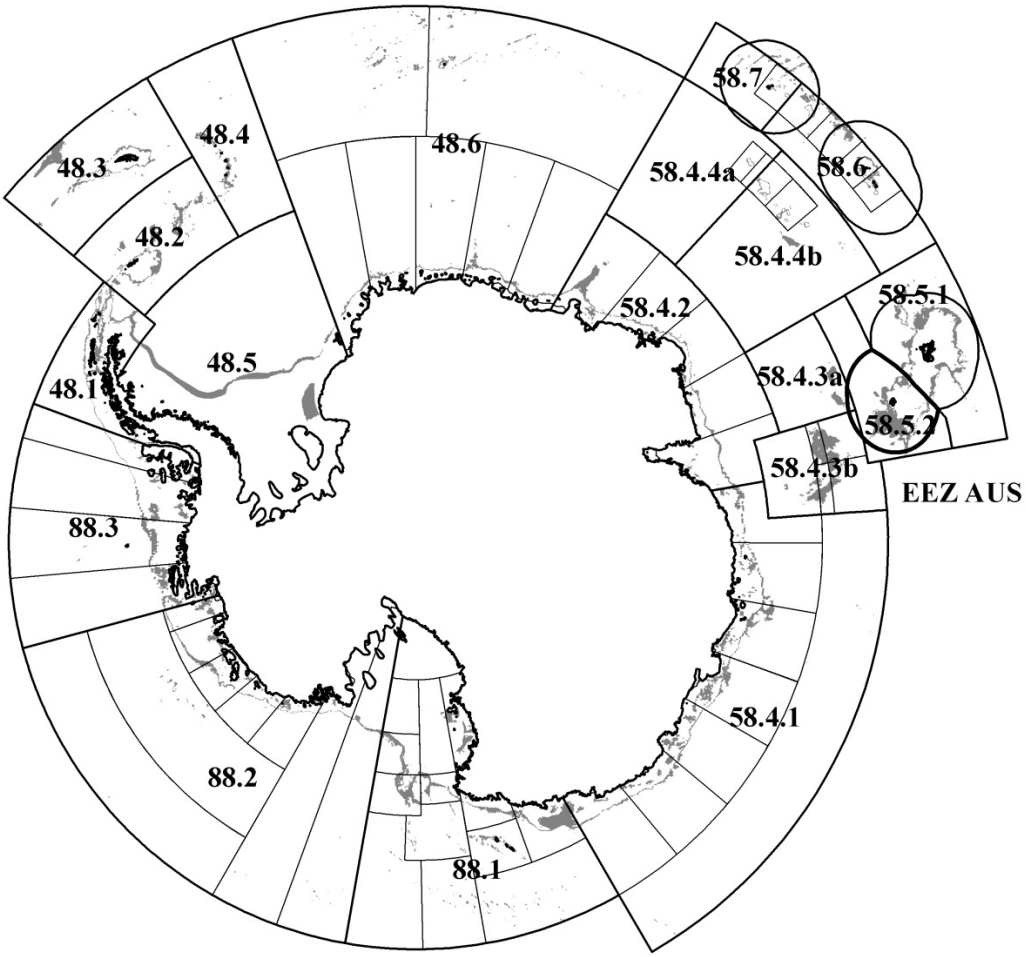
Fishery Report 2014: *Dissostichus eleginoides* Heard Island Australian EEZ (Division 58.5.2)



Contents

The map on the cover page shows the management areas within the CAMLR Convention Area, the specific region related to this report is outlined in bold. Depths between 600 and 1 800 m (the 'fishable depths' for *Dissostichus* spp.) are shaded.

Throughout this report the CCAMLR fishing season is represented by the year in which that season ended, e.g. 2014 represents the 2013/14 CCAMLR fishing season (from 1 December 2013 to 30 November 2014).

Fishery Report 2014: *Dissostichus eleginoides*
Heard Island, Australian EEZ (Division 58.5.2)

Introduction to the fishery

1. This report describes the licensed fishery for Patagonian toothfish (*Dissostichus eleginoides*) in the Australian Fishing Zone (AFZ) in Division 58.5.2. The area includes the AFZ surrounding Heard Island and McDonald Islands located on the Kerguelen Plateau between 50°–56°S and 67°–79°E.

2. The fishery began in 1997 as a trawl fishery. Longline fishing was introduced in 2003 and both fishing methods continued until 2014, with an increasing proportion of longline fishing in each year.

3. The fishery is managed by the Australian Fisheries Management Authority (AFMA) under the precautionary principles of CCAMLR. The annual catch limit is based on the management advice from CCAMLR. The current catch limits on the fishery for *Dissostichus* spp. in Division 58.5.2 are described in Conservation Measure (CM) 41-08.

4. In the 2014 season, which extended from 1 December 2013 to 30 November 2014, the longline fishery was active from 15 April 2014 and the trawl fishery was active throughout the whole season. Three vessels undertook fishing by longline and one vessel undertook fishing by trawl.

Reported catch

5. The historical catch limits and catches of *D. eleginoides* in Division 58.5.2 are provided in Table 1.

6. The catch limit, established using the CCAMLR decision rules, has varied from 3 800 tonnes in 1997 to 2 427 tonnes in 2007. Since 2012, the catch limit has been 2 730 tonnes.

7. The reported catch of *D. eleginoides* in 2014 was 2 743 tonnes.

Illegal, unreported and unregulated (IUU) fishing

8. Due to increased surveillance, IUU fishing has virtually been eliminated inside Division 58.5.2 and there have been no official reports of IUU fishing in Division 58.5.2 since 2007 (Table 1). Following the recognition of methodological issues in its assessment, no estimates of the IUU catch of *Dissostichus* spp. have been provided since 2011 (SC-CAMLR-XXIX, paragraph 6.5).

Table 1: Catch history for *Dissostichus eleginoides* in Division 58.5.2. (Source: STATLANT data for past seasons and catch and effort reports for current season, past reports for IUU catch.)

Season	Catch limit (tonnes)	Reported catch (tonnes)				Estimated IUU catch (tonnes)
		Longline	Pot	Trawl	Total	
1997	3800	0	0	1927	1927	7117
1998	3700	0	0	3765	3765	4150
1999	3690	0	0	3547	3547	427
2000	3585	0	0	3566	3566	1154
2001	2995	0	0	2980	2980	2004
2002	2815	0	0	2756	2756	3489
2003	2879	270	0	2574	2844	1274
2004	2873	567	0	2296	2864	531
2005	2787	621	0	2122	2744	265
2006	2584	659	68	1801	2528	74
2007	2427	601	0	1787	2387	0
2008	2500	835	0	1445	2280	0
2009	2500	1168	10	1287	2464	0
2010	2550	1213	30	1215	2459	0
2011	2550	1383	34	1148	2564	*
2012	2730	1356	0	1361	2717	*
2013	2730	2074	40	563	2677	*
2014	2730	2734	0	0	2743	*

* Not estimated

Life-history parameters

9. The life history of *D. eleginoides* is characterised by slow growth, low fecundity and late maturity. In Division 58.5.2, fish up to 175 cm long and older than 35 years of age have been found (Welsford et al., 2011). *Dissostichus eleginoides* are widespread across the entire Kerguelen Plateau and are known to move long distances across the plateau associated with the different stages of the life cycle. On maturation they migrate to a few discrete spawning locations, with tagging studies showing migrations of more than 2 500 km (Welsford et al., 2011).

10. *Dissostichus eleginoides* of Heard Island and McDonald Islands as well as Kerguelen, Crozet and Marion/Prince Edward Islands appear to be genetically homogenous (Appleyard et al., 2004) and distinctly different from those at more distant locations such as South Georgia and Macquarie Island (Appleyard et al., 2002). This genetic homogeneity, combined with results from tagging data which show movement of some fish from Heard Island to Kerguelen and Crozet Islands (Williams et al., 2002; WG-FSA-07/48 Rev. 1; Welsford et al., 2011), suggests that a metapopulation of *D. eleginoides* exists in the Indian Ocean sector.

Data collection

11. Catch limits for CCAMLR's fisheries for *D. mawsoni* and *D. eleginoides* for the 'assessed' fisheries in Subareas 48.3, 88.1 and 88.2 and Division 58.5.2 are based on integrated assessments.

12. The collection of biological data in Division 58.5.2 is conducted as part of the CCAMLR Scheme of International Scientific Observation and 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. Data are collected during commercial fishing trips and during random stratified trawl surveys (RSTS). The surveys cover a geographic area over the whole of the plateau shallower than 1 000 m in Division 58.5.2 to determine abundance of *D. eleginoides*. These surveys have been conducted since 1990 with survey designs described in detail in WG-FSA-06/44 Rev. 1 and in WG-FSA-14/41 for the 2014 survey.

Length distributions of catches

13. *Dissostichus eleginoides* occurs throughout the Heard Island and McDonald Islands area of the Kerguelen Plateau in Division 58.5.2, from shallow depths near Heard Island to at least 3 000 m depth around the periphery of the plateau. Fish smaller than 60 cm total length (TL) are predominantly distributed on the plateau in depths less than 500 m, where few areas of persistently high local abundance have been discovered. As fish grow, they move to deeper waters and are recruited to the fishery on the plateau slopes in depths of 450 to 800 m where they are vulnerable to trawling. Some areas of high local abundance comprise the main trawling grounds where the majority of fish caught are between 50 and 75 cm TL (Figure 1). Older larger fish are seldom caught by trawling and there is evidence from tag recaptures and size distribution of the catch by depth that these fish move into deeper water (>1 000 m depth) where they are caught by longline. This method mostly operates in depths between 1 000 and 1 800 m and predominantly catches fish >1 000 mm TL.

14. The length-frequency distributions of *D. eleginoides* caught by trawl and by longline in Division 58.5.2 for the last 10 years are presented in Figures 1 and 2 respectively. Since the start of the fishery >50 000 fish have been measured in this division.

15. The majority of *D. eleginoides* caught by trawl measured between 30 and 100 cm while those caught by longline measured between 50 and 125 cm. The modal size of fish caught in the trawl fishery (Figure 1) was smaller (~50–60 cm) in all seasons than those for longline (~70–80 cm) (Figure 2). The length-frequency distribution for the longline fishery includes larger fish because of gear selectivity and because the longline fishery occurs in deeper water where larger toothfish occur. 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 figure may reflect differences in the fished population but is also likely to reflect changes in the spatial and temporal distribution of fishing.

Tagging

16. A tagging study has been undertaken in Division 58.5.2 since 1998. Numbers of tag releases and recaptures up to 2007 are provided in Candy and Constable (2008) and WG-FSA-07/48 Rev. 1. By 2014 there had been 27 679 releases of tagged fish in Division 58.5.2 and 4 925 recaptures (WG-FSA-14/43). A small proportion (4.3%) travelled long distances and were recaptured in the French EEZ.

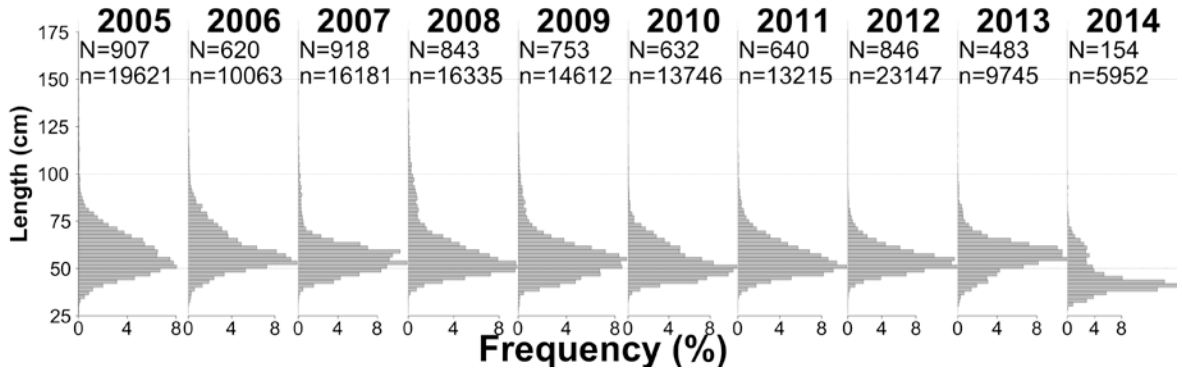


Figure 1: Annual length-frequency distributions of *Dissostichus eleginoides* caught by trawl in the Australian EEZ in Division 58.5.2 since 2005. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided. The length-frequency distribution in 2014 is from the trawl survey only which targets smaller fish than commercial trawl.

(b)

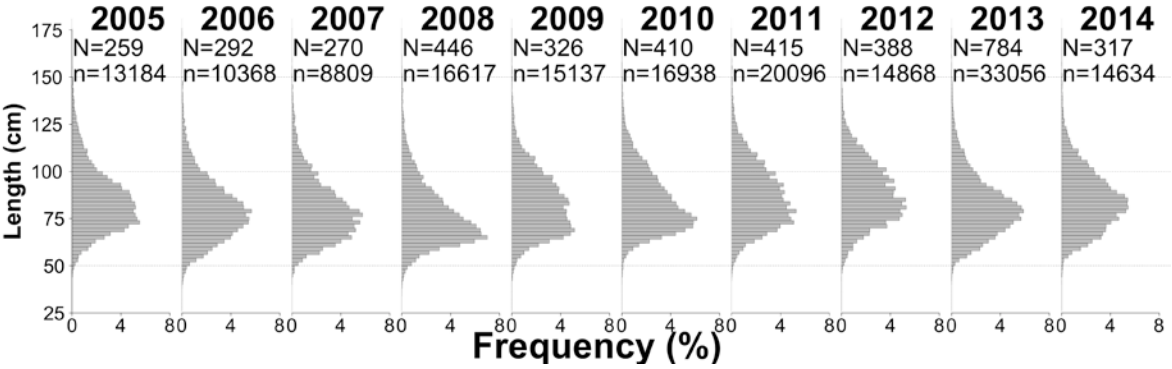


Figure 2: Annual length-frequency distributions of *Dissostichus eleginoides* caught by longline in the Australian EEZ in Division 58.5.2 since 2005. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided.

17. Historically, the tagging program had been largely restricted to releases and recaptures of fish caught by trawl on the main trawl ground (Candy and Constable, 2008). Tagging data from the main trawl ground were used to estimate natural mortality independently of the CASAL assessment as described in Candy et al. (2011), while the limited spatial extent of the program and mixing of the population to other areas restricted the ability to include tagging data as an unbiased index of abundance in the stock assessment. With the start of longlining in 2003, tagging and recapturing of fish has become more widespread. However, the spatial distribution of longline fishing and tagging of fish has been highly variable between years and the level of fish movement and the period of complete mixing is still unknown. Data from tag releases in 2012 and 2013 were incorporated for the first time into the stock assessment in 2014 (see Appendix 1).

Stock assessment

Parameter estimates

18. An integrated stock assessment is carried out biennially which is peer reviewed by CCAMLR's Working Group on Fish Stock Assessment (WG-FSA).

Fixed parameters

19. A natural mortality estimate of M = 0.155 was derived from catch-at-age and aged mark-recapture data (Candy et al., 2011; Candy, 2011, for the simulation method) and has been used in the stock assessments since 2011.

20. Between 1997 and 2011, over 10 000 *D. eleginoides* were aged using otoliths of individuals caught by commercial fishing, research surveys and mark-recapture experiments (WG-FSA-09/21; WG-SAM-09/09; WG-FSA-11/24). Tables of numbers of fish aged (up to 2011), length-frequency data and effective sample sizes for catch-at-length and catch-at-age proportions by sub-fishery and year are provided in WG-FSA-11/24. Further ageing was carried out in 2014 (WG-FSA-14/45) which included the otoliths from the 2012, 2013 and 2014 (part) RSTS, and commercial samples from 2013, including additional samples from older age classes.

Stock assessment status

21. Data from the RSTS, commercial catch and length data and biological data on age, growth and mortality provided input to the integrated stock assessment model for this fishery. The population model in 2014 was a single-sex, single-area, age-structured model including age classes from 1 to 35 years.

22. The 2014 assessment incorporated the recommendations of WG-FSA-2013, SC-CAMLR-2013 and WG-SAM-2014 by simplifying the model structure, adding new fishery observations up to 2014, including new ageing data, a Beverton-Holt stock-recruitment relationship, an updated growth model, an updated ageing error matrix, a prior for the survey catchability q, and tag-release data for 2012 and 2013 (WG-FSA-14/34 and WG-FSA-14 Report (SC-CAMLR-XXXIII, Annex 7)). The fisheries structure comprised one survey group from the RSTS and the commercial sub-fisheries of trawl, pot, longline from <1 500 m and longline from >1 500 m depth. The assessment model estimated virgin biomass B_0, year-class strength (YCS) from 1986 to 2009, the selectivity parameters for the survey and all commercial sub-fisheries and survey catchability q.

23. The 2014 assessment model provided an estimated median B_0 of 108 586 tonnes (92 263–132 167; 95% CI), with the median spawning stock biomass (SSB) at 0.65 (0.59–0.71) of B_0. Annual estimates of SSB status relative to virgin SSB and YCS are given in Table 2. WG-FSA agreed to use the average recruitment and cv from 1992 to 2009 for the stock projections with a lognormal empirical randomisation method of recruitment. The estimated long-term yield from this projection was 4 410 tonnes with a depletion probability of 0.0 and an escapement probability of 0.5.

Table 2: MCMC median estimates of spawning stock biomass (SSB), SSB status relative to B_0, and year-class strength (YCS).

Year	SSB (tonnes)	SSB status	YCS
1995	10 8586	1.00	1.20
1996	10 7210	0.99	1.29
1997	10 3490	0.95	1.08
1998	9 9335	0.91	0.96
1999	9 5800	0.88	1.24
2000	9 1928	0.85	0.84
2001	8 7695	0.81	1.35
2002	8 3288	0.77	1.03
2003	7 9093	0.73	0.89
2004	7 5977	0.70	1.34
2005	7 3574	0.68	0.67
2006	7 1908	0.66	1.82
2007	7 0826	0.65	1.68
2008	7 0200	0.64	1.11
2009	7 0049	0.64	0.68
2010	6 9985	0.64	1.00
2011	7 0413	0.65	1.00
2012	7 0453	0.65	1.00
2013	7 0712	0.65	1.00
2014	7 0714	0.65	1.00

By-catch of fish and invertebrates

Fish by-catch

24. A number of conservation measures, which ensure that impacts on the target and other species are minimised, currently apply to this fishery. CM 33-02 specifies that there should be no directed fishing other than for the target species, the by-catch limits for incidentally caught species and the move-on rules if the limits for any one haul are exceeded.

25. Catch limits for by-catch species groups (macrourids, rajids and other species) are defined in CM 33-02 and provided in Table 3.

26. The by-catch limits for macrourids (*Macrourus carinatus*) are based on assessments carried out in 2002 and 2003 (SC-CAMLR-XXII, Annex 5, paragraphs 5.244 to 5.249) and for rajids (*Bathyraja* sp.) limits were set in 1997 (SC-CAMLR-XVI, paragraphs 5.119 to 5.122).

27. By-catch in the toothfish trawl fisheries is generally less than 10% of the total catch. Landed by-catch in the longline fisheries ranged from 6 to 13% of the total catch, and including cut-offs revised these estimates to between 11 and 26% of the total catch. No by-catch species was caught in quantities approaching the catch limit.

Table 3: Catch history for by-catch (macrourids and rajids), including catch limits and number of rajids released alive, in Division 58.5.2. Catch limits are for the whole fishery (see CM 33-03 for details). (Source: fine-scale data.)

Season	Macrourids				Rajids				
	Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)			Number released
		Longline	Trawl	Total		Longline	Trawl	Total	
1997	-	0	0	0	-	0	3	3	-
1998	-	0	0	0	120	0	3	3	-
1999	-	0	1	1	-	0	2	2	-
2000	-	0	4	4	-	0	6	6	-
2001	-	0	1	1	50	0	5	5	-
2002	50	0	4	4	50	0	4	4	-
2003	465	3	1	4	120	7	27	33	-
2004	360	42	3	46	120	62	14	76	155
2005	360	72	2	74	120	71	8	79	8 412
2006	360	26	1	27	120	17	19	36	3 814
2007	360	61	5	66	120	8	10	18	7 886
2008	360	81	5	86	120	13	9	22	9 799
2009	360	110	2	112	120	15	16	32	10 738
2010	360	100	3	103	120	11	18	29	19 319
2011	360	147	4	151	120	11	3	14	7 164
2012	360	89	3	92	120	7	3	9	8 484
2013	360	154	3	157	120	13	27	40	13 135
2014	360	107	2	108	120	12	9	21	18 457

28. An analysis of the by-catch species unicorn icefish (*Channichthys rhinoceratus*) and grey rock cod (*Lepidonotothen squamifrons*) indicated that both species are widespread over the plateau in depths of <1 000 m (WG-FSA-12/24). The catch limits of *C. rhinoceratus* and *L. squamifrons* are based on assessments carried out in 1998 (SC-CAMLR-XVII, Annex 5). Over the past 10 years, the catches of each of these species were well below the limits set by CCAMLR (Table 4).

29. Length–weight relationships, length-at-maturity data and estimates of abundance from survey data for rajids were presented in WG-FSA-05/70, details of the skate tagging program in WG-FSA-08/55 and distribution and abundance of skates across the Kerguelen Plateau in WG-FSA-09/43. An update on the skate tagging program was presented in WG-FSA-13/22, showing a recapture rate of <1% and an average distance between release and recapture of 4 n miles.

Incidental mortality of birds and mammals

Incidental mortality

30. A summary of the seabird mortality by longline in the Australian EEZ in Division 58.5.2 for the past 10 years is presented in Table 5. The three most common species injured or killed in the fishery were the Cape petrel *(Daption capense*), black-browed albatross (*Thalassarche melanophrys*) and white-chinned petrel (*Procellaria aequinoctialis*).

Table 4: Catch history for by-catch (*Channichthys rhinoceratus*, *Lepidonotothen squamifrons*) and other species in Division 58.5.2. Catch limits are for the whole fishery (see CM 33-02 for details). (Source: fine-scale data.)

Season	*Channichthys rhinoceratus*				*Lepidonotothen squamifrons*				Other species			
	Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)		
		Longline	Trawl	Total		Longline	Trawl	Total		Longline	Trawl	Total
2004	150	0	7	7	80	0	3	3	50	3	16	19
2005	150	0	36	36	80	0	2	2	50	3	9	12
2006	150	0	32	32	80	0	5	5	50	3	7	12
2007	150	0	15	15	80	0	10	10	50	1	4	5
2008	150	0	37	37	80	0	20	20	50	2	18	21
2009	150	0	53	53	80	0	27	27	50	9	17	26
2010	150	0	78	78	80	0	48	48	50	6	16	22
2011	150	0	25	25	80	0	27	27	50	11	6	18
2012	150	0	42	42	80	0	34	34	50	7	5	12
2013	150	0	73	73	80	0	45	45	50	9	26	35
2014	150	0	>1	>1	80	0	2	2	50	4	>1	5

Table 5: Number of seabirds killed and injured in the fishery of the Australian EEZ in Division 58.5.2.

Season	*Daption capense*	*Thalassarche melanophrys*	*Procellaria aequinoctialis*	Other
2005		7	6	7
2006	1			
2007	2			
2008				2
2009	2			
2010	5			1
2011	1		1	
2012	7			
2013	1	1		2
2014				1
Total	19	8	7	13

31. In 2014, there was one seabird mortality, a southern rockhopper penguin (*Eudyptes chrysocome*) observed inside the Australia EEZ in Division 58.5.2. The seabird mortality rate was calculated as <0.001 birds/thousand hooks (this figure is calculated from the number of birds killed divided by number of hooks observed) and is extrapolated to give an estimated total of 2 seabirds for the season.

32. The level of risk of incidental mortality of seabirds in Division 58.5.2 is category 4 (average-to-high) (SC-CAMLR-XXX, Annex 8, paragraph 8.1).

33. Two southern elephant seal (*Mirounga leonina*) and one Antarctic fur seal (*Arctocephalus gazella*) mortalities were reported in the longline fishery in Division 58.5.2 during 2014. There had been no reports of marine mammal mortalities in the trawl fishery for Division 58.5.2 since 2005.

Mitigation measures

34. CM 25-03 is in force to minimise the incidental mortality of seabirds and marine mammals during trawl fishing. Measures include developing gear configurations which minimise the chance of birds encountering the net, and the prohibition of discharge of offal and discards during the shooting and hauling of trawl gear.

35. Longline fishing is conducted in accordance with CMs 24-02 and 25-02 for the protection of seabirds so that hook lines sink beyond the reach of seabirds as soon as possible after being put in the water. Between them, these measures specify the weight requirements for different longline configurations and the use of streamer lines and a bird exclusion device to discourage birds from accessing the bait during setting and hauling. If three seabirds are caught in any one season, fishing during the season extension is to cease immediately for that vessel.

Ecosystem implications and effects

36. Fishing gear deployed on the seabed can have negative effects on sensitive benthic communities. The potential impacts of fishing gear on the benthic communities in Division 58.5.2 are limited by the small size and number of commercial trawl grounds and the protection of large representative areas of sensitive benthic habitats from direct effects of fishing within the Heard Island and McDonald Islands Marine Reserve where fishing is prohibited, an IUCN Category 1a reserve (SC-CAMLR-XXI/BG/18). The marine reserve covers a total area of 71 200 km^2, which in March 2014 was extended by 6 200 km^2.

37. By-catch of benthos has been monitored by observers since the early stages of the development of the fishery and the rate of by-catch of benthos is generally lower in areas that have subsequently become the main fishing grounds as opposed to locations sampled in the RSTS.

Current management advice and conservation measures

Conservation measures

38. The limits on the fishery for *D. eleginoides* in Division 58.5.2 are defined in CM 41-08. The limits in force are summarised in Table 6.

Table 6: Limits on the fishery for *Dissostichus eleginoides* in Division 58.5.2 in force (CM 41-08).

Element	Limit in force
Access (gear)	Trawls or longlines or pots
Catch limit	4 410 tonnes west of 79°20'E (see CM 41-08)
Season:	
Trawl and pot	1 December to 30 November
Longline	1 May to 14 September, with possible extension from 15 to 30 April and 15 September to 31 October each season for any vessel that has demonstrated full compliance with CM 25-02 in the previous season.
By-catch	Fishing shall cease if the by-catch limit of any species, as set out in CM 33-02, is reached: *Channichthys rhinoceratus* 150 tonnes *Lepidonotothen squamifrons* 80 tonnes *Macrourus* spp. 360 tonnes Skates and rays 120 tonnes
Mitigation	In accordance with CMs 24-02, 25-02 and 25-03, minimisation of risk of the incidental mortality of seabirds and marine mammals
Observers	Each vessel to carry at least one scientific observer and may include one additional CCAMLR scientific observer
Data	Ten-day reporting system as in Annex 41-08/A Monthly fine-scale reporting system as in Annex 41-08/A on haul-by-haul basis Fine-scale reporting system as in Annex41-08/A. Reported in accordance with the CCAMLR Scheme of International Scientific Observation

(continued)

Table 6 (continued)

Element	Limit in force
Target species	For the purpose of Annex 41-08/A, the target species is *Dissostichus eleginoides* and the by-catch is any species other than *D. eleginoides.*
Jellymeat	Number and weight of fish discarded, including those with jellymeat condition, to be reported. These catches count towards the catch limit.
Environmental protection	Regulated by CM 26-01

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Appendix 1

Stock assessment

A1. The Heard Island and McDonald Islands (HIMI) fishery for Patagonian toothfish (*Dissostichus eleginoides*) in Division 58.5.2 was assessed in 2014 with an integrated stock assessment using CASAL (WG-FSA-14/34).

Model data

A2. The historical catches of *D. eleginoides* in Division 58.5.2 are provided in Table 1. For 2014, it was assumed that the catch limit for 2014 would be reached, with 13 tonnes from the random stratified trawl surveys (RSTS), 100 tonnes from trawl and 2 620 tonnes from longline.

A3. A large number of toothfish have been measured annually for length in the surveys and the commercial fishery (Table A1). Over 12 000 otoliths collected from the surveys and commercial fishery have been aged and used in the assessment.

Table A1: Number of toothfish measured for length or age and used in the HIMI assessment for surveys and commercial fisheries. Where numbers are in bold, the ages have been used to calculate age–length keys (ALKs). Ageing of otoliths sampled in 2014 is incomplete.

Year	Length			Age		
	Survey	Commercial	Total	Survey	Commercial	Total
1997	0	11 387	11 387	0	**55**	55
1998	169	11 229	11 398	0	**286**	286
1999	2 294	14 623	16 917	2	**623**	625
2000	2 258	20 483	22 741	20	**807**	827
2001	2 505	27 079	29 584	2	**909**	911
2002	2 965	18 476	21 441	4	**829**	833
2003	2 301	27 298	29 599	13	**675**	688
2004	2 462	33 509	35 971	4	**336**	340
2005	2 355	28 899	31 254	1	**370**	371
2006	2 081	31 427	33 508	**119**	**1 100**	1 219
2007	2 050	22 843	24 893	**547**	**588**	1 135
2008	1 281	31 475	32 756	**652**	**107**	759
2009	1 922	44 342	46 264	**641**	1	642
2010	5 893	30 485	36 378	**917**	0	917
2011	2 484	35 568	38 052	**518**	14	532
2012	6 062	37 026	43 088	**549**	0	549
2013	2 912	42 736	45 648	**266**	**1 109**	1 375
2014	2 770	22 266	25 036	**197**	0	197
Total	44 764	491 151	535 915	4 255	7 822	12 261

Random stratified trawl surveys

A4. RSTS to estimate the abundance and size structure of *D. eleginoides* and mackerel icefish (*Champsocephalus gunnari*) have been conducted in this division in 1990, 1992, 1993 and annually from 1997 to 2014. However, the structure and sampling intensity of the surveys varied over these years as the objectives for the surveys have changed, and information for survey design and power has improved (WG-FSA-06/44 Rev. 1) (Table A2). The survey design was consolidated in 2001 and the distribution of sampling effort amongst strata was revised in 2003, with an identical survey design for the years 2001–2002 and 2004–2014.

Table A2: Details of trawl surveys considered for estimating the abundance of juvenile *Dissostichus eleginoides* in waters shallower than 1 000 m deep in Division 58.5.2. AA – RV *Aurora Australis*, SC – FV *Southern Champion*, DT – demersal trawl. Note: surveys from 2007 to 2013 exclude Shell Bank.

Survey year	Group	Month	Vessel	Gear	Original design area (km^2)	Area following reassignment (km^2)	Hauls	Catch (tonnes)
1990	3	May	AA	DT	97 106	53 383	59	16
1992	4	Feb	AA	DT	55 817	38 293	49	3
1993	5	Sep	AA	DT	71 555	53 383	62	12
1999	2	Apr	SC	DT	84 528	80 661	139	93
2000	6	May	SC	DT	39 839	32 952	103	9
2001	1	May	SC	DT	85 170	85 694	119	45
2002	1	May	SC	DT	85 910	85 694	129	35
2003	7	May	SC	DT	42 280	42 064	111	13
2004	1	May	SC	DT	85 910	85 694	145	65
2005	1	May	SC	DT	85 910	85 694	158	21
2006	1	May	SC	DT	85 694	85 694	158	12
2007	1	Jul	SC	DT	83 936	83 936	158	12
2008	1	Jul	SC	DT	83 936	83 936	158	4
2009	1	Apr–May	SC	DT	83 936	83 936	161	19
2010[a]	1	Apr	SC	DT	83 936	83 936	134	6
2010	1	Sep	SC	DT	83 936	83 936	158	9
2011	1	Mar–May	SC	DT	83 936	83 936	156	7
2012	1	Mar–May	SC	DT	83 936	83 936	174	15
2013	1	Apr	SC	DT	83 936	83 936	158	8
2014	1	Jun	SC	DT	83 936	83 936	163[b]	14

[a] Incomplete survey.
[b] Includes five hauls on Shell Bank.

A5. For the assessment, one survey group was assumed for these years with an identical selectivity function (Survey group 1). Survey abundance-at-length (2001–2002, 2004–2005) and abundance-at-age data (2006–2014) were used as observations in the model.

A6. For surveys from 2001–2002 and 2003–2005, a bootstrap resampling procedure for estimating annual abundance by length bin and the corresponding coefficients of variation was used (WG-FSA-06/64).

A7. For the surveys years from 2006 to 2014, catch-at-length data were used to estimate proportions-at-length, weighted by stratum-area and total population numbers vulnerable to the survey. These were then converted to proportions-at-age for surveys (Table A1). The method of calculating proportions-at-age using proportions at length and age–length keys (ALKs) is described in WG-FSA-09/22 Rev. 1, along with a Monte Carlo sampling method

for estimating effective sample size (ESS) for use as the nominal multinomial sample size. Catch-at-length proportions and ALKs were grouped by 50 mm length bins with a lower bin limit of 150 mm and upper bin limit of 2 000 mm.

A8. Abundances at age were obtained by multiplying proportions-at-age with the estimated total population size vulnerable to the survey. Assuming a lognormal distribution, the CV of abundance-at-age estimates was obtained using the variance of the proportions at age and the variance of estimated total vulnerable population size (i.e. the variance for a stratified random sample, Cochran, 1977), as described in Appendix 2 of WG-FSA-11/24.

A9. Catchability q for the survey group was estimated based on a lognormal prior for q with mean of 0.423 and a CV = 0.257. This prior was estimated from the ratio of survey fish abundance using the swept-area method and the proportion of tag recaptures in survey catch on the main trawl ground (WG-FSA-14/34, Appendix B).

A10. The fishery structure was evaluated following the method developed by Candy et al. (2014). Based on this analysis, the commercial sub-fishery structure for the assessment consisted of sub-fisheries for trawl, pot and longline in waters shallower than 1 500 m depth (LL1), and longline in waters deeper than 1 500 m depth (LL2). The IUU catches from Table 1 were included in all scenarios. It was assumed that IUU catches had been taken by longline, with a selectivity function similar to that of the longline sub-fishery LL1.

A11. For all years with commercial fishing (1997–2014), catch-at-length data were used to estimate catch proportions-at-length. For the years from 1997 to 2008 and 2013, sufficient numbers of fish had been aged to calculate year-specific ALKs, where the age–length samples were pooled across all commercial sub-fisheries (Table A1). For the years 1997 and 2008, the relatively low age–length sample sizes were pooled with those from the adjacent years. Proportions-at-age for commercial sub-fisheries were calculated in the same way as those for surveys, following the method of WG-FSA-09/22 Rev. 1.

Tagging data

A12. A tagging study has been undertaken in Division 58.5.2 since 1998 (Williams et al., 2002). Numbers of tag releases and recaptures up to 2007 are provided in WG-FSA-14/43. Historically, the tagging program has been largely restricted to the main trawl ground (Candy and Constable, 2008) and tag releases from longline-caught fish commenced in 2003. Tagging data from the main trawl ground were used to estimate natural mortality independently of the CASAL assessment as described in Candy et al. (2011).

A13. Longline tag-releases from 2012 and 2013 were incorporated into the assessment model. Within-season recaptures were not used in the analysis. Recaptures from 2014 were included in the model although longline fishing had not been completed for this season. In the model, tag-shedding rate was incorporated into the tag-detection rate and estimated to be 0.993 for longline (Candy and Constable, 2008), tag-release mortality was 0.1 and the no-growth period after tagging was 0.5 years. Tag-dispersion φ was estimated at 1.

Stock assessment

CASAL model structure and parameter estimates

Overview

A14. The CASAL population model used in the assessment of *D. eleginoides* in Division 58.5.2 was a single-sex, single-area, age-structured model with age classes from 1 to 35 years (WG-FSA-14/34). Natural mortality was assumed to be 0.155 (Candy et al., 2011) and constant across all age classes. CASAL 2.30-2012-03-21 rev 4648 was used following the recommendation of WG-SAM-14.

A15. The assessment models were run for the period from 1982 to 2014. The annual cycle was divided into three time steps or seasons during which (1) fish recruitment, the first half of natural mortality, and fishing; (2) the second part of natural mortality and spawning; and (3) ageing occurred. The models estimated B_0, annual year-class strength (YCS) from 1986 to 2009, the parameters for the selectivity functions of the survey group and all commercial sub-fisheries and survey catchability q. The population parameters are given in Table A3.

Table A3: Population parameters and data for the assessment model in Division 58.5.2.

Parameters	Step 12: 2014 Model
Assessment period	1982–2014
B_0 and recruitment:	
Prior distribution of B_0	Uniform (bounds 30 000–250 000)
Mean recruitment R_0	Estimated
Period of estimated *YCS*	1986–2009
Prior distribution of *YCS*	Uniform with bounds 0.001–200
σ_R for projections	Calculated from *YCS* 1992–2009
Stock–recruitment relationship	Beverton-Holt with steepness h = 0.75
Age classes	1–35 y
Length classes	300–2000 mm by 50 mm bins
Size-at-age: Model	Von Bertalanffy (accounting for dome-shaped selectivity and length-bin sampling)
Size-at-age	L_∞: 2190 K: 0.028 t_0: –5.37 CV: 0.129
Ageing error matrix	WG-FSA-14/46
Weight at length L (mm to t)	c = 2.59E-12, d = 3.2064
Maturity: Range 5–95%	11–17 y
Natural mortality M	0.155
Survey q	Estimated
Data	
RSTS:	
Survey numbers-at- length	2001–2002, 2004–2005
Survey numbers-at-age	2006–2014
Commercial sub-fisheries:	Trawl1, LL1, LL2, Pot
Proportions-at-age	1997–2008, 2013
ESS	From data, except ESS set to 1 for Pot
Tagging data	Tag releases from 2012 and 2013, recaptures from 2013 and 2014 (excluding within-season recaptures)

A16. Either double-normal (DN) or double-normal-plateau (DNP) fishing selectivity functions were fitted for the survey group and each commercial sub-fishery. When the parameter for plateau length was estimated to be very small (~ 0.1 yr), the DNP collapsed to a DN and was replaced with a DN function in the assessment model. This was the case for the survey and the trawl sub-fishery, while all longline and the pot sub-fisheries were fitted with DNP functions.

Model fitting procedure

A17. When fitting the assessment models, excluding the effect of process error by using the initial effective sample size (ESS) gave too much weight in parameter estimation to the commercial proportions-at-length and proportions-at-age observations. Therefore, a number of iterations were run for each model scenario using the method described in Candy (2008) to account for process error until the ESS stabilised with no further reductions of practical significance.

A18. Initially, a point estimate (maximum posterior density, MPD) and its approximate covariance matrix for all free parameters in the inverse Hessian matrix were estimated. These estimates were then used as starting point for Monte Carlo Markov Chains (MCMCs) sampling. For the MCMCs, the first 500 000 iterations, and every 1000th sample taken from the next 1 million iterations, were dismissed (burn-in). MCMC trace plots were used to determine evidence of non-convergence.

Penalties

A19. For all tested scenarios, the models included penalties for YCS and catch. A penalty for YCS was intended to force the average of estimated YCS towards 1. Strong catch penalties prohibited 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.

Priors

A20. Priors were defined for all free parameters in the models and set to be non-informative (i.e. uniform) with the exception of the prior for survey catchability q. A prior for q was estimated following the method described in Appendix B of WG-FSA-14/34. The estimated parameters, starting values for the minimisation and bounds are given in Table A4.

Table A4: Estimated (free) parameters and their numbers, priors, starting values and lower and upper bounds. DN is double-normal, DNP is double-normal-plateau.

Parameter			Number	Starting values[a]	Prior	Lower bound	Upper bound
SSB_0			1	90 000	uniform	30 000	250 000
Survey q			1	μ = 0.423 CV = 0.257	lognormal	0.2	1.5
Selectivities	DN	a_1	1	4	uniform	1	10
		σ_L	1	1	uniform	0.02	20
		σ_R	1	7	uniform	1	20
	DNP	a_1	1	10	uniform	1	20
		a_2	1	6	uniform	0.1	20
		σ_L	1	1	uniform	0.02	20
		σ_R	1	3	uniform	1	20
		a_{max}	1	1	uniform	1	1
YCS	1982–2009		24	1	uniform	0.001	200

[a] Starting values for the selectivity functions varied slightly between survey groups and the commercial trawl sub-fisheries.

Yield calculations

A21. Catch projection trials accounted for uncertainty surrounding parameter estimates of the model as well as future recruitment variability. In order to integrate across uncertainty in the model parameters, MCMC samples were used for CASAL's projection procedure to obtain 1 000 random time series samples of estimated numbers of age-1 recruits for the period from 1987 to 2010, corresponding to YCS estimates from 1986 to 2009. The median of the square root of the variance of the yearly numbers of these age-1 recruits from 1992 to 2009 provided a robust estimate of the CV_R for recruitment required for the lognormal random recruitment generation.

A22. The estimated CVs were used to generate the random recruitment from 2010 until the end of the 35-year projection period. Based on this sample of projections for spawning stock biomass, long-term catch limits were calculated following the CCAMLR decision 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 of the spawning biomass 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.

A23. The depletion probability was calculated as the proportion of samples from the Bayesian posterior where the projected future SSB was below 20% of the pre-exploitation median spawning biomass in any one year, for each year over a 35-year projected period.

A24. The level of escapement was calculated as the proportion of samples from the Bayesian posterior where the projected future status of the SSB was below 50% of B_0 in the respective sample at the end of a 35-year projected period.

A25. For the projections, catch limit estimates were based on the assumption of constant annual catches. While future surveys were assumed to be conducted every two years with a catch of 40 tonnes, they were implemented as an annual constant catch of 20 tonnes in the projections. The entire remaining future catch was assumed to be taken by longline. The catch splits were based on the catch distribution of longline sub-fisheries in 2013. This meant that 50% of the total catch was attributed to LL1 and 50% to LL2.

Model estimates

A26. MCMC results of the key parameters are shown in Table A5.

Table A5: MCMC estimates of median SSB_0, *SSB* status in 2014 and CV_R (coefficient of variation of the annual YCS series 1992–2009) with 95% confidence intervals in brackets; and the number of estimated parameters (*N* Param).

B_0 (95% CI)	SSB status 2014 (95% CI)	R_0 (million)	Survey *q* (95% CI)	CV_R	*N* Param
108 586 (92 263–132 167)	0.65 (0.59–0.71)	8.07 (6.86–9.82)	0.48 (0.39–0.58)	0.41 (0.27–0.83)	44

A27. Estimates of YCS and selectivity functions are shown in Figures A1 and A2. The selectivity functions showed distinct differences between the surveys, trawl, longline and pot sub-fisheries. The trawl surveys and the commercial trawl sub-fisheries observed predominantly young fish, while the longline and pot sub-fisheries concentrated on older fish, with LL2 in waters deeper than 1 500 m catching older fish compared to LL1 in waters shallower than 1 500 m. Pot was estimated to catch mainly fish older than 15 years.

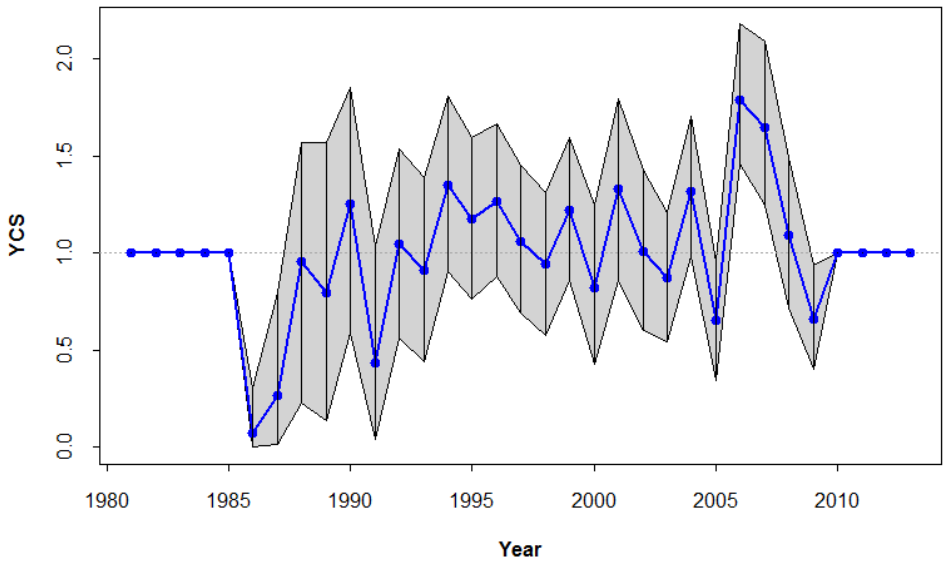


Figure A1: Year-class strength (YCS) estimates with 95% confidence bounds obtained from the MCMC samples.

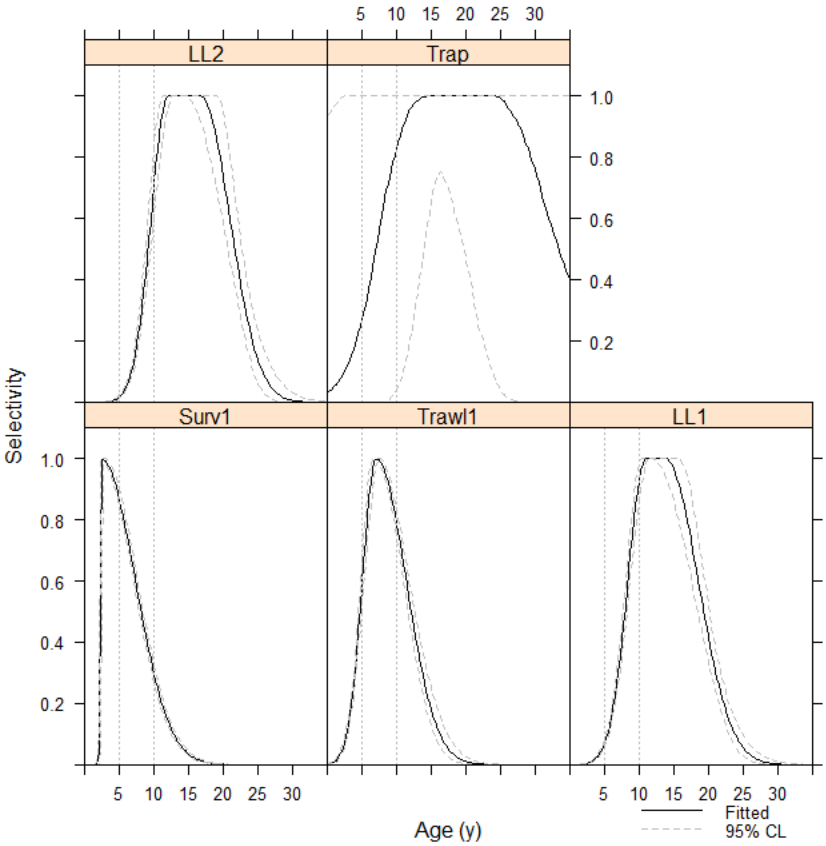
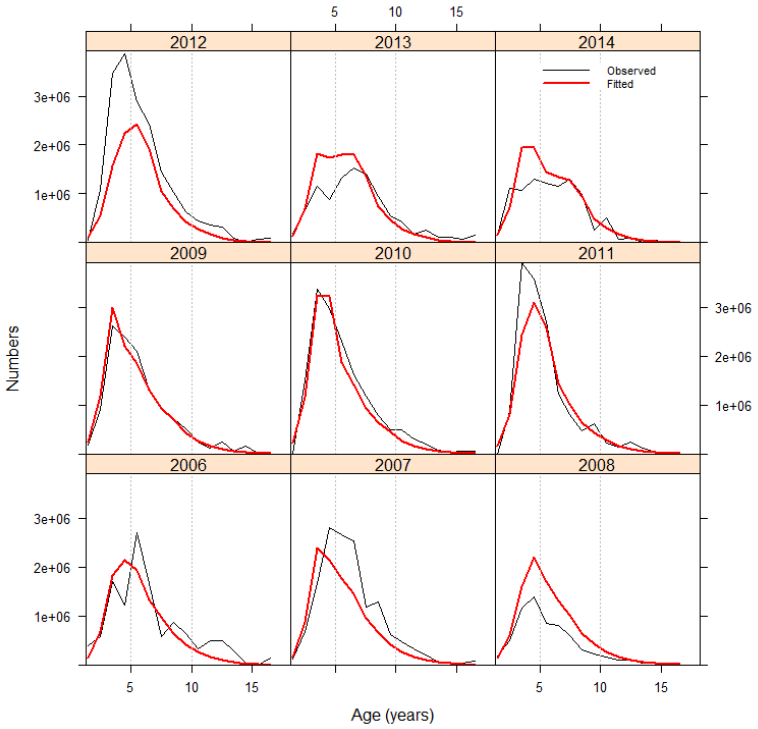


Figure A2: Estimated double-normal-plateau and double-normal fishing selectivity functions for the Survey ('Surv1') and commercial sub-fisheries, showing 95% confidence bounds obtained from the MCMC samples. LL1 and LL2 are longline in <1 500 m and >1 500 m depth respectively. Vertical reference lines are shown at ages 5 and 10.

A28. The model fits to the survey observations, the proportions-at-age datasets for the commercial sub-fisheries, and the tag-releases from the longline sub-fisheries are shown in Figures A3 to A7. The good fits to proportions-at-age for both longline sub-fisheries LL1 and LL2 indicated that the subdivision of longline hauls into these two sub-fisheries, defined by a split at 1 500 m depth, was reasonable. Fits to the pot sub-fishery were reasonable, despite the fact that the ESS of this sub-fishery was set to 1 because the information content of the data was considered poor due to high interannual variability in areas and depths fished.

A29. The contributions to the likelihood and the likelihood profiles are shown in Figure A8.

(a)



(b)

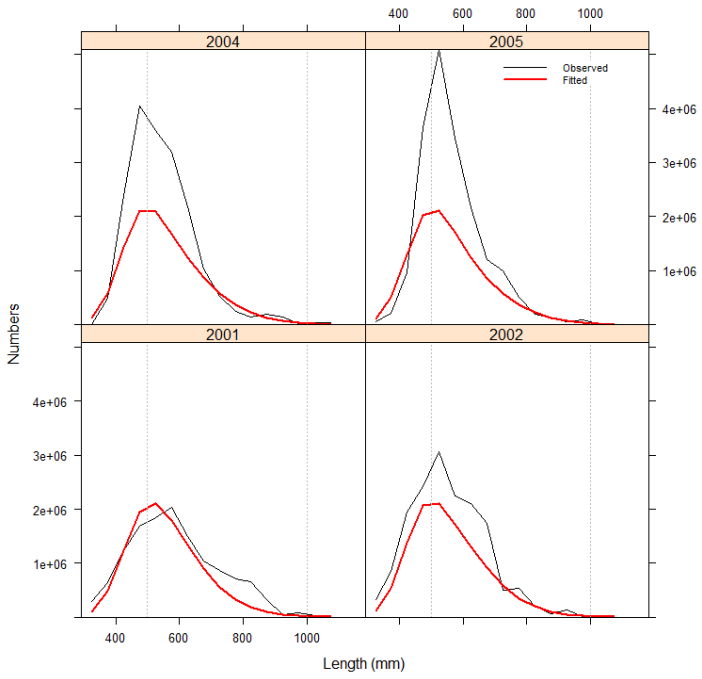


Figure A3: (a) Abundance-at-age and (b) abundance-at-length (black lines: observed; red lines: fitted) for the Survey.

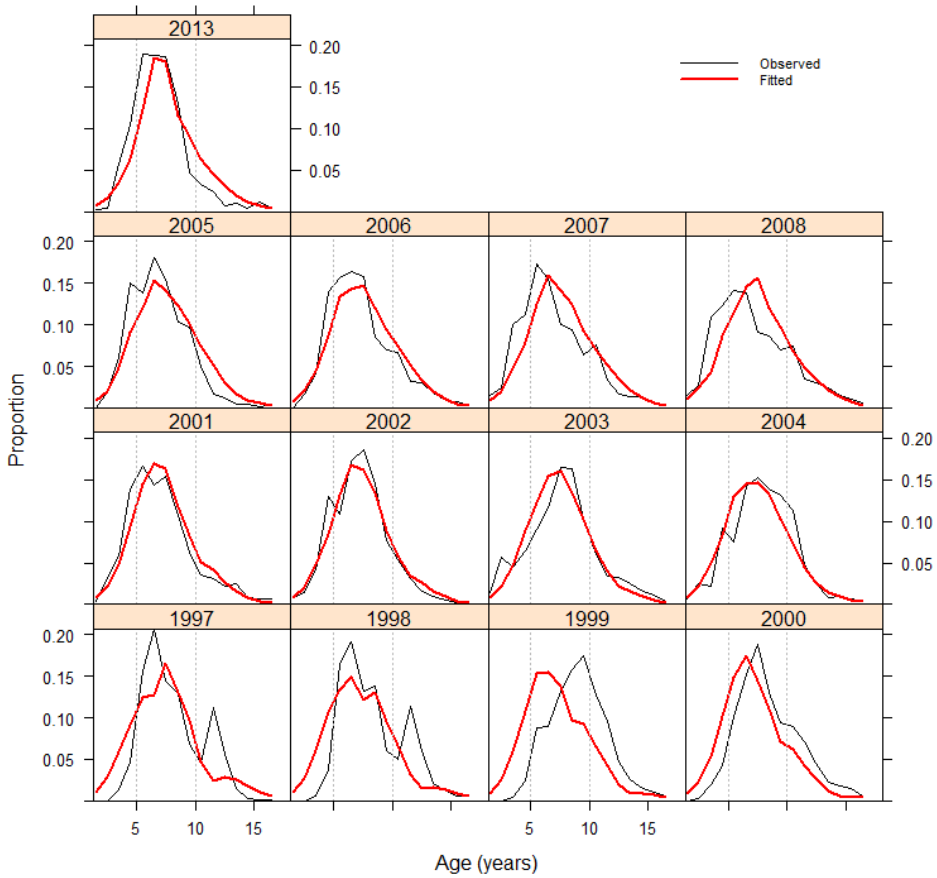
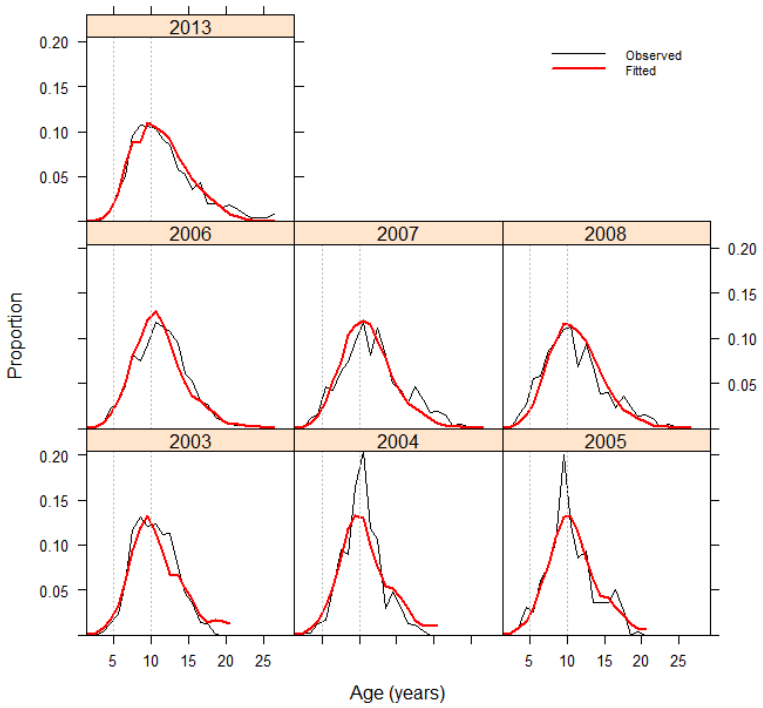


Figure A4: Proportions-at-age (black lines: observed; red lines: fitted) for the trawl sub-fishery. Note that some years are not consecutive.

(a)



(b)

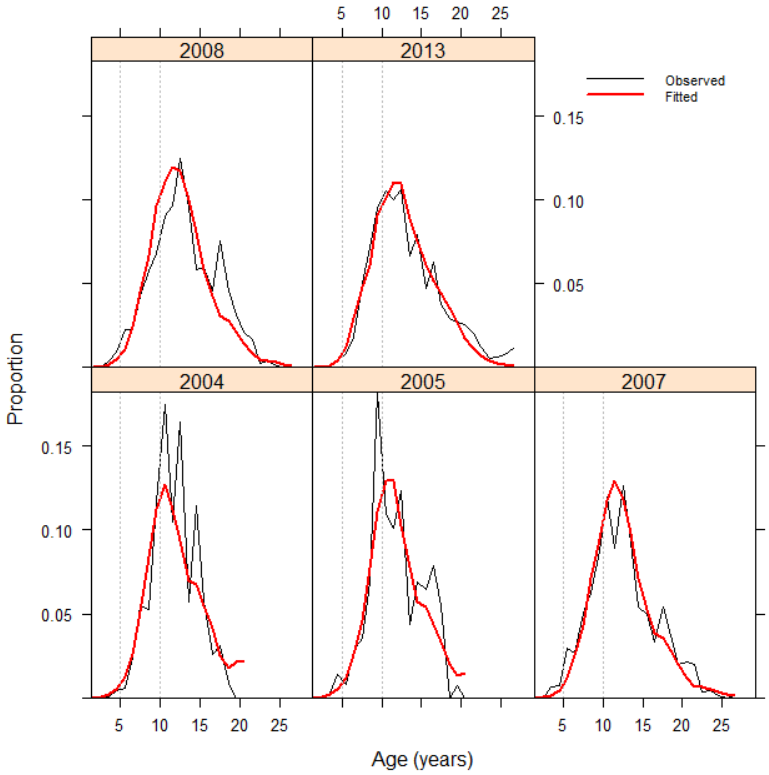


Figure A5: Proportions-at-age (black lines: observed; red lines: fitted) for (a) the longline LL1 and (b) longline LL2 sub-fisheries. Note that some years are not consecutive.

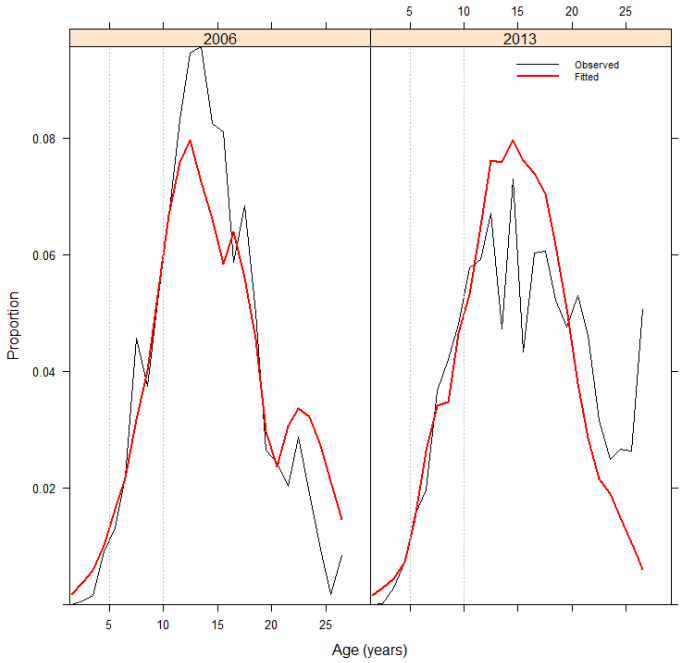


Figure A6: Proportions-at-age (black lines: observed; red lines: fitted) for the pot sub-fishery. Note that years are not consecutive.

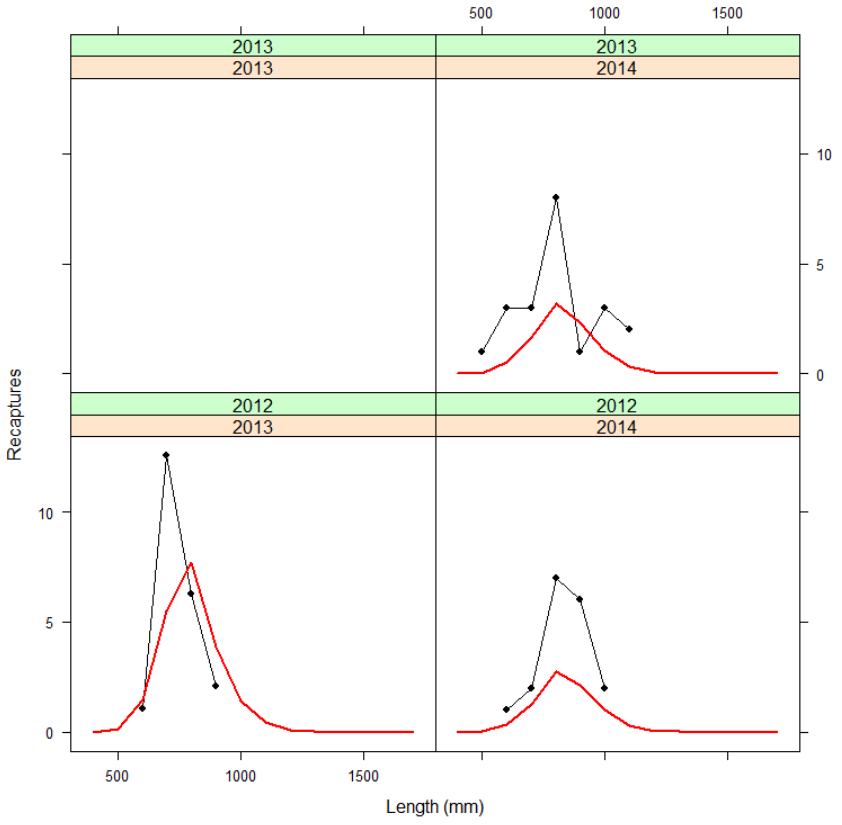


Figure A7: Observed (black) and estimated (red) numbers of recaptures from the 2012 and 2013 longline tag releases.

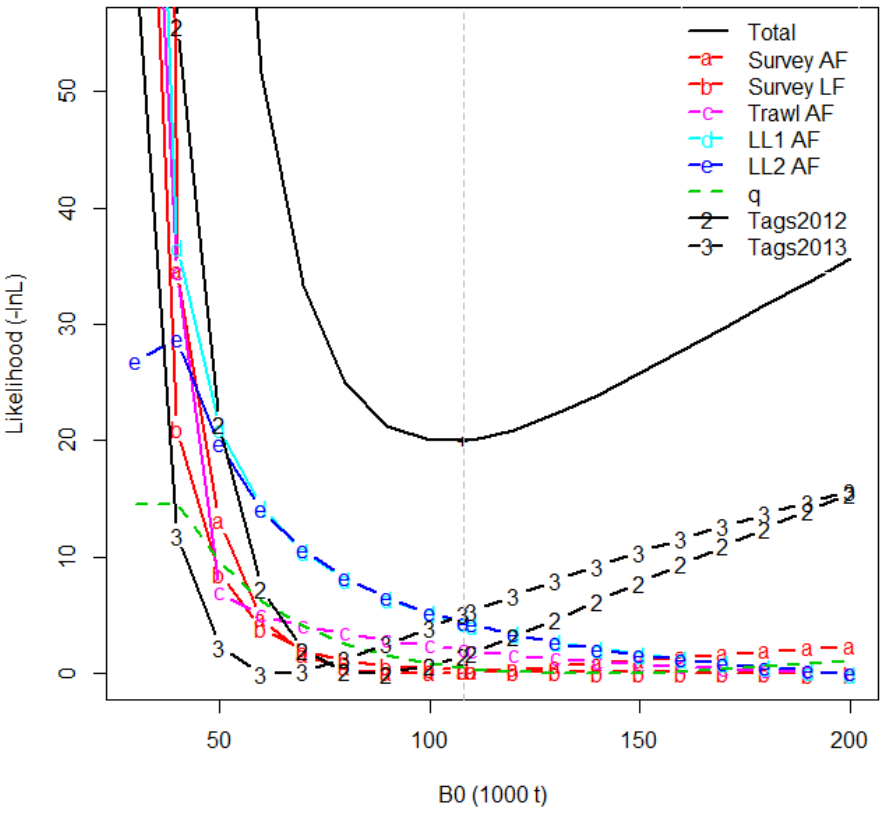


Figure A8: Likelihood profiles (–2 log-likelihood) across a range of B_0 values. Shown are the total objective function (Total) and contributions to the total objective function from survey abundance-at-age (SurveyAF), abundance-at-length (SurveyLF), trawl catch-at-age (TrawlAF), longline catch-at-age in depths shallower than 1 500 m (LL1 AF) and deeper than 1 500 m (LL2 AF), survey catchability q (q), tag releases in 2012 (Tags2012) and tag releases in 2013 (Tags2013). To create these profiles, B_0 values were fixed while only the remaining parameters were estimated. Values for each dataset were rescaled to have a minimum of 0, while the total objective function was rescaled to 20. The dotted grey line indicates the MPD estimate.

Estimation of yield

A30. The estimated long-term yield that satisfies the CCAMLR harvest control rules was 4 410 tonnes with a depletion probability of 0.0 and an escapement probability of 0.50 (Figure A9).

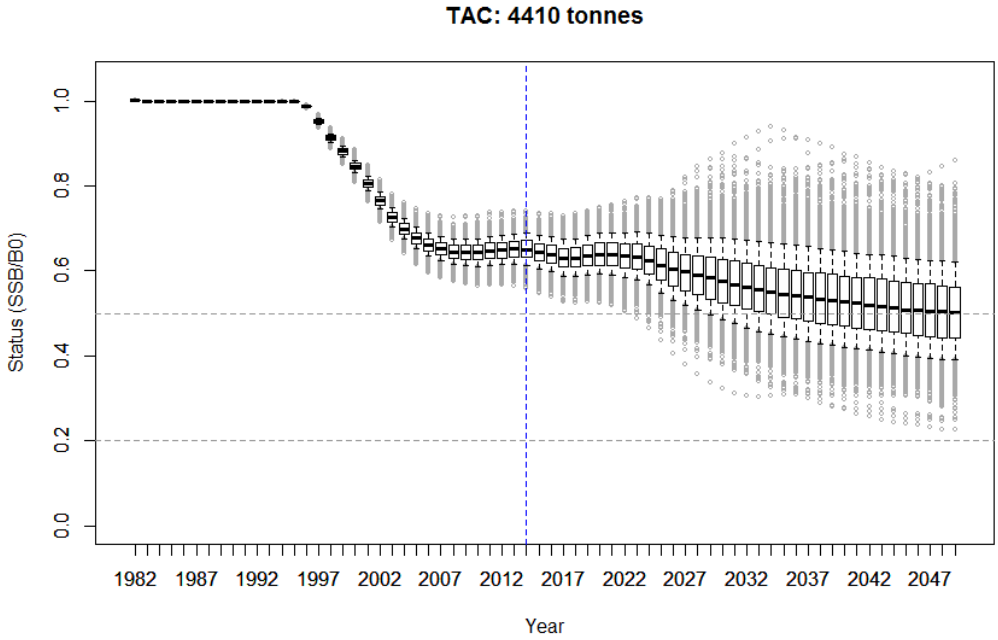


Figure A9: Projected *SSB* status relative to SSB_0 using MCMC samples and random lognormal recruitment from 2011 to 2049 with annual constant catches. Boxplots represent the distribution of the estimates across 1 000 projection trials. Dotted lines show the 50% and 20% status levels used in the CCAMLR decision rules.