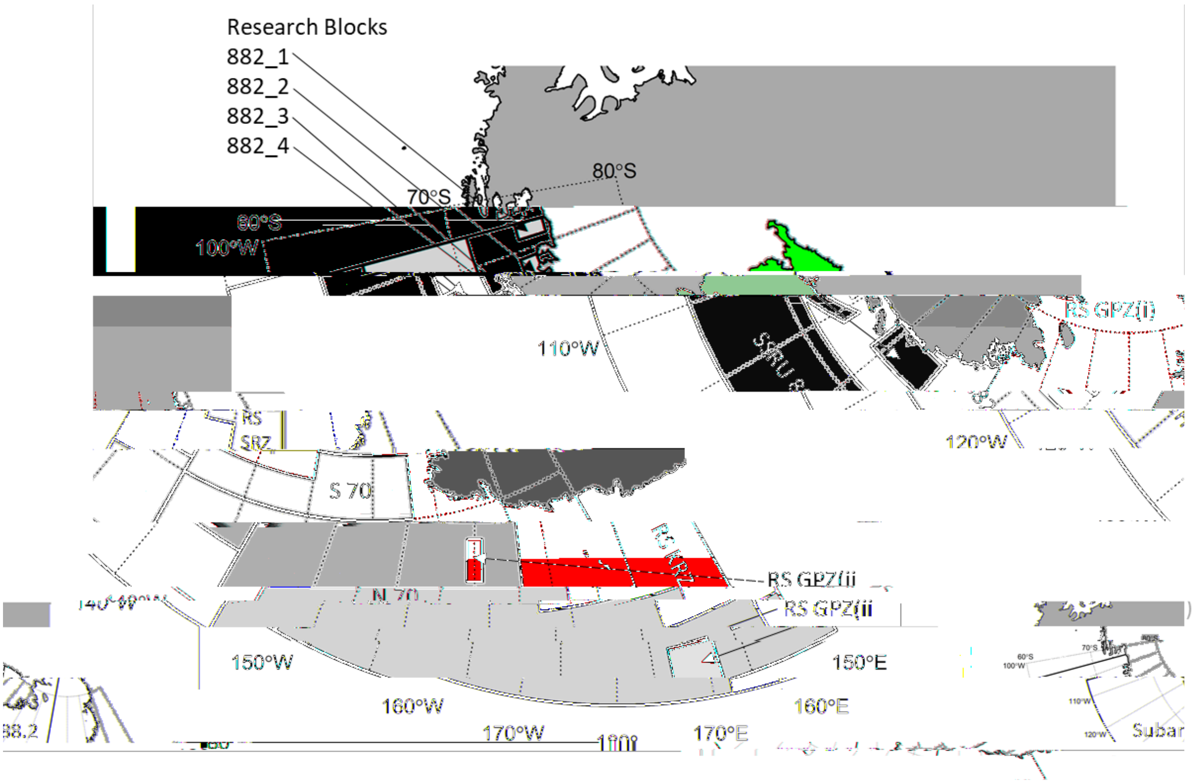


Figure 1: Fishery management areas and the Ross Sea region MPA (red) in Subareas 88.1 and 88.2.

Table 1: Catch history for *Dissostichus mawsoni* and *D. eleginoides* in Subarea 88.1. (Source: STATLANT data for past seasons, and catch and effort reports for the current season, past reports for IUU catch.)

Season	Subarea 88.1				
	Catch limit (tonnes)	Reported catch (tonnes)			Estimated IUU catch (tonnes)
		D. mawsoni	*D. eleginoides*	Total	
1997	1980	0	0	0	0
1998	1510	41	1	42	0
1999	2281	296	1	297	0
2000	2090	752	0	752	0
2001	2064	591	31	622	0
2002	2508	1314	12	1367	92
2003	3760	1769	26	1795	0
2004	3250	2165	12	2190	240
2005	3250	3061	7	3217	28
2006	2964	2950	1	2968	0
2007	3032[1]	3079	12	3091	0
2008	2700	2250	9	2259	272
2009	2700	2432	17	2449	0
2010	2850	2868	<1	2869	0
2011	2850	2793[q]	3	2850	*
2012	3282	3199	5	3214	*

(continued)

Table 1 (continued)

Season	Subarea 88.1				
	Catch limit (tonnes)	Reported catch (tonnes)			Estimated IUU catch (tonnes)
		D. mawsoni	*D. eleginoides*	Total	
2013	3282	3030[q]	<1	3187	*
2014	3044	2221[q]	4	2925	*
2015	2844[1]	2251[q]	1	2834	*
2016	2870	2678	5	2683	*
2017	2870	2820	1	2821	*
2018	3157	2680	<1	2826	*

[1] In 2015, the catch limit in CM 41-09 was discounted by 200 tonnes for research in SSRUs 882A–B and this catch was not included in the catch reports for Subarea 88.1.

* IUU catch levels not estimated; no evidence of IUU presence or activity reported.

[q] Some catch data in this year is quarantined. The following catch is not included in the reported catch table above:
2011 – vessel *In Sung No. 7*, 45 tonnes of *D. mawsoni*
2013 – vessel *Yantar 35*, 156 tonnes of *D. mawsoni*
2014 – vessel *Yantar 35*, 108 tonnes of *D. mawsoni*
2015 – vessel *Yantar 35*, 251 tonnes of *D. mawsoni*.

7. In 2018, 25 vessels (from ten Members) fished in Subarea 88.1. For 2018, nine Members with a total of 25 vessels notified their intention to participate in the exploratory fishery for *D. mawsoni* in Subarea 88.1.

8. The fishery in Subarea 88.1 saw a steady expansion of effort (number of sets) from 1998 to 2001, and an almost three-fold increase in 2004. Since 2005, effort has become more stable. In earlier years, most vessels fished with the autoline system, but these were joined by vessels fishing with Spanish lines and, more recently, trotlines. However, since 2015 autoline vessels again led the fishery by number and total catch. Although most SSRUs in Subareas 88.1 and 88.2 have been fished at some point in time, the proportion of effort in each SSRU has varied considerably each year in relation to the catch limits of the target and by-catch species and ice conditions. The two slope SSRUs, 881H and 881I, have been the most consistently fished SSRUs. In years with favourable ice conditions (2005, 2009, 2012−2014), fishing also extended into SSRU 881K.

9. The length of the fishing season in the Ross Sea fishery has contracted over time. In the first few years, the fishery was mainly carried out from January to March, and between 2001 and 2003 extended into April and May. More recently, fishing has started in early December and has usually finished in January or February depending on ice conditions.

10. Catches of *D. eleginoides* have mainly come from the northwest of the Ross Sea region in SSRUs 881A–C (WG-FSA-13/48). Catches were quite high in the early part of the fishery, particularly in 2001, but have been relatively low since then as fishing occurred in more easterly areas. The catch rates for *D. eleginoide*s have been much higher in SSRU 881A than the other SSRUs; this SSRU was closed to fishing from 2008–2017, and reopened in 2018 as part of the N70 area.

Reported catch

11. The catches of *D. mawsoni* and *D. eleginoides* from Subarea 88.1 are provided in Table 1. The catches reported from Subarea 88.1 include catch data from particular vessels that CCAMLR has agreed should be quarantined as there is no confidence in the amount and/or the location of those catches (SC-CAMLR-XXXIII, paragraph 3.68). Those seasons that include quarantined data are indicated with a superscript q and vessel-specific details are provided in the footnote to Table 1. All ancillary data associated with these vessels (e.g. by-catch, tagging, observer data) are also quarantined and not included in the data presented in this report.

12. In 2018, the total reported catch of *D. mawsoni* in Subarea 88.1 was 2 680 tonnes (98% of the catch limit of 3 178 tonnes) and the fishery closed on 14 January 2018. The following SSRUs were closed during the course of fishing:

- N70 closed on 23:59 2 December 2017, re-opened on 5 December and then closed on 6 December 2017, triggered by the catch of *D. mawsoni* and the total catch was 395 tonnes (67% of the catch limit of 591 tonnes)

- S70 closed on 14 January 2018, triggered by the catch of *D. mawsoni*, and the total catch was 2 054 tonnes (99% of the catch limit of 2 054 tonnes)

- SSRUs 881J, L closed on 22 December 2017, triggered by the closure of *D. mawsoni* and the total catch was 475 tonnes (77% of the catch limit of 467 tonnes).

13. In addition, 25 tonnes were taken from GPZ (i) in January 2018 during the Ross Sea shelf survey.

Illegal, unreported and unregulated (IUU) fishing

14. The estimated illegal, unreported and unregulated (IUU) catch in Subarea 88.1 was 240 tonnes in 2004, 28 tonnes in 2005 and 272 tonnes in 2008 (Table 1).

15. Following the recognition of methodological issues regarding the estimation of IUU catch levels since 2011, evidence of IUU presence or activity has continued to be recorded but no corresponding estimates of the IUU catch for *Dissostichus* spp. have been provided (SC-CAMLR-XXIX, paragraph 6.5). One IUU-listed fishing vessel was observed in Subarea 88.1 during 2008 and an unknown vessel sighting was reported in 2012. Information relating to the retrieval of unidentified fishing gear in Subarea 88.1 in 2017 was submitted by the Republic of Korea and provided to Members in COMM CIRC 17/100.

Sea-ice

16. The effect of sea-ice has a major influence on fishing operations in high latitudes. The major effects of sea-ice are firstly to restrict or deny access to preferred fishing grounds but of much more consequence, to hamper fishing operations, with resulting effects on catches and time spent on the grounds. An ice index developed for Subarea 88.1 provides a quantitative index of the influence of variable sea-ice conditions on the operation of a fishery at the

resolution of a season (WG-FSA-15/35). The index shows that 2015 was the third-most 'constraining' season, with 24% of the fishing grounds clear of ice, compared to 17% in 2001 and 18% in 2008 (Figure 2). In contrast, 2014 was considered a 'good' ice year with 71% of the fishing grounds clear of ice, as was 2011 at 81%. The sea-ice conditions in 2017 enabled the fishery to access most of the northern fishing grounds immediately on 1 December 2016, and after a short fishing period, then allowed access to fishing grounds on the Ross Sea slope. High catch rates in all areas then permitted vessels to reach the catch limit quickly.

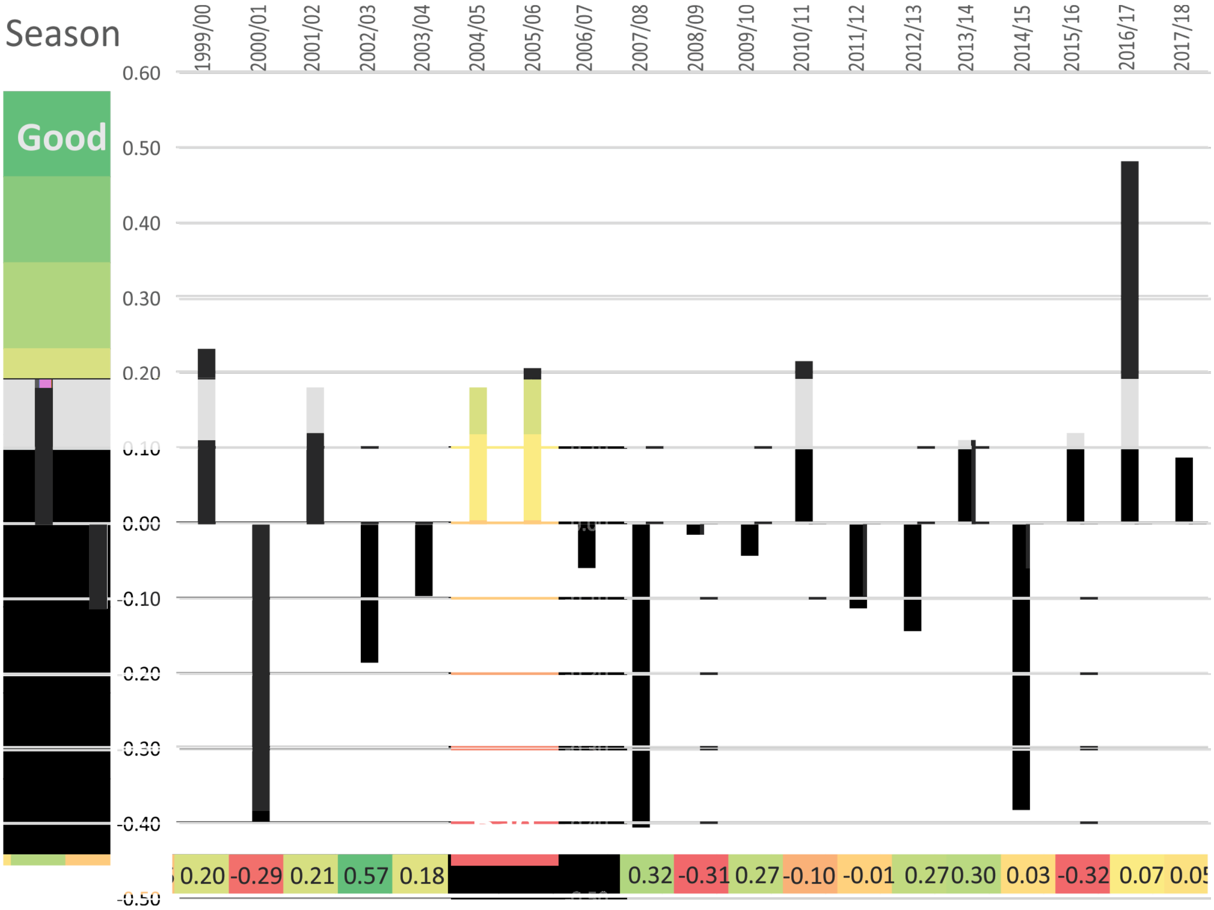


Figure 2: Ross Sea fishery ice index. The lower colour bar indicates the proportion of fishing grounds that were clear of ice in the subarea (updated from WG-FSA-17/07).

Data collection

17. Catch limits for *D. mawsoni* in Subarea 88.1 are set by CCAMLR using a fully integrated assessment. In Subarea 88.1, the integrated assessment is for *D. mawsoni* with catches of *D. eleginoides* included as part of the overall catch limits. Subareas 88.1 and 88.2 are managed under the umbrella of the exploratory fisheries CM 41-01 and, as such, have an associated data collection plan (Annex 41-01/A), a research plan (Annex 41-01/B) and a tagging program (Annex 41-01/C). The data collected under this conservation measure are described below. The medium-term research plan for this area is in Appendix 2.

Biological data

18. The collection of biological data under CM 23-05 is conducted as part of the CCAMLR Scheme of International Scientific Observation. In exploratory longline fisheries targeting *D. mawsoni* or *D. eleginoides*, biological data collection includes representative samples of length, weight, sex and maturity stage, as well as collection of otoliths for age determination of the target and most frequently taken by-catch species.

Length distributions of catches

19. The length-frequency distributions of *D. mawsoni* and *D. eleginoides* caught in this fishery from 2009 to 2018 are presented in Figures 3 and 4 respectively. These length-frequency distributions are unweighted (i.e. they have not been adjusted for factors such as the size of the catches from which they were collected). The interannual variability exhibited in the figures may reflect differences in the fished population but is also likely to reflect changes in the gear used, the number of vessels in the fishery and the spatial and temporal distribution of fishing.

20. The length-frequency distribution of the catches for *D. mawsoni* in this fishery ranged from 50 to 180 cm (Figure 3). In all seasons and areas, there has been a broad mode at about 120–170 cm. In most years, there has also been a mode of smaller fish, at 50–100 cm, caught on the Ross Sea shelf, but the length distribution of fish captured here is more variable between years due to less consistency of the spatial distribution of fishing.

21. The length-frequency distribution of the catches for *D. eleginoides* are sparse as in some years there are very few fish caught and/or measured; the length-frequency distributions for most years were relatively consistent (Figure 4).

Tagging

22. Under CM 41-01, each longline vessel fishing in exploratory fisheries for either *D. mawsoni* or *D. eleginoides* is required to tag and release toothfish at the rate of 1 fish per tonne of green weight caught throughout the season since 2004. In order to ensure that there is sufficient overlap between the length distribution of all fish caught and those fish that are tagged, a vessel is required to achieve a minimum tag-overlap statistic (see Annex 41-01/C, footnote 3). The requirement to achieve a minimum tag-overlap statistic of 50% was first introduced for 2011 and this was then increased to 60% for 2012 and subsequent seasons (Table 2). The number of toothfish tagged and recaptured are shown in Table 3.

23. Vessel-specific tag-detection rates and recapture rates were developed using a methodology which controls for the spatial and temporal variability of fishing operations by pairing each individual tag release or recapture event with all other fishing events which occurred in the same time and place (i.e. within a specific distance and in the same fishing season) (WG-SAM-14/30). The resulting indices were used to derive the effective tag releases and effective tag recaptures for each vessel in the tagging dataset used for the assessment model (WG-FSA-17/36). Both effective tagging survival rates and tag-detection rates have been variable but generally decreasing over time in the fishery, with catch-weighted effective survival rates at about 65% in the most recent years and effective tag-detection rates at about

85%. This decrease is due to the combination of changes in individual vessel performance over time and changes in relative contribution of vessels with lower rates; as such it may not indicate a decrease in rates for all vessels.

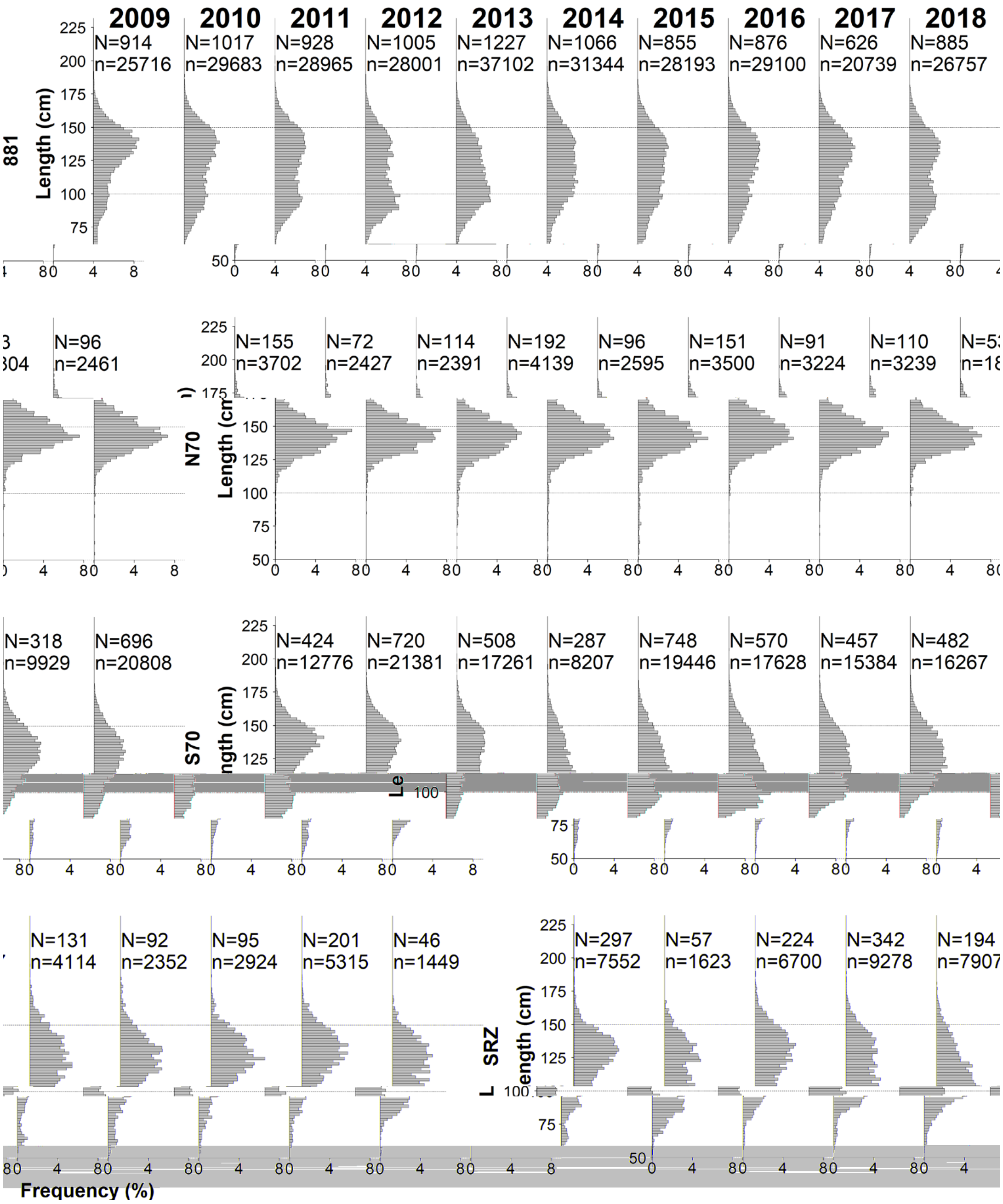


Figure 3: Annual length-frequency distributions of *Dissostichus mawsoni* caught in Subarea 88.1 (top panel) and in the three areas of the fishery (see paragraph 4) (lower panels). The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided.

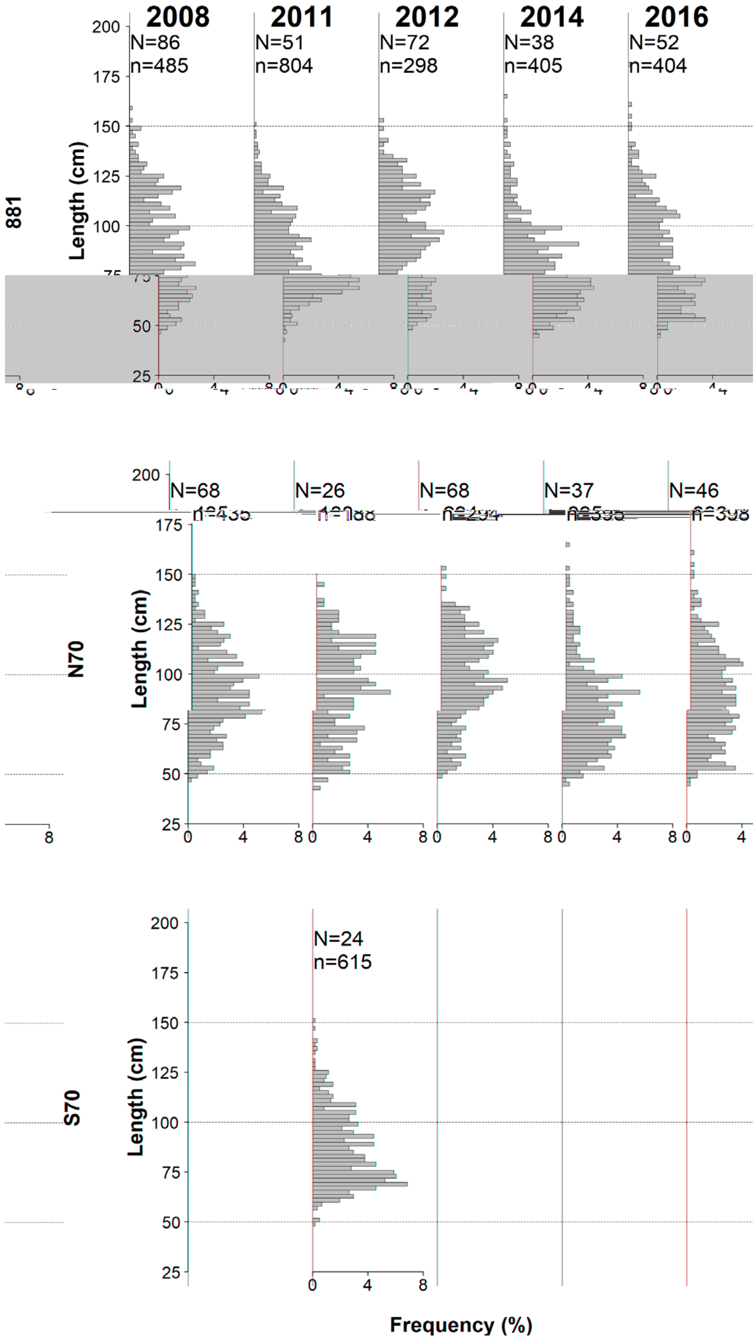


Figure 4: Annual length-frequency distributions of *Dissostichus eleginoides* caught in Subarea 88.1 (top panel) and three areas of the fishery (see paragraph 4) (lower panels) for those years in which >100 fish were measured. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided.

Table 2: Annual tagging rate, reported by vessel, operating in the exploratory fishery for *Dissostichus mawsoni* in Subarea 88.1 since 2010. The tag-overlap statistics (CM 41-01) for *D. mawsoni* and *D. eleginoides* respectively are provided in brackets. Values for the tag-overlap statistic are not calculated for catches of less than 10 tonnes (2010–2014) or less than 30 fish tagged (since 2015) (*). - indicates that no fish were tagged.

Flag State	Vessel name	Season								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
Argentina	*Argenova XXI*	1.1 (52, -)								
Australia	*Antarctic Discovery*								1.1 (81, *)	1.0 (86, -)
Korea, Republic of	*Greenstar*									1.1 (87, -)
	Hong Jin No. 701			1.3 (72, *)	1.1 (82, -)	1.1 (83, -)	1.1 (77, *)		1.1 (75, -)	1.1 (85, -)
	Hong Jin No. 707	1.1 (50, -)	1.1 (64, *)	1.0 (71, -)	1.0 (82, -)	1.1 (83, -)				
	Insung No. 1	1.1 (23, -)								
	Insung No. 3				1.5 (92, *)					
	Insung No. 5				1.6 (91, -)					
	Jung Woo No. 2	1.2 (26, -)	1.1 (93, -)	1.2 (91, *)						
	Jung Woo No. 3	1.1 (42, -)	1.0 (88, -)	1.2 (86, *)						
	Kingstar								1.1 (85, -)	
	Kostar				1.1 (94, -)	1.1 (78, -)	1.0 (82, -)	1.0 (80, -)	1.0 (82, -)	1.1 (83, -)
	Southern Ocean									1.1 (89,-)
	Sunstar				1.2 (85, -)	1.1 (76, -)	1.1 (72, -)	1.1 (87, -)	1.0 (87, -)	1.0 (81, -)
New Zealand	*Antarctic Chieftain*	1.0 (61, -)	1.0 (96, *)	1.2 (89, *)		1.1 (74, -)				
	Janas	1.0 (79, -)	1.0 (85, *)	1.3 (81, *)	1.0 (91, *)	1.1 (88, *)	1.0 (82, *)	1.6 (92, *)	1.1 (90, -)	1.1 (78, -)
	San Aotea II	1.1 (79, *)	1.1 (88, *)	3.8 (87, *)	1.8 (80, *)	1.8 (88, *)	1.7 (86, *)	1.7 (86, *)	1.8 (87, -)	1.6 (82, -)
	San Aspiring	1.1 (88, *)	1.1 (90, *)	1.1 (92, *)	1.2 (93, *)	1.1 (91, *)	1.1 (93, *)	1.1 (88, *)	1.0 (90, -)	1.1 (75, -)
Norway	*Seljevaer*			1.0 (79, -)	1.1 (76, -)	1.0 (81, *)	1.1 (62, *)			
Russia	*Chio Maru No. 3*		1.4 (78, *)	1.0 (75, *)						
	Gold Gate		1.3 (88, *)							
	Mys Marii					1.1 (79, -)	1.0 (66, -)			
	Mys Velikan									1.0 (77, -)
	Ostrovka		1.0 (65, -)							
	Palmer					1.2 (83, -)	1.0 (80, -)	1.0 (70, *)	1.0 (73, -)	1.3 (80, -)
	Sparta		1.2 (63, -)	1.6 (*, *)	1.1 (*, -)	1.1 (72, -)			1.0 (*, -)	
	Ugulan				1.0 (74, *)	1.0 (78, *)			1.1 (77, -)	
	Yantar 31			1.2 (90, -)	1.1 (83, -)	1.0 (81, -)	1.0 (72, -)	1.1 (86, -)		
	Oladon 1							1.1 (85, -)		
Spain	*Tronio*	1.0 (69, -)	1.0 (69, *)	1.0 (69, -)	1.0 (90, *)	1.0 (77, -)	1.1 (80, *)	1.1 (90, -)	1.1 (70, -)	1.0 (84, -)
	Yanque							1.2 (79, *)		
UK	*Argos Froyanes*	1.0 (54, -)	1.1 (76, -)	1.3 (61, -)	1.0 (91, -)	1.0 (89, *)	1.1 (82, -)	1.1 (86, -)	1.0 (81, -)	1.2 (88, -)
	Argos Georgia	1.1 (47, -)	1.0 (68, -)	1.1 (90, *)	1.1 (78, *)	1.1 (80, -)	1.1 (92, -)	1.2 (84, -)	1.1 (90, -)	1.1 (85, -)

(continued)

Table 2 (continued)

Flag State	Vessel name	Season								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
Ukraine	*Calipso*									1.1 (87, -)
	Marigolds								1.0 (*, -)	1.1 (73, -)
	Poseydon I					1.0 (68, -)				
	Simeiz				1.2 (43, -)	1.1 (83, *)		1.0 (86, -)	1.0 (86, -)	1.3 (79, -)
Required tagging rate		1	1	1	1	1	1	1	1	

Table 3: The number of individuals of (a) *Dissostichus mawsoni* and (b) *D. eleginoides* tagged in each season in Subarea 88.1. The number of fish recaptured by each vessel is provided in brackets.

(a)

Flag State	Vessel name	Season								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
Argentina	*Argenova XXI*	33 (2)								
Australia	*Antarctic Discovery*								85 (2)	104 (36)
Korea, Republic of	*Greenstar*									333 (21)
	Hong Jin No. 701			106 (0)	209 (4)	270 (2)	235 (4)		39 (0)	34 (1)
	Hong Jin No. 707	368 (24)	224 (9)	456 (8)	291 (1)	405 (6)				
	Insung No. 1	313 (29)								
	Insung No. 3				249 (10)					
	Insung No. 5				427 (16)					
	Jung Woo No. 2	270 (3)	283 (0)	186 (3)						
	Jung Woo No. 3	185 (8)	157 (2)	236 (5)						
	Kingstar								276 (11)	
	Kostar				223 (1)	117 (1)	352 (2)	312 (15)	313 (15)	299 (17)
	Southern Ocean									64 (0)
	Sunstar				154 (4)	122 (1)	199 (6)	206 (7)	218 (4)	224 (15)
New Zealand	*Antarctic Chieftain*	164 (36)	238 (18)	127 (2)						
	Janas	415 (34)	172 (4)	168 (0)	130 (13)	150 (14)	105 (4)	338 (42)	206 (12)	99 (27)
	San Aotea II	288 (24)	321 (50)	289 (4)	348 (21)	354 (70)	299 (20)	412 (50)	457 (22)	338 (10)
	San Aspiring	513 (59)	199 (19)	527 (62)	243 (32)	307 (76)	193 (40)	408 (64)	298 (37)	300 (59)
Norway	*Seljevaer*			178 (14)	238 (53)	264 (55)	218 (27)			

(continued)

Table 3 (continued)

Flag State	Vessel name	Season								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
Russia	*Chio Maru No. 3*		196 (4)	201 (3)						
	Gold Gate		98 (1)							
	Mys Marii					21 (1)	44 (4)			
	Mys Velikan									82 (4)
	Ostrovka		18 (3)							
	Oladon 1							188 (3)		
	Palmer					54 (7)	68 (0)	336 (1)	279 (0)	476 (2)
	Sparta		110 (8)		7 (1)	28 (3)			31 (3)	
	Ugulan				41 (3)	49 (2)			81 (3)	
	Yantar 31			362 (7)	82 (8)	93 (0)	178 (1)	126 (5)		
Spain	*Tronio*	308 (23)	429 (12)	546 (8)	388 (12)	298 (22)	311 (20)	230 (18)	359 (30)	180 (24)
	Yanque							46 (7)		
UK	*Argos Froyanes*	158 (4)	332 (28)	38 (1)	183 (23)	220 (25)	239 (30)	70 (4)	230 (20)	147 (13)
	Argos Georgia	51 (2)	213 (48)	300 (13)	293 (10)	244 (22)	287 (26)	263 (37)	203 (25)	176 (28)
	Calipso									196 (1)
Ukraine	*Marigolds*								23 (5)	43 (7)
	Poseydon I					30 (2)				
	Simeiz				75 (1)	73 (4)		203 (4)	62 (1)	13 (1)
Total		3066 (248)	2990 (206)	3720 (130)	3747 (222)	3249 (322)	2997 (195)	3138 (257)	3160 (190)	3099 (266)

Table 3 (continued)

(b)

Flag State	Vessel name	Season								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
Korea, Republic of	*Hong Jin No. 701*			3 (6)						0 (1)
	Hong Jin No. 707		34 (5)	0 (1)			1 (0)			
	Insung No. 3				1 (0)					
	Jung Woo No. 2			0 (1)						
New Zealand	*Antarctic Chieftain*			1 (2)						
	Janas		0 (2)			4 (0)	3 (2)			
	San Aotea II		2 (0)	15 (4)		4 (4)	0 (1)	17 (1)		
	San Aspiring	2 (1)	3 (0)	1 (1)			1 (0)	2 (0)	0 (1)	
	Seljevaer						3 (2)			
Russia	*Chio Maru No. 3*			2 (1)						
	Gold Gate		1 (3)							
	Palmer							1 (0)	1 (0)	
	Sparta			2 (0)						
Spain	*Tronio*		1 (2)		1 (0)		2 (0)		2 (0)	
UK	*Argos Froyanes*					1 (0)				
	Argos Georgia	1 (0)		1 (0)	3 (1)					
	Argos Helena									
Ukraine	*Simeiz*					11 (1)				
Total		2 (2)	41 (12)	25 (16)	5 (1)	20 (5)	7 (4)	20 (1)	3 (1)	0 (1)

Life-history parameters

Stock structure

24. The current working hypothesis regarding spawning dynamics and early life history of *D. mawsoni* in Subareas 88.1 and 88.2 is described in Hanchet et al. (2008). A multidisciplinary approach incorporating otolith microchemistry, age data and Lagrangian particle simulations reached similar conclusions (Ashford et al., 2012). Under this hypothesis, spawning takes place to the north of the Antarctic continental slope, mainly on the ridges and banks of the Pacific–Antarctic Ridge (Hanchet et al., 2008). Spawning appears to take place during winter and may extend over a period of several months. Depending on the exact location of spawning, eggs and larvae become entrained by the Ross Sea gyres (a small clockwise rotating western gyre located around the Balleny Islands and a larger clockwise rotating eastern gyre covering the rest of Subareas 88.1 and 88.2), and may either move west settling out around the Balleny Islands and adjacent Antarctic continental shelf, or eastwards with the eastern Ross Sea gyre settling out along the continental slope and shelf to the east of the Ross Sea in Subarea 88.2 (WG-FSA-12/48). As the juveniles grow in size, they move west back towards the Ross Sea shelf and then move out into deeper water (>600 m). The fish gradually move deeper as they grow, feeding in the slope region in depths of 1 000–1 500 m, where they gain condition before moving north onto the Pacific–Antarctic Ridge to start the cycle again. Spawning fish may remain in the northern area for up to two or three years, although this pattern may be different for males versus females. They may then move southwards back onto the shelf and slope where productivity is higher and food is more plentiful and where they regain condition before spawning.

25. Analysis of the genetic diversity for *D. mawsoni* from Subareas 48.1 and 88.1 and Division 58.4.2 found weak genetic variation between the three areas (Smith and Gaffney, 2005). This differentiation is supported by oceanic gyres, which may act as juvenile retention systems, and by limited movement of tagged fish. Kuhn and Gaffney (2008) expanded the work of Smith and Gaffney (2005) by examining nuclear and mitochondrial single nucleotide polymorphisms on tissue samples collected from Subareas 48.1, 88.1 and 88.2 and Division 58.4.1. They found broadly similar results to those of the earlier studies, with some evidence for significant genetic differentiation between the three ocean sectors but limited evidence for differentiation within ocean sectors. A lack of differentiation between stocks has also been reported (Mugue et al., 2014).

26. *Dissostichus eleginoides* in Subarea 88.1 are clearly at the southern edge of their range, only extending into the northwest corner of Subarea 88.1 in significant numbers. The fishery catches very few small fish (<50 cm) and the origin of *D. eleginoides* in this area is unclear, although one *D. eleginoides* tagged at Macquarie Island was caught in SSRU 881B in 2007.

Parameter estimates

Standardised CPUE

27. Standardised catch-per-unit-effort (CPUE) analyses of *D. mawsoni* in the Ross Sea were updated for 2018 (WG-FSA-18/46). In 2006, it was concluded that the CPUE indices did not appear to be monitoring abundance of toothfish in the Ross Sea fishery (SC-CAMLR-XXV,

Annex 5, paragraph 5.58). In the 2018 update of the CPUE analyses, the individual year effects were quite variable but there was a general increasing trend to 2007 followed by a slight decreasing trend to 2014, followed by another increase to 2017 and a slight decrease in 2018. The trend in CPUE was variable among the north, slope and shelf fisheries, and is not considered to provide an index of population abundance.

Catch at age

28. Approximately 800 *D. mawsoni* otoliths collected by observers from New Zealand vessels have been selected for ageing each year, and used to construct annual area-specific age–length keys (ALKs). In the Ross Sea, annual ALKs for each sex were applied to the shelf/slope fisheries and the north fishery separately. The annual ALKs were applied to the scaled length-frequency distributions for each year to produce annual catch-at-age distributions (WG-FSA-18/46).

29. The mean age of the catch in the fishery has varied over time with no obvious trends (WG-FSA-18/46).

30. There has been a small increase in the proportion of males in the north, and to a much lesser extent on the slope and shelf, over time (WG-FSA-18/46) even after discounting the first two years' data (which are likely to be unrepresentative because fishing occurred mainly in shallow water in SSRU 881G).

Recruitment surveys

31. Annual research surveys of sub-adult (70–110 cm) toothfish have been carried out in the southern Ross Sea since 2011 (e.g. WG-FSA-12/41; WG-SAM-13/32; WG-FSA-14/51; WG-SAM-15/44; WG-SAM-16/14; WG-SAM-17/01 and WG-SAM-18/10) and incorporating the survey age structure into the assessment had the effect of stabilising the index of year-class strength (YCS) (WG-FSA-175/378).

Tag-recapture data

32. The tagging program in Subarea 88.1 has now exceeded 47 000 tagged fish released and 2 700 recaptured fish (WG-FSA-18/46). Tagging and recapture data used in the Ross Sea assessments (C2, observer and tagging databases) were processed and prepared for input into CASAL, as described in WG-FSA-17/36. These include effective tag releases and tag recaptures as detailed in paragraph 23.

Parameter values

33. Estimates of natural mortality, length–mass, growth and maturity parameters for *D. mawsoni* in Subarea 88.1 are given in Table 4.

Table 4: Parameter values for *Dissostichus mawsoni* for base-case models in Subarea 88.1.

Relationship	Parameter	Value	
		Male	Female
Natural mortality	M (y^{-1})	0.13	0.13
Von Bertalanffy	t_0 (y)	–0.256	0.021
	k (y^{-1})	0.093	0.090
	L_∞ (cm)	169.07	180.20
	c.v.	0.102	0.102
Length–weight	a (t cm^{-1})	1.387e-008	7.154e-009
	b	2.965	3.108
Age at maturity (y)	A_{50} ($\pm A_{to95}$)	11.99 (±5.25)	16.92 (±7.68)
Stock recruit steepness (Beverton-Holt)	h	0.75	
Recruitment variability	σ_R	0.6	
Ageing error (CV)	cv	0.1	
Initial tagging mortality		10%	
Initial tag loss (per tag)		3.3%	
Instantaneous tag loss rate (per tag)		0.062y^{-1}	
Tag detection rate		98.7%	
Tag related growth retardation		0.5 y	

34. To account for the 1.0% of *D. mawsoni* that were recaptured but could not be linked to a release event (WG-FSA-17/36), a tag-detection rate of 99% was assumed in the assessment models for the Ross Sea.

35. In the Ross Sea, the assessment is for *D. mawsoni* with catches of *D. eleginoides* included as part of the overall catch limits.

Model structure and assumptions

36. The Ross Sea (Subarea 88.1 and SSRUs 882A–B) fishery for *D. mawsoni* was assessed using a CASAL integrated stock assessment model (WG-FSA-17/37 Rev. 1 and 17/38).

37. The assessment for this fishery is conducted on a biennial basis, details of the assessment conducted in 2017 (for 2018 and 2019) are provided in Appendix 1.

Yield estimates

38. The constant catch for which there was median escapement of 50% of the median pre-exploitation spawning biomass level at the end of the 35-year projection period was between 3 234 and 3 258 tonnes depending on the assumed future catch split. At this yield, there is less than a 10% chance of spawning biomass dropping to less than 20% of the initial biomass. This yield is higher than the upper bound of that defined in CM 91-05, which states that 'the total catch limit shall be fixed at a level within the range of 2 583 to 3 157 tonnes per fishing season, based on advice from the Scientific Committee in 2017, 2018 and 2019' (CM 91-05, paragraph 28i).

39. Based on the outcome of the assessment presented in 2017, the precautionary catch limit for *D. mawsoni* for 2018 and 2019 was set at 3 157 tonnes.

Future research requirements

40. In 2017, the Working Group on Fish Stock Assessment (WG-FSA) supported the advice of the 2017 meeting of the Working Group on Statistics, Assessments and Modelling (WG-SAM) (SC-CAMLR-XXXVI, Annex 7, paragraph 3.86) and recommended that the Ross Sea shelf survey be continued and extended to strata in McMurdo Sound in 2018 and Terra Nova Bay in 2019 to contribute to the Ross Sea region MPA research and monitoring plan.

By-catch of fish and invertebrates

Fish by-catch

41. Catch limits for by-catch species groups (macrourids, rajids and other species) are defined in CM 41-09, paragraph 6, and in CM 33-03; these are also provided in Table 5. In 2018, a precautionary catch limit of 157 tonnes of skates and rays and 485 tonnes of *Macrourus* spp. had the following individual limits applied:

- N70 – 30 tonnes of skates and rays, 96 tonnes of *Macrourus* spp., 30 tonnes of other species

- S70 – 104 tonnes of skates and rays, 317 tonnes of *Macrourus* spp., 104 tonnes of other species

- SRZ of the Ross Sea region MPA – 23 tonnes of skates and rays, 72 tonnes of *Macrourus* spp., 23 tonnes of other species.

Catches of macrourids, rajids and 'Other' taxa are shown in Table 5.

Table 5: Catch history for by-catch species (macrourids, rajids and other species), catch limits and number of rajids released alive in Subarea 88.1. Catch limits are for the whole fishery (see CM 33-03 for details). (Source: fine-scale data.)

Season	Macrourids		Rajids			Other species	
	Catch limit (tonnes)	Reported catch (tonnes)	Catch limit (tonnes)	Reported catch landed dead (tonnes)	Number released	Catch limit (tonnes)	Reported catch (tonnes)
2004	520	319	163	23	1745	180	23
2005	520	462	163	69	5057	180	24
2006	474	258	148	5	14640	160	18
2007	485	153	152	38	7336	160	43
2008	426	112	133	4	7190	160	20
2009	430	183	135	7	7088	160	16
2010	430	119	142	8	6796	160	15
2011	430	189	142	4	5439	160	8
2012	430	143	164	1	2238	160	4
2013	430	125	164	4	5675	160	9
2014	430	127	152	2	5534	160	16
2015	430	87	152	5	12977	160	24
2016	430	90	152	7	6016	160	22
2017	430	66	143	4	3857	160	12
2018	485	76	157	8	5867	157	13

42. If the by-catch of any one species is equal to, or greater than, 1 tonne in any one haul or set, then the fishing vessel must move at least 5 n miles away for a period of at least five days.

43. If the catch of *Macrourus* spp. taken by a single vessel in any two 10-day periods in a single SSRU exceeds 1 500 kg in a 10-day period and exceeds 16% of the catch of *D. mawsoni* in that period, the vessel shall cease fishing in that SSRU for the remainder of the season.

44. Skates evaluated to have a good chance of survival (based on a skate condition guide) are released at the surface in accordance with CM 33-03. The current by-catch limits and move-on rules for rajids are given in CM 41-09.

45. Catches of non-target species groups (macrourids, rajids and other species), their respective catch limits and number of rajids cut from lines and released alive, are summarised for Subarea 88.1 in Table 5. The retained by-catch in Subarea 88.1 consists predominantly of macrourids with a maximum, over the past 10 years, of 462 tonnes (88% of the annual catch limit for that group) in 2005 (Table 5).

46. A characterisation of the by-catch (WG-FSA-12/42) showed that the three most frequently recorded 'other' by-catch species were icefish (mainly *Chionobathyscus dewitti*), eel cods (probably mainly *Muraenolepis evseenkoi*) and morid cods (mainly *Antimora rostrata*). The total catch for each of these species groups from 1998 to 2012 was 100, 102 and 97 tonnes respectively, and each formed about 0.3% of the total catch. Further details on the catch and biology of eel cods are summarised in WG-FSA-12/50.

Assessments of impacts on affected populations

47. The estimate of γ for *Macrourus* spp. in Subarea 88.1 in 2003 was 0.01439 for a coefficient of variation (CV) of 0.2 (SC-CAMLR-XXII, paragraph 4.132) or 0.01814 for a CV of 0.5 (SC-CAMLR-XXII, Annex 5, paragraph 5.242).

48. WG-FSA-08/32 provided biomass and yield estimates of *Macrourus* spp. for the Ross Sea fishery based on extrapolations under three different density assumptions from a trawl survey (Table 6). Yield estimates for macrourids were calculated using the constant density assumption when extrapolating the biomass estimate across the slope region, noting that this would provide a more precautionary estimate of yield than one based on extrapolations using longline CPUE data. The resulting biomass estimate was 21 401 tonnes with an estimated CV of 0.5, which gave a yield estimate of 388 tonnes. This yield estimate was then apportioned taking into account maximum historical catches. Yields per SSRU are detailed in Table 7. Existing move-on rules are retained, and macrourid by-catch limits and catches are expected to be reviewed on an annual basis.

Table 6: Biomass estimates of *Macrourus* spp. from the trawl surveys for the New Zealand BioRoss survey 400–600 and 600–800 m and IPY-CAML survey 600–1 200 and 1 200–2 000 m strata (bold numbers) and extrapolated biomass estimates (with CVs) for the remaining strata based on three methods of extrapolation.

Survey	Depth range (m)	Biomass (tonnes)	Extrapolated biomass (tonnes)					
			Constant density		CPUE (all vessels)		CPUE (New Zealand vessels)	
BioRoss – 881H	400–600	**230**	**230**	**(49)**	**230**	**(49)**	**230**	**(49)**
BioRoss – 881H	600–800	**3531**	**3531**	**(38)**	**3531**	**(38)**	**3531**	**(49)**
SSRU 881H west	800–1200		92	(50)	83	(54)	103	(55)
SSRU 881H west	1200–2000		713	(40)	1114	(49)	1038	(47)
IPY – 881H	600–1200	**975**	**975**	**(50)**	**975**	**(50)**	**975**	**(50)**
IPY – 881H	1200–2000	**3356**	**3356**	**(40)**	**3356**	**(40)**	**3356**	**(49)**
SSRU 881I	600–1200		3297	(50)	7883	(51)	5992	(50)
SSRU 881I	1200– 2000		4670	(40)	11168	(42)	8576	(41)
SSRU 881K	600–1200		1539	(50)	5027	(51)	2774	(51)
SSRU 881K	1200–2000		2998	(40)	5995	(45)	9111	(43)
SSRUs 882A–B	600–1200		1404	(50)	1396	(58)	857	(60)
SSRUs 882A–B	1200–2000		4087	(40)	525	(70)	-	
Total			26892	(29)	41823	(28)	36542	(30)

Table 7: Catch limits (tonnes) of grenadiers in Subarea 88.1 assuming a CV of 0.5 for the estimate of B_0 and that the grenadier density was constant across the entire slope (WG-FSA-08/32).

SSRU	Current catch limit	Estimated yield	Maximum historic catch	Proposed catch limit
881B, C, G	50	-	34	40
881H, I, K	271		390	320
881J	79	388	46	50
881L	24		6	20
882A–B	0	100	8	0
Total	424	488		430

49. In 2011, it was recognised that specimens originally identified in the Ross Sea region as Whitson's grenadier (*Macrourus whitsoni*) did in fact comprise two sympatric species: *M. whitsoni* and *M. caml* (McMillan et al., 2012). *Macrourus caml* grows larger than *M. whitsoni* and is about 20% heavier for a given length (Pinkerton et al., 2013). The two species can be distinguished morphologically through the number of rays in the left pelvic fin and the number of rows of teeth in the lower jaw. The distribution of *M. whitsoni* and *M. caml* seems to almost completely overlap by depth and area, with both appearing to be abundant in depths between 900 and 1 900 m. Catches of females of both species exceed that of males (especially for *M. caml*) and this sex selectivity cannot be explained by size or age of fish (Pinkerton et al., 2013). It is almost certain that previous work which was presumed to have been carried out on *M. whitsoni* would actually have been carried out on a mix of the two species.

50. Otolith aging data show that the two species have very different growth rates (Pinkerton et al., 2013). *Macrourus whitsoni* approaches full size at about 10–15 years of age and can live to at least 27 years, whereas *M. caml* reaches full size at about 15–20 years and can live in excess of 60 years. Sexual maturity in female *M. whitsoni* is reached at 52 cm and 16 years, but in female *M. caml* at 46 cm and 13 years. Gonad staging data imply that the spawning period of both species is protracted, extending from before December to after February. Work describing the distribution and ecology of each species is ongoing.

51. WG-SAM-07/04 presented data and a preliminary developmental model for Antarctic skates in SSRUs 881H, I, K of the Ross Sea. The developmental model attempted to create a catch history of all skates and rays in the Ross Sea, and integrate these data with the available observational data (including tag-recapture data) into a single integrated stock assessment model.

52. WG-FSA-10/25 provided a characterisation of skate catches in the Ross Sea region and concluded that aspects of the catch history were very uncertain, including the species composition, the weight and number of skates caught, the proportion discarded and the survival of those fish that were tagged. While the size composition of the commercial catch was uncertain before 2009 because of the low numbers sampled each year, data collected in the Year-of-the-Skate (2009) resulted in improved estimates of the length frequency of the catch. During the Year-of-the-Skate a total of about 3 300 georgian ray (*Amblyraja georgiana*) and 700 Eaton's skate (*Bathyraja* cf. *eatonii*) were tagged and a total of 179 skates recaptured.

53. WG-FSA-05/21 presented risk categorisation tables for *M. whitsoni* and *A. georgiana* which are the major by-catch species in Subarea 88.1 (SC-CAMLR-XXIV, Annex 5, Appendix N, Tables 5 and 6).

54. *Amblyraja georgiana* were categorised as risk category 3 (on a scale of 1 to 5). The risk to *A. georgiana* is potentially mitigated due to the requirement to cut rajids from longlines whilst still in the water and release them. *Macrourus whitsoni* were categorised as between risk category 2 and 3 but this did not take into account the presence of two different species of *Macrourus* in the Ross Sea region with potentially different risks.

Invertebrate by-catch including VME taxa

55. All Members are required to submit, within their general new (CM 21-01) and exploratory (CM 21-02) fisheries notifications, information on the known and anticipated impacts of their gear on vulnerable marine ecosystems (VMEs), including benthos and benthic communities such as seamounts, hydrothermal vents and cold-water corals. All of the VMEs in CCAMLR's VME Register are currently afforded protection through specific area closures.

56. Two registered VMEs and 59 VME Risk Areas have been identified in Subarea 88.1; none have been identified since 2015. The locations and other details can be found at www.ccamlr.org/node/85695.

Incidental mortality of seabirds and marine mammals

Incidental mortality

57. In 2014, a single mortality of a southern giant petrel (*Macronectes giganteus*) was observed in Subarea 88.1. This is the first reported bird mortality in Subarea 88.1 since 2004, and none have been reported since 2014. There have been no reports of incidental mammal mortalities since 2014.

58. The risk levels of birds in the fishery in Subarea 88.1 is category 1 (low) south of 65°S, category 3 (average) north of 65°S and overall is category 3 (SC-CAMLR-XXX, Annex 8, paragraph 8.1).

Mitigation measures

59. CM 25-02 applies to this subarea and, in addition to the specific mitigation measures in place, there is also a bird by-catch limit specified in CM 41-09. The discharge of offal or discards is prohibited in this subarea under CM 26-01.

Ecosystem implications and effects

60. Developments in evaluating ecosystem effects of the *D. mawsoni* fishery were discussed at the Fisheries Ecosystem Models in the Antarctic (FEMA) and FEMA2 Workshops (SC-CAMLR-XXVI/BG/06, paragraphs 45 to 48 and SC-CAMLR-XXVIII, Annex 4) and are summarised below, together with more recent developments.

61. Two key types of trophic interactions were identified as being potentially important for *D. mawsoni*. The first concerned the nature of the interaction between toothfish predators (e.g. Type C killer whales (*Orcinus orca*), sperm whales (*Physeter catodon*) and Weddell seals (*Leptonychotes weddellii*)) and toothfish. Results from the Ross Sea mass balance model suggest that, at the scale of the Ross Sea and averaged over a full annual cycle, toothfish only forms about 6–7% of the diet of its predators (Pinkerton et al., 2010). However, these estimates are premised on top-predator population estimates that are themselves uncertain, and the

consumption of toothfish in particular locations, at particular times of the year or by particular parts of the population, may be important to these predators, even though the total contribution of toothfish to the diet of the predator population in a year is relatively low.

62. The second key type of trophic interaction was between toothfish and its prey, in particular, demersal fish species. Results from the Ross Sea trophic model suggest that toothfish consumes 64% of the annual production of medium-sized demersal fish species (Pinkerton et al., 2010), and so a reduction of the toothfish population could have a substantial impact on the natural mortality of these species. Mixed trophic impact analysis (WG-EMM-12/53) suggests that the impact of toothfish on medium-sized demersal fish was the strongest negative (top–down) impact in the Ross Sea food web. The FEMA Workshop recognised the interaction with the fishery, whereby demersal fish are taken as by-catch, so that a reduction in natural mortality may be partially offset by an increase in fishing mortality.

63. In regard to spatial overlap, the FEMA2 Workshop examined information on foraging patterns of mammals and concluded that the available evidence suggests that the spatial overlap of Weddell seals and killer whales with the fishery is negligible. More recent work on diving depths of killer whales in the Ross Sea has shown that killer whales in the Ross Sea dive to much greater depths than was previously assumed (WG-EMM-13/29) but the majority of the fished area (i.e. over the Ross Sea slope and north) is still deeper than diveable depths.

64. WG-EMM-13/29 considered the available evidence regarding the importance of toothfish as prey for killer whales in the Ross Sea. Killer whales with toothfish in their mouths have been observed in McMurdo Sound (WG-EMM-14/52), but the proportion of toothfish consumed by killer whales in the Ross Sea in general is not known. The available data – on habitat overlap, stable isotopes, and a comparison between natural mortality rates of *D. mawsoni* in McMurdo Sound and potential consumption by killer whales – were limited and inconclusive. At present, the balance of evidence suggests that toothfish are likely to be significant in the diet of Type C killer whales in McMurdo Sound in summer, but it is not possible to say whether toothfish are an important prey item to Type C killer whales in other locations on the Ross Sea shelf or at the scale of the whole Ross Sea shelf and slope (WG-EMM-13/29). An important consideration for Type C killer whales, as for Weddell seals, is that toothfish, due to their large mass and high energy content, may be a unique food resource that is required to support periods of high energy demand such as lactation (WG-EMM-14/52).

65. The FEMA2 Workshop noted that the decision rule to estimate long-term precautionary yield for toothfish to satisfy Article II of the Convention (which relates to maintenance of ecological relationships between harvested, dependent and related species) is the proportion of spawning biomass permitted to escape the fishery to safeguard predators. This is set at 50% for the Ross Sea, as well as for other toothfish fisheries for which robust stock assessments are available. It also noted that the escapement level in the decision rule for the spawning biomass may need to be modified upwards if the size/age classes of *D. mawsoni* that are important prey for predators are reduced below a suitable escapement level for those classes.

66. WG-EMM-14/51 described the development of a spatially explicit minimum realistic model of demersal fish population dynamics, predator–prey interactions and fishery removals based on the spatial population model (SPM) for toothfish in the Ross Sea. The model includes *D. mawsoni* as well as macrourids and channichthyids, the two groups that make up ~50% of *D. mawsoni* prey. The model indicates that channichthyids, with a relatively high productivity, would be expected to substantially increase in abundance within fished locations as predation

pressure by toothfish is decreased, particularly in SSRU 881H where historical fishery removals have been most concentrated. Macrourids would be expected to show a modest increase in biomass based on their lower productivity.

67. WG-FSA-12/P04 provided an analysis of a McMurdo Sound vertical longline survey for *D. mawsoni*, which started in 1972, for which recent substantial reductions in the CPUE were attributed to the effects of the longline fishery in the Ross Sea. WG-FSA-12 considered that the apparent decline in toothfish CPUE at McMurdo Sound since 2001 was not consistent with data from the fishery. For example, the standardised catch rates from a research longline survey of pre-recruit toothfish (70–110 cm total length (TL)) in the southern Ross Sea in 2012 were similar to those made by the same vessel fishing in the area earlier in the fishery, between 1999 and 2003 (WG-FSA-12/41). However, it also agreed that a time series in McMurdo Sound could be a useful tool to monitor local toothfish abundance and ecology within McMurdo Sound and recommended it be continued.

68. WG-FSA-15/P01 provided results from a new monitoring program for *D. mawsoni* and other top predators carried out in McMurdo Sound in 2014. The results showed that toothfish catch rate, fish size and fish age in 2014 were similar to those observed prior to 2002. These results suggest that either large old fish have returned to McMurdo Sound following a temporary environmentally driven absence, or that they remained locally present but were not detected in the areas sampled. These findings highlight the importance of continued standardised monitoring for detecting the potential effects of fishing on the Ross Sea ecosystem, and a proposal for continued monitoring was provided in WG-FSA-15/33.

69. WG-FSA-12/P03 concluded that there had been changes in the mean number of killer whales per pod during the past decade at McMurdo Sound. WG-FSA-12 considered that this may also have been caused by local environmental effects.

Current conservation measures

70. The limits on the exploratory fishery for *D. mawsoni* in Subarea 88.1 in 2018 and 2019 are defined in CM 41-09: www.ccamlr.org/measure-41-09.

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2017 Stock assessment

A1. The Ross Sea (Subarea 88.1 and small-scale research units (SSRUs) 882A–B) fishery for Antarctic toothfish (*Dissostichus mawsoni*) was assessed using CASAL integrated stock assessment models.

A2. The stock assessment models were sex- and age-structured, with ages from 1 to 50 and the last age group was a plus group (i.e. an aggregate of all fish aged 50 and older). The annual cycle is given in Table A1.1. Five runs were carried out (WG-FSA-17/37 Rev. 1 and 17/38). A complete description of the CASAL modelling software was given in Bull et al., 2005.

Table A1.1: Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

Step	Period	Processes	M [1]	Age[2]	Observations	
					Description	M [3]
1	November–April	Recruitment and fishing mortality	0.5	0.0	Tag-recapture Catch-at-age proportions	0.5 0.5
2	May–November	Spawning	0.5	0.0		
3	-	Increment age	0.0	1.0		

1 M is the proportion of natural mortality that was assumed to have occurred in that time step.
2 Age is the age fraction, used for determining length at age, that was assumed to occur in that time step.
3 M is the proportion of the natural mortality in each time step that was assumed to have taken place at the time each observation was made.

A3. The Secretariat undertook a validation of the CASAL parameter files, maximum of the posterior density (MPD) estimates, and yield calculations for the Ross Sea model.

A4. The models were run from 1995 to 2017 for the Ross Sea, and were initialised assuming an equilibrium age structure at an unfished equilibrium biomass, i.e. a constant recruitment assumption. Recruitment was assumed to occur at the beginning of the first (summer) time step. Recruitment was assumed to be 50:50 male to female, with year-class strengths (YCS) estimated from 2003 to 2011.

A5. The Ross Sea model was implemented as a single-area three-fishery model. A single area was defined with the catch removed using three concurrent fisheries (slope, shelf and north). Each fishery was parameterised by a sex-based double-normal selectivity ogive (i.e. domed selectivity). The double-normal selectivity was parameterised using four estimable parameters and allowed for differences in maximum selectivity by sex – the maximum selectivity was fixed at one for males, but estimated for females. The double-normal selectivity ogive was employed as it allowed the estimation of a declining right-hand limb in the selectivity curve.

A6. Fishing mortality was applied only in the first (summer) time step. The process was to remove half of the natural mortality occurring in that time step, then apply the mortality from the fisheries instantaneously, then to remove the remaining half of the natural mortality.

A7. The population model structure includes tag-release and tag-recapture events. Here, the model replicated the basic age-sex structure described above for each tag-release event. The age and sex structure of the tag component was seeded by a tag-release event. Tagging was applied to a 'cohort' of fish simultaneously (i.e. the 'cohort' of fish that were tagged in a given year and time step). Tagging from each year was applied as a single tagging event. The usual population processes (natural mortality, fishing mortality etc.) were then applied over the tagged and untagged components of the model simultaneously. Tagged fish were assumed to suffer a retardation of growth from the effect of tagging, equal to 0.5 of a year.

Model estimation

A8. The model parameters were estimated using a Bayesian analysis, first by maximising[1] an objective function (MPD), which is the combination of the likelihoods from the data, prior expectations of the values of those parameters and penalties that constrain the parameterisations; and second, by estimating the Bayesian posterior distributions[2] using a Markov Chains Monte Carlo (MCMCs).

A9. Initial model fits were evaluated at the MPD by investigating model fits and residuals.

A10. Parameter uncertainty was estimated using MCMCs. These were estimated using a burn-in length of 5×10^5 iterations, with every 1 000th sample taken from the next 1×10^6 iterations (i.e. a final sample of length 1 000 was taken).

Observation assumptions

A11. The catch proportions-at-age data for the 1998–2015 seasons were fitted to the modelled proportions-at-age composition using a multinomial likelihood.

A12. Tag-release events were defined for the 2001–2014 seasons, and tag-recapture observations for the 2002–2015 seasons. Within-season recaptures and recaptures after more

1 Technically, this is done by minimising the negative log objective function.

2 The analysis produces point estimates of parameters, but this ignores uncertainty in their values. Other combinations of parameters may also be likely, though not necessarily as likely as the point estimates. Bayesian posterior distributions describe the likely distribution of the parameters, given the uncertainty in the observations and model. One way of finding these distributions is to search within the parameter space of all parameters, using a technique called Markov Chains Monte Carlo (MCMC). A useful analogy is a landscape in which the lowest point (the point estimate) is found by rolling a ball around the landscape (the parameter space). Then look around the landscape and find all the other places that, given the uncertainty about the measurements, might also be low. In a Bayesian analysis, the resulting distribution is referred to as a Bayesian posterior distribution.

than six years at liberty were ignored (WG-FSA-15/37). Tag-release events were assumed to have occurred at the end of the first (summer) time step, following all (summer) natural and fishing mortality.

A13. The tagging initial mortality (expressed as survival) rates and tag-detection rates were calculated as per the methods of Mormede (WG-SAM-14/30), recommended in 2014 by the Working Group on Statistics, Assessments and Modelling (WG-SAM) for use in the Ross Sea stock assessment (SC-CAMLR-XXXIII, Annex 5, paragraph 2.37). Tag-recapture events were assumed to occur at the end of the first (summer) time step, and were assumed to have a detection probability of 98.7% to account for unlinked tags.

A14. For each year, the recovered tags-at-length for each release event were fitted in 10 cm length classes (range 40–230 cm) using a binomial likelihood.

A15. The results of the Ross Sea shelf survey estimate of biomass and catch proportions-at-age data for the 2012–2017 seasons were fitted to the modelled survey estimate of biomass and proportions-at-age composition using binomial and multinomial likelihoods respectively.

Process error and data weighting

A16. Additional variance, assumed to arise from differences between model simplifications and real-world variation, was added to the sampling variance for all observations. Adding such additional errors to each observation type has two main effects: (i) it alters the relative weighting of each of the datasets (observations) used in the model, and (ii) it typically increases the overall uncertainty of the model, leading to wider credible bounds on the estimated and derived parameters.

A17. The additional variance, termed process error, was estimated for the base-case MPD run, and the total error assumed for each observation was calculated by adding process error and observation error following the methods of Francis (2011). A single process error was estimated for each of the observation types (i.e. one for the age data and one for the tag data).

Penalties

A18. Two types of penalties were included within the model. First, the penalty on the catch constrained the model from returning parameter estimates where the population biomass was such that the catch from an individual year would exceed the maximum exploitation rate (here, set equal to 0.999). Second, a tagging penalty discouraged population estimates that were too low to allow the correct number of fish to be tagged.

Priors

A19. The parameters estimated by the models, their priors, starting values for the minimisation and their bounds are given in Table A1.2. In models presented here, priors were chosen that were relatively non-informative but also encouraged lower estimates of B_0.

Table A1.2: Number (N), start values, priors and bounds for the free parameters.

Parameter		N	Start value	Prior	Bounds	
					Lower	Upper
B_0		1	80 000	Uniform-log	1×10^4	1×10^6
Male fishing selectivities	a_1		8.0	Uniform	1.0	50.0
	s_L		4.0	Uniform	1.0	50.0
	s_R	9	10.0	Uniform	1.0	500.0
Female fishing selectivities	a_{max}		1.0	Uniform	0.01	10.0
	a_1		8.0	Uniform	1.0	50.0
	s_L		4.0	Uniform	1.0	50.0
	s_R	12	10.0	Uniform	1.0	500.0
YCS	YCS	9	1.0	Lognormal	0.001	100.0
Survey biomass	cv	1	0.001	Uniform	0	10.0

Yield calculations

A20. Yield estimates were calculated by projecting the estimated current status for each model under a constant catch assumption, using the rules:

1. Choose a yield, γ_1, so 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).

2. Choose a yield, γ_2, so that the median escapement at the end of a 35-year period is 50% of the median pre-exploitation level.

3. Select the lower of γ_1 and γ_2 as the yield.

A21. The depletion probability was calculated as the proportion of samples from the Bayesian posterior where the predicted future spawning stock biomass (SSB) was below 20% of B_0 in any one year, for each year over a 35-year projected period.

A22. The level of escapement was calculated as the proportion of samples from the Bayesian posterior where the predicted future status of the SSB was below 50% of B_0 at the end of a 35-year projected period.

A23. Note that in applying the CCAMLR decision rules using CASAL, the pre-exploitation median SSB was replaced with the estimate of B_0 in each sample. This will result in a small downwards bias of the status of the stock in each trial and a small upwards bias in the probability of depletion. The effect of these biases will be a small downwards bias in the estimate of yield. The probability of depletion and the level of escapement were calculated by projecting forward for a period of 35 years, under a scenario of a constant annual catch (i.e. for the period 2016−2051) for each sample from the posterior distribution.

A24. Recruitment from 2013 to 2051 was assumed to be lognormally distributed with a standard deviation of 0.6 with a Beverton-Holt stock-recruitment steepness, $h = 0.75$.

A25. For the Ross Sea, future catch was assumed to follow the split between areas as that in Conservation Measure (CM) 91-05 (19%, 66% and 15% of the total future catch was allocated to north of 70°S, south of 70°S and the special research zone (SRZ) respectively).

Model estimates

Likelihood profiles

A26. The likelihood profiles for the Ross Sea base-case model are given in Figure A1.1 (the run labelled as R1 in WG-FSA-17/37 Rev. 1). The likelihood profiles were carried out by fixing B_0 at values across a range of plausible values (i.e. 40 000–150 000 tonnes), while estimating the remaining model parameters. The catch-at-age data and recaptures of tagged fish from 2001, 2003, 2012 and 2016 as well as survey age-frequency data suggested that very low biomass levels were less likely, whilst recaptures of tagged fish from 2002, 2004 and 2006 as well as age frequencies from fisheries suggested that high biomass estimates were less likely.

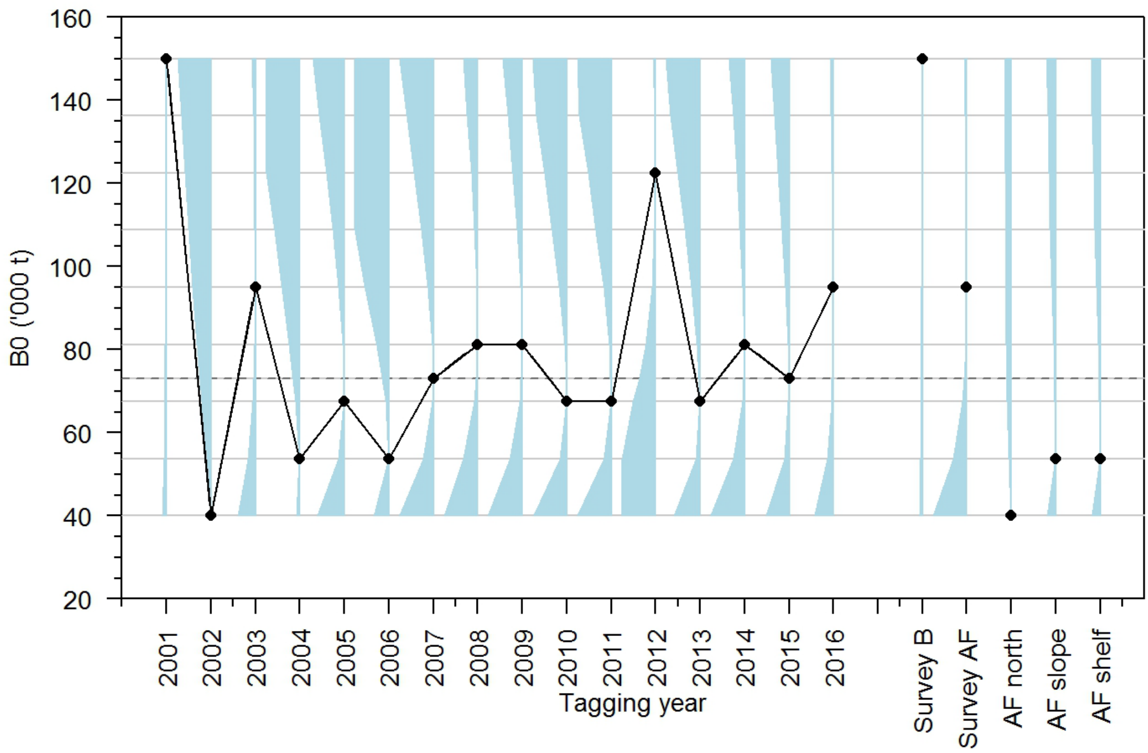

Figure A1.1: Likelihood profiles for B_0 for model R2. Negative log likelihood values rescaled to have minimum 0 for each dataset. The dashed line indicates the MPD value for B_0.

MCMC diagnostics

A27. For the model runs in the Ross Sea assessment, 1 000 MCMC posterior samples were taken from 1 000 000 iterations, after a burn-in of 500 000 iterations. MCMC diagnostics suggested no evidence of poor convergence in the key biomass parameters and between-sample autocorrelations were low.

Ross Sea model estimates

A28. Key output parameters for the Ross Sea assessment model are summarised in Table A1.3. The projected biomass trajectory assuming a future constant catch of 3 258 tonnes for the Ross Sea model with survey data is shown in Figure A1.2 (the run labelled as R1 in WG-FSA-17/37 Rev. 1).

Table A1.3: Median MCMC estimates (and 95% credible intervals) of B_0, B_{2017} and B_{2015} as percentage of B_0 for models R1 (with survey data) and R3 (without survey data).

Model	B_0	B_{2017}	B_{2015} (% B_0)
2015	65 050 (57 820–72 180)	-	-
R1	72 620 (65 040–81 050)	52 240 (44 980–60 460)	71.9 (68.8–74.9)
R2	71 750 (64 560–79 890)	51 420 (44 730–59 430)	71.6 (68.6–75.3)

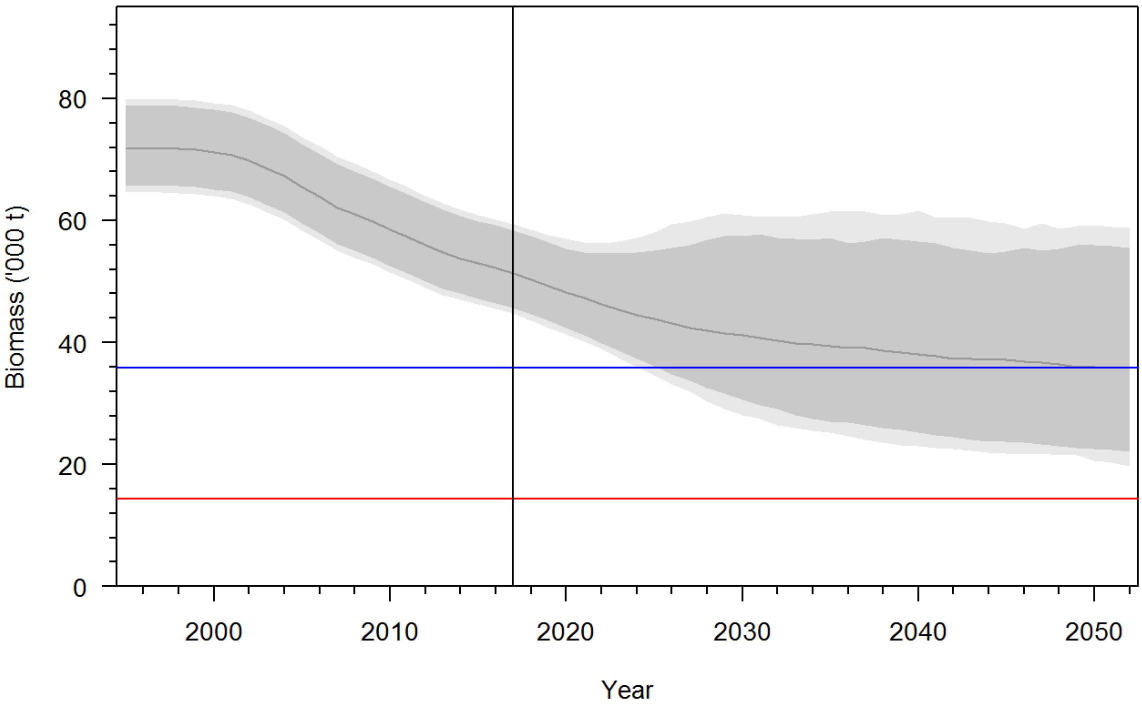

Figure A1.2: MCMC estimates of the spawning stock biomass trajectory as a percentage of initial biomass (black line) with the 90%ile (grey shading), projected to 2053 for model R1. The blue and red horizontal lines correspond to 50% B_0 and 20% B_0.

Medium-term research objectives

Table A2.1: Medium-term research plan (MTRP) objectives (WG-FSA-14/60; SC-CAMLR-XXXIII, paragraph 3.209 and CCAMLR-XXXIII, paragraph 5.52), alignment of proposed and current research proposals with the objectives and their status.

MTRP objectives	Research proposals	Paper number	Year running
(a) Reduce uncertainty in toothfish model parameters			
(i) To spatially and temporally delineate toothfish spawning grounds.	Winter research	WG-SAM-15/47, WG-FSA-18/40	2019
(ii) To delineate stock structure – especially in relation to SSRUs 882C–I.	Structured fishing 882C–G	WG-FSA-18/36	2019
(iii) To define and quantify fine-scale movement patterns, including by size and sex.	Satellite pop-up tags	WG-FSA-15/08	2019
(iv) To improve estimates of initial (and longer-term tagging) mortality, and tag detection.			
(v) To continue monitoring the relative abundance of sub-adults and to estimate recruitment variability and autocorrelation.	Shelf survey	WG-FSA-18/41	2016, 2017
(vi) To monitor key population-level parameters (e.g. growth, age/length at maturity, sex ratio) which could potentially be affected by fishing.			
(b) Reduce management uncertainty			
(i) To continue to improve the stock assessment (e.g. improve diagnostics, estimation of year-class strength etc.).	Shelf survey	WG-FSA-15/34	2018, 2019
(ii) To develop simple stock performance indicators/dashboard.			
(iii) To develop prioritised list of management strategy evaluation (MSE) scenarios and begin MSE testing of high-priority issues (e.g. alternative model parameters, spatial management, movement and stock assumptions etc.).			
(iv) To continue development of operating models as additional tag and fishery data are collected, through improved predictive layers (e.g. ice coverage) and better knowledge of life cycle.	882A–B North	WG-FSA-18/34	2018, 2019
(c) Maintenance of ecosystem structure and function			
(i) To determine the temporal and spatial extent of the overlap in the distribution of toothfish and its key predators (in particular, killer whales and Weddell seals).			

(ii) To investigate the abundance, foraging ecology, habitat use, functional importance and resilience of key toothfish predators (in particular, killer whales and Weddell seals).	McMurdo ice-based survey		2015, 2016

(continued)

Table A2.1 (continued)

MTRP objectives	Research proposals	Paper number	Year running
(iii) To develop methods of monitoring changes in relative abundance of key prey/by-catch species (in particular, macrourids and icefish) on the Ross Sea slope and hence assess the potential impact of the toothfish fishery on these species.			
(iv) To monitor diet of toothfish in key areas, especially on the Ross Sea slope.			
(v) To simulate the effect of the fishery on populations of toothfish, its predators, and its prey (using minimum realistic models or similar).			
(vi) To develop quantitative and testable hypotheses as to the ‘second-order’ effects (such as trophic cascades, regime shift) and ensure data collection is adequate to monitor for any risks deemed reasonable.			
(vii) To assess the impact of the toothfish fishery on Patagonian toothfish (*Dissostichus eleginoides*).			
(viii) To estimate survivorship of released skates.			
(ix) To develop semi-quantitative and spatially explicit risk assessments for macrourids and Antarctic skates (*Amblyraja georgiana*), especially in the slope fishery of the Ross Sea.			
(x) To develop methods to assess whether the potential impacts of the toothfish fishery on the ecosystem are likely to be reversible in two to three decades.			