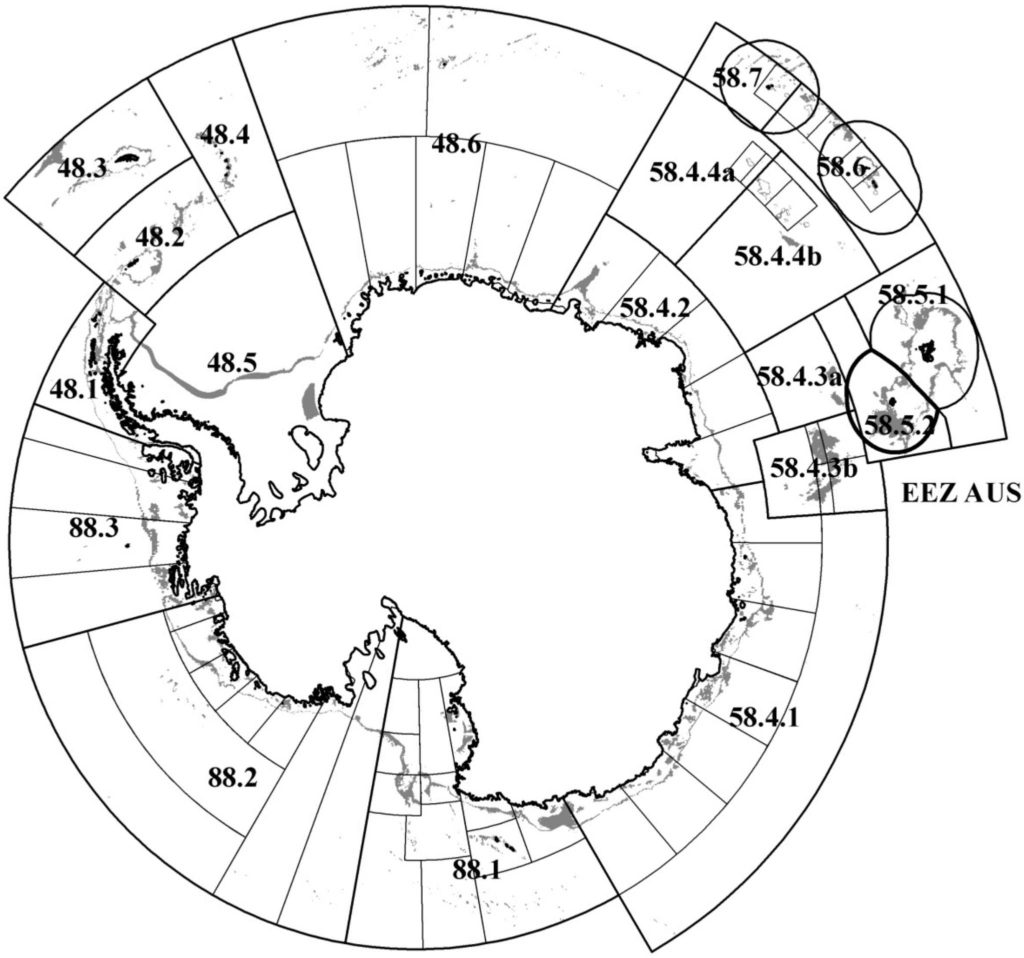
Fishery Report 2013: *Dissostichus eleginoides* Heard Island Australian EEZ (Division 58.5.2)



CONTENTS

Page

Introduction to the fishery ... 1
Reported catch ... 1
Illegal, unreported and unregulated (IUU) fishing ... 2

Data collection ... 2
Biological data ... 3
Length distributions of catches ... 3
Tagging ... 5

Life-history parameters ... 5
Data collection ... 5

Parameter estimates ... 6
Fixed parameters ... 6

Stock assessment status ... 6

By-catch of fish and invertebrates ... 7
Fish by-catch ... 7

Incidental mortality of birds and mammals ... 9
Incidental mortality ... 9
Mitigation measures ... 9

Ecosystem implications and effects ... 11

Current management advice and conservation measures ... 11
Conservation measures ... 11

References ... 13

Appendix 1: Stock assessment ... 14

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. 2013 represents the 2012/13 CCAMLR fishing season (from 1 December 2012 to 30 November 2013).

FISHERY REPORT 2013: *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, with the introduction of longline fishing in 2003. Both fishing methods continued until 2013, 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, setting an annual catch limit based on the scientific advice from CCAMLR. The current limits on the exploratory fishery for *Dissostichus* spp. in Division 58.5.2 are described in Conservation Measure (CM) 41-08. At the commencement of the fishery, the catch limit was 3 800 tonnes but has since been reduced and since 2012 has remained at 2 730 tonnes.

4. In the 2013 season, which extended from 1 December 2012 to 30 November 2013, the longline fishery was active from 20 December 2012 and the trawl fishery was active throughout the whole season. Three vessels undertook longline fishing and one vessel undertook trawling.

Reported catch

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

6. Over the past 10 seasons, the reported catch in this fishery peaked at 2 864 tonnes in 2004, which accounted for 99.5% of the catch limit set for that year.

7. In 2013, the final reported catch of 2 718 tonnes accounted for 99.5% of the catch limit of 2 730 tonnes.

8. The catch limit was exceeded in 2011 by 1% when the catch of 2 564 tonnes surpassed the catch limit of 2 550 tonnes.

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
2006	2584	659	68	1801	2528	74
2005	2787	621	0	2122	2744	265
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	2123	39	556	2718	*

* Not estimated

Illegal, unreported and unregulated (IUU) fishing

9. 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 2010 (SC-CAMLR-XXIX, paragraph 6.5).

Data collection

10. 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 set by CCAMLR using fully integrated assessments; more basic approaches are used for the 'data-poor' fisheries (in Subarea 48.6 and in Area 58 outside the exclusive economic zones (EEZs)).

11. In order to obtain the data necessary for a stock assessment, catch limits for research fishing by commercial vessels are set at a level intended to provide sufficient information (including sufficient recaptures of tagged fish) to achieve a stock assessment within a time period of 3–5 years. These catch limits are also set so that they provide reasonable certainty that exploitation rates at the scale of the stock or research unit will not negatively impact the stock. Appropriate exploitation rates are based on estimates from areas with assessed fisheries and are not more than 3–4% of the estimated stock size. In the case of the fisheries in Division 58.5.2, the assessment is for *D. eleginoides* and the collection of the data required for the assessments is described below.

Biological data

12. The collection of biological data 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.

Length distributions of catches

13. The highest number of length measurements, with >50 000 fish measured, was recorded from this division along with Division 58.5.1 and Subarea 48.3.

14. The median length of *D. eleginoides* recorded in Division 58.5.2 was 97 cm, with these larger fish being recorded in the more southern portion of the division than smaller fish.

15. The length-frequency distributions of *D. eleginoides* caught by trawl and by longline in Division 58.5.2 for all years in which more than 150 fish were measured are presented in Figures 2 and 3 respectively.

16. 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 2) was smaller (~50–60 cm) in all seasons than those for longline (~70–80 cm) (Figure 3). 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 gear used, the number of vessels in the fishery and the spatial and temporal distribution of fishing.

17. The difference in selectivities between trawl and longline sub-fisheries in Division 58.5.2 was estimated using large amounts of catch-at-age data for the first time in WG-FSA-09/20. The work of Welsford et al. (2009) confirmed previous modelling studies indicating that pot and longline gear is able to catch older fish (>20 years) more efficiently than trawl gear. For trawl gear, selectivity is high for 6-year-old fish and effectively declines to zero for fish older than 20 years.

18. Interannual variability in unweighted length frequencies may reflect differences in the fished population but is also likely to be affected by changes in factors such as the characteristics/number of vessels in the fishery and the spatial and temporal distribution of fishing. A description of how length data are used in assessments is provided in the commercial catch-at-age and catch-at-length data section of this report.

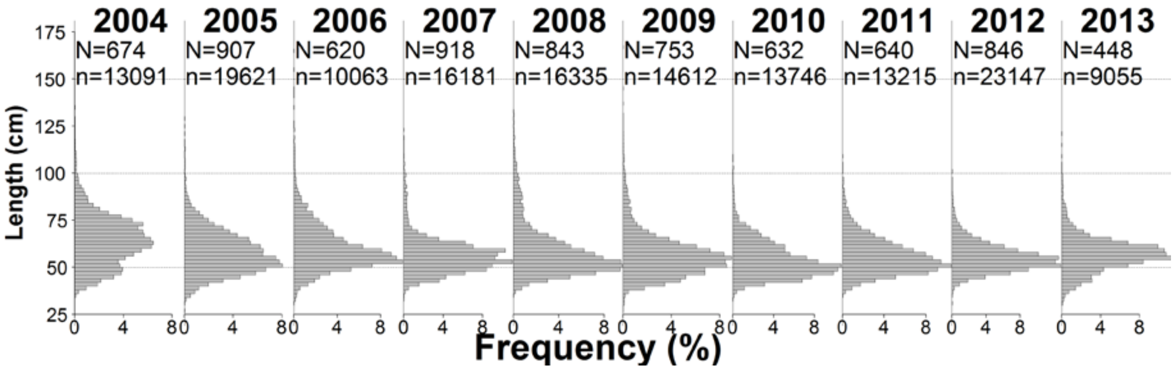


Figure 2: Annual length-frequency distributions of *Dissostichus eleginoides* caught by trawl in the Australian EEZ in Division 58.5.2. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided. Note: length-frequency distributions are only presented for those years/SSRUs in which the number of fish measured was >150.

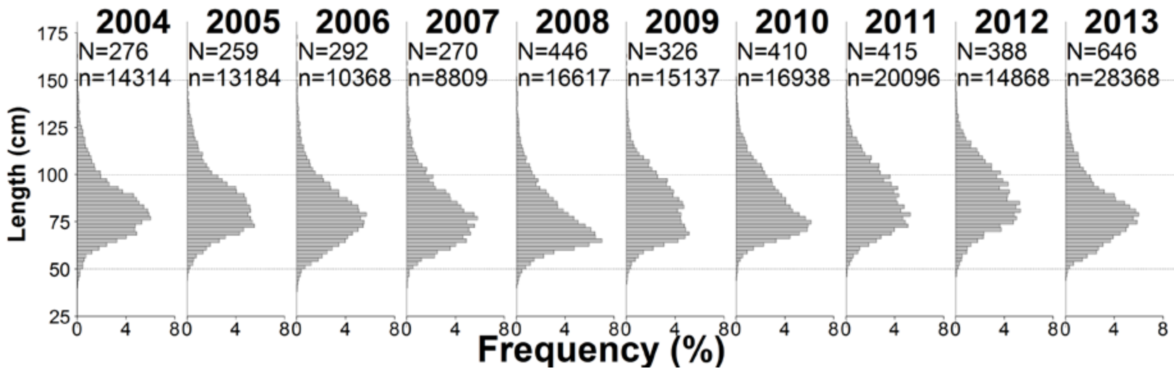


Figure 3: Annual length-frequency distributions of *Dissostichus eleginoides* caught by longline in the Australian EEZ in Division 58.5.2. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided. Note: length-frequency distributions are only presented for those years/SSRUs in which the number of fish measured was >150.

19. *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 are predominantly distributed on the plateau in depths less than 500 m, where few areas of persistently high local abundance having 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 total length (TL) (Figure 2). 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.

Tagging

20. 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. It is anticipated that, as the spatial extent of fishing effort increases, these data will provide important inputs to future integrated assessments.

21. Historically, the tagging program has been largely restricted to the main trawl ground B (Candy and Constable, 2008). At present, the small spatial extent of the program and the limited mixing of the population to other areas restrict the ability to undertake a comprehensive stock assessment. These data are therefore not utilised in the integrated assessment. However, the tag data from trawl ground B were used to estimate natural mortality independently of the CASAL assessment as described in Candy et al. (2011).

Life-history parameters

22. The life history of *D. eleginoides* is characterised by slow growth, low fecundity and late maturity. *Dissostichus eleginoides* is a large long-lived fish of the family Nototheniidae. 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).

23. *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

24. Length frequency and biological data (sex and gonad stage) of *D. eleginoides* and by-catch species have been collected by scientific observers on all commercial trips for the duration of the fishery. The data collected are provided to the Australian government (Australian Antarctic Division and AFMA) and to the CCAMLR Secretariat. Similar length frequency and biological data were collected in the random stratified trawl surveys conducted each year at Heard Island. The surveys cover a geographic area over the whole of the plateau shallower than 1 000 m 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 for the 2013 survey in WG-FSA-13/21.

Parameter estimates

25. An integrated stock assessment is carried out biennially which is peer reviewed by the Working Group on Fish Stock Assessment (WG-FSA) of CCAMLR (last assessment in WG-FSA-13/24).

Fixed parameters

26. 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 used in the stock assessments since 2011, while M = 0.13 was used in assessments prior to 2011.

27. 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, 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.

Stock assessment status

28. Data from the random stratified trawl surveys, commercial catch and length data and biological data on age, growth and mortality provided input to the integrated stock assessment model assessed biennially for this fishery. The 2011 model was a combined-sex, single-area and three-season model, with spawning occurring on 1 July. The fisheries were divided into three trawl and five longline fisheries on a geographical basis.

29. The 2011 assessment (WG-FSA-11/24) estimated a virgin stock biomass (B_0) of 86 400 tonnes and the spawning stock in 2011 at 0.63 of virgin biomass. Annual estimates of spawning stock biomass (SSB), SSB status relative to virgin SSB, and year-class strength (YCS) are given in Table 2. Based on this assessment, the estimated long-term yield that satisfies the CCAMLR harvest control rules was 2 730 tonnes with a depletion probability of 0.001 and an escapement probability of 0.501.

30. An assessment was conducted in 2013 and the results were presented in WG-FSA-13/24 (see Appendix 1). WG-FSA-13 considered several scenarios on which to base management advice but had insufficient time to conclude the assessment that took account of assessment scenarios raised at the meeting, notably the inclusion of a stock-recruitment relationship, removal of the influence of two of the trawl fisheries and exclusion of the estimate of YCS in 2009 (SC-CAMLR-XXXII, Annex 6, paragraphs 4.47 to 4.53). In addition, advised catches and biomass status of the stock were conditional on the CASAL assessment version in which the model was fitted (SC-CAMLR-XXXII, Annex 6). As a result, the advice from the 2011 assessment was carried forward to 2014, the details of which can be found in SC-CAMLR-XXXII, Annex 6.

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

Year	SSB (tonnes)	SSB status	YCS
1997	82 678	0.96	1.56
1998	79 476	0.92	2.21
1999	76 427	0.88	2.00
2000	74 764	0.87	2.51
2001	72 889	0.84	3.93
2002	70 783	0.82	0.40
2003	68 266	0.79	4.76
2004	66 244	0.77	1.57
2005	63 910	0.74	5.93
2006	62 436	0.72	3.01
2007	60 896	0.70	4.24
2008	59 343	0.69	1.00
2009	57 879	0.67	1.00
2010	56 008	0.65	1.00
2011	54 340	0.63	0.00

31. The Scientific Committee agreed it was important to consider the following work (Annex 6, paragraph 4.53):

(i) update the age data used in the assessment to include all recent years for which the information is available

(ii) review the tagging data available for inclusion on the assessment, including:

(a) an analysis of the spatial and temporal patterns of releases and recaptures, including linkage with other stocks

(b) localised and stock-based estimates of abundance using Petersen estimators

(c) sensitivity tests when including tag-recapture information in the CASAL stock assessment

(iii) compare MCMC runs with covariance matrix resampling for stock projections for this stock

(iv) evaluate the consequence, including information from ALKs and externally estimated growth functions that account for length-based selectivity in the model.

By-catch of fish and invertebrates

Fish by-catch

32. A number of conservation measures, which ensure that impacts on the target and other species are minimised, currently apply to this fishery. CMs 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.

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

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	105	3	108	120	10	26	36	13 114

34. 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).

35. 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.

36. An analysis of the by-catch species *Channichthys rhinoceratus* and *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).

37. 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

38. A summary of the historic 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*).

39. In 2013, there were four seabird mortalities observed inside the Australia EEZ in Division 58.5.2, including one *D. capense*, one *T. melanophrys* (Table 5) and one southern giant petrel (*Macronectes giganteus*).

40. 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).

41. Six southern elephant seal (*Mirounga leonina*) mortalities were reported in the longline fishery in Division 58.5.2 during 2013. Previously there had been no reports of marine mammal mortalities in the trawl fishery for Division 58.5.2 since 2004.

Mitigation measures

42. 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.

43. 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.

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

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

Season	*Daption capense*	*Thalassarche melanophris*	*Procellaria aequinoctialis*	Other
2004				3
2005		7	6	7
2006	1			
2007	2			
2008				2
2009	2			
2010	5			1
2011	1		1	
2012	7			
2013	1	1		2
Total	19	9	9	16

Ecosystem implications and effects

44. 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 and associated conservation zone comprise around 17% of the area of the Australian EEZ around Heard Island and McDonald Islands and fall entirely within CCAMLR Division 58.5.2.

45. The Working Group noted that by-catch of benthos was monitored by observers in the early stages of the development of the fishery and that by-catch of benthos was much lower in areas that have subsequently become the main fishing grounds.

Current management advice and conservation measures

Conservation measures

46. The limits on the fishery for *D. eleginoides* in Division 58.5.2 are defined in CM 41-08. The limits in force and the advice of WG-FSA to the Scientific Committee are summarised in Table 6.

Table 6: Limits on the exploratory fishery for *Dissostichus eleginoides* in Division 58.5.2 in force (CM 41-08) and advice to the Scientific Committee.

Element	Limit in force	Advice for 2014
Access (gear)	Trawls or longlines or pots	
Catch limit	2 730 tonnes west of 79°20'E (see CM 41-08)	Carry forward
Season:		
Trawl and pot	1 December to 30 November	Carry forward
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.	Carry forward
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.	Carry forward
Mitigation	In accordance with CMs 24-02, 25-02 and 25-03, minimisation of risk of the incidental mortality of seabirds and marine mammals	Carry forward
Observers	Each vessel to carry at least one scientific observer and may include one additional CCAMLR scientific observer	Carry forward
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	Carry forward
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.*	Carry forward
Jellymeat	Number and weight of fish discarded, including those with jellymeat condition, to be reported. These catches count towards the catch limit.	Carry forward
Environmental protection	Regulated by CM 26-01	Carry forward

References

Appleyard, S.A., R.D. Ward and R. Williams. 2002. Population structure of the Patagonian toothfish around Heard, McDonald and Macquarie Islands. *Ant. Sci*., 14: 364–373.

Appleyard, S.A., R. Williams and R.D. Ward. 2004. Population genetic structure of Patagonian toothfish in the West Indian Ocean sector of the Southern Ocean. *CCAMLR Science*, 11: 21–32.

Candy, S.G. 2004. Modelling catch and effort data using generalised linear models, the Tweedie distribution, random vessel effects and random stratum-by-year effects. *CCAMLR Science*, 11: 59–80.

Candy, S.G. 2008. Estimation of effective sample size for catch-at-age and catch-at-length data using simulated data from the Dirichlet-multinomial distribution. *CCAMLR Science*, 15: 115–138.

Candy, S.G. 2011. Estimation of natural mortality using catch-at-age and aged mark-recapture data: a multi-cohort simulation study comparing estimation for a model based on the Baranov equations versus a new mortality equation. *CCAMLR Science*, 18: 1–27.

Candy, S.G. and A.J. Constable. 2008. An integrated stock assessment for the Patagonian toothfish, *Dissostichus eleginoides*, for the Heard and McDonald Islands using CASAL. *CCAMLR Science*, 15: 1–34.

Candy, S.G., A.J. Constable, S. Candy, T. Lamb and R. Williams. 2007. A von Bertalanffy growth model for toothfish at Heard Island fitted to length-at-age data and compared to observed growth from mark–recapture studies. *CCAMLR Science*, 14: 43–66.

Candy, S.G., D.C. Welsford, T. Lamb, J.J. Verdouw and J.J. Hutchins. 2011. Estimation of natural mortality for the Patagonian toothfish at Heard and McDonald Islands using catch-at-age and aged mark-recapture data from the main trawl ground. *CCAMLR Science*, 18: 29–45.

Francis, R.I.C. 2011. Data weighting in statistical fisheries stock assessment models. *Can. J. Fish. Aquat. Sci*., 68: 1124–1138.

Welsford, D.C., G.B. Nowara, S.G. Candy, J.P. McKinlay, J. Verdouw and J. Hutchins. 2009. Evaluating gear and season specific age–length keys to improve the precision of stock assessments for Patagonian toothfish at Heard Island and McDonald Islands. Final Report, Fisheries Research and Development Council project 2008/046.

Welsford, D.C, S.G. Candy, T.D. Lamb, G.B. Nowara, A.J. Constable and R. Williams. 2011. Habitat use by Patagonian toothfish (*Dissostichus eleginoides* Smitt 1898) on the Kerguelen Plateau around Heard Island and the McDonald Islands. Kerguelen Plateau Symposium. *First International Scientific Symposium on the Kerguelen Plateau: Marine Ecosystem and Fisheries*: 125–136.

Williams, R., G.N. Tuck, A.J. Constable and T. Lamb. 2002. Movement, growth and available abundance to the fishery of *Dissostichus eleginoides* Smitt, 1898 at Heard Island, derived from tagging experiments. *CCAMLR Science*, 9: 33–48.

STOCK ASSESSMENT

A1. The following description of the stock assessment model for Heard Island and McDonald Islands toothfish fishery relates to the assessment model of 2011 (WG-FSA-11/24).

Model parameters

Spatial and temporal coverage

A2. The spatial and temporal coverage of the fishing for *D. eleginoides* used in the model is summarised in Table A1 (see also Candy and Constable, 2008). A minor amount of longline fishing has occurred in trawl ground B to date, while longline fishing has increased in areas other than the known grounds.

Table A1: Spatial and temporal coverage of historical fishing activity for *Dissostichus eleginoides* in Division 58.5.2, including summary codes for the different elements of the fishery (sub-fishery). f – sub-fishery; s – season. The seasons are defined by the fishery being open to longline fishing, with season 1 from 1 December to 30 April, season 2 from 1 May to 30 September, and season 3 from 1 October to 30 November.

Gear type	Season			
	Approximate area (km^2)	Season 1: Prior to longline fishing	Season 2: Open to longline fishing	Season 3: Post longline fishing
Survey[a]	85 694	-	f1	-
Trawl on ground B	442	f2_s1	f2_s2	f2_s3
Trawl on ground C	2 033	f3_s1	f3_s2	f3_s3
Trawl on ground E		f8_s1	f8_s1	f8_s1
Longline on ground A	16 678	-	f4_s2	-
Longline on ground C	2 033	-	f5_s2	-
Longline on ground D	90 625	-	f6_s2	-
Longline on ground E	na	-	f7_s2	-
Longline on ground F	na	-	f9_s2	-
Pot	na	f10_s1	-	-

[a] Random stratified trawl survey.

Fixed parameters

A3. In 2011, estimates of parameters except natural mortality remained unchanged from those used in the Division 58.5.2 toothfish assessment as detailed in SC-CAMLR-XXVI, Annex 5, Appendix L, and Candy and Constable (2008; see also Table A2). Natural mortality was estimated from catch-at-age and aged mark-recapture data as M = 0.55 (Candy et al., 2011; Candy, 2011, for simulation method), whereas a value of 0.13 was used previously.

A4. A substantial amount of ageing of otoliths from the commercial catch, surveys and mark-recapture experiments was undertaken in 2008 and 2009 (WG-FSA-09/21; WG-SAM-09/09). Since then a substantial number of fish have been aged for all survey years from 2006 to 2011 and abundance-at-age data were available for all these years. Tables of numbers of fish aged, length-frequency data and effective sample sizes (ESS) for catch-at-length and catch-at-age proportions by sub-fishery and year are given in WG-FSA-11/24.

Table A2: Input parameters for the assessment of *Dissostichus eleginoides* in Division 58.5.2: natural mortality (*M*), length-at-age (age in parentheses) and coefficient of variation (CV), length-at-weight parameters, and maturity-at-age (age in parentheses).

Component	Parameter	Value	Units
Natural mortality	*M*	0.155	y^{-1}
Length-at-age	(1) 251.0	(2) 307.5	(year) mm
	(3) 367.3	(4) 430.4	
	(5) 497.0	(6) 547.5	
	(7) 594.8	(8) 641.1	
	(9) 686.5	(10) 730.9	
	(11) 774.5	(12) 817.1	
	(13) 858.9	(14) 899.9	
	(15) 940.0	(16) 979.3	
	(17) 1017.8	(18) 1055.5	
	(19) 1092.5	(20) 1128.7	
	(21) 1164.1	(22) 1198.8	
	(23) 1232.9	(24) 1266.2	
	(25) 1298.9	(26) 1330.9	
	(27) 1362.2	(28) 1392.9	
	(29) 1423.0	(30) 1452.5	
	(31) 1481.3	(32) 1509.6	
	(33) 1537.3	(34) 1564.5	
	(35) 1591.1		
	CV	0.1	
Length-at-weight	*a*	2.59E-09	mm, kg
	b	3.2064	
Maturity-at-age	(0–11) 0	(12) 0.1667	Proportion
	(13) 0.3333	(14) 0.5000	
	(15) 0.6667	(16) 0.8333	
	(17+) 1		

Recruitment surveys

A5. Research surveys using trawl to catch small *D. eleginoides* have been undertaken since 1990 (Table A3). The survey design was consolidated in 2001 and the distribution of sampling effort amongst strata was revised in 2003 (WG-FSA-04/74).

A6. Australia undertook a trawl survey during April 2013 to estimate the density of juvenile toothfish (WG-FSA-13/21). A consistent survey design has been in place since 2006, with sampling in nine strata which are based on depth and fish abundance. The same number of trawls in each stratum, but with unique randomly selected positions, is conducted in each year.

Table A3: 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 since 2007 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

[a] Incomplete survey.

A7. The allocation of sample stations to strata in the historical surveys was reviewed in 2006 (WG-FSA-06/44 Rev. 1). The Working Group agreed to the reassignment of stations according to the stratification of the survey design finalised in 2003 and noted the following groupings of surveys:

- Group 1 – the core surveys with the most reliable estimates of the abundance of young fish in the vicinity of Heard Island and McDonald Islands in waters less than 1 000 m deep in May–June. Random stratified trawl surveys undertaken by a commercial vessel – 2001, 2002, 2004–2013.

- Group 2 – the first large-scale random stratified trawl survey for *D. eleginoides* in the region taking into account deep water but with an emphasis on fishing grounds. The survey was undertaken by a commercial vessel in April 1999.

- Group 3 – the first survey in the region undertaken by the RV *Aurora Australis* – autumn, 1990.

- Group 4 – the second survey in the region undertaken by the RV *Aurora Australis* – winter, 1992. This survey is considered incomplete for the purposes of estimating abundance of juvenile toothfish.

- Group 5 – the third survey in the region undertaken by the RV *Aurora Australis* – spring, 1993.

- Group 6 – the second survey in the region undertaken by a commercial vessel – 2000. This survey is considered incomplete for the purposes of estimating abundance of juvenile toothfish.

- Group 7 – a survey undertaken by a commercial vessel but not sampling all strata – 2003.

A8. WG-FSA confirmed that the bootstrap resampling procedure for estimating annual abundance by length bin and the corresponding coefficients of variation is preferred over the Aitchison delta lognormal method (WG-FSA-06/64), and hence this method was used in estimating length-density estimates from surveys.

A9. Survey abundance (abundance-at-length) was used as observations in the CASAL model for all years up to 2005. Sufficient aged fish from otoliths collected during the survey were available for the years 2006 to 2011 to determine abundance-at-age using survey- and year-specific age–length keys (ALKs). The method of calculating the CV for abundance-at-age data is described in WG-FSA-11/24.

Tagging studies

A10. 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 Candy and Constable (2008) and WG-FSA-07/48 Rev. 1. It is anticipated that, as the spatial extent of fishing effort increases, these data will provide important inputs to future integrated assessments.

A11. Historically, the tagging program has been largely restricted to the main trawl ground B (Candy and Constable, 2008). At present, the small spatial extent of the program and the limited mixing of the population to other areas restrict the ability to undertake a comprehensive stock assessment. These data are, therefore, not utilised in the integrated assessment, however, the tag data from trawl ground B were used to estimate natural mortality independently of the CASAL assessment as described in Candy et al. (2011).

Commercial catch-at-length and catch-at-age data

A12. Random length samples of *D. eleginoides* were obtained from commercial catches and aggregated into 100 mm size cohorts between 200 to 1 900 mm TL for use in the assessment. Commercial catch-at-length data were used only from 2009 to 2011 for each sub-fishery since there were no aged fish available for these years. Candy (2008) described the profile maximum likelihood method used for accounting for overdispersion of the length-frequency data relative to a multinomial distribution by estimating an effective sample size (ESS) for each distribution.

A13. Random fish length samples were combined with year-specific ALKs to obtain catch-at-age data for input as observations in CASAL for each year between 1997 and 2008. Proportions at length that were combined with ALKs were calculated specifically for each sub-fishery, fishing year and season (where more than one season was fished within a year) (WG-FSA-11/24). The method of calculating ESS for catch-at-age data was described in WG-SAM-09/08 and tables of ESS are given in WG-FSA-11/24.

Standardised CPUE series

A14. The method for standardising catch-and-effort time series data was described in Candy (2004) and used to provide CPUE series for each of the main trawl grounds (grounds B and C) and the longline fishery on ground D up to, and including, 2011. These CPUE time series were used as observations of relative abundance in the assessment. The catchability constant (*q*_CPUE), treated as 'relative' observation, is an estimated parameter calculated separately for each of the three CPUE series.

Stock assessment

CASAL model structure and assumptions

Overview

A15. The CASAL population model used in the assessment of *D. eleginoides* in Division 58.5.2 was a combined-sex, single-area, three-season model (Candy and Constable, 2008). The annual cycle was defined in three seasons: 1 December – 30 April, 1 May – 30 September, 1 October – 30 November. Mortality and growth were assumed to occur uniformly over the year. Spawning was timed to occur on 1 July.

A16. The time series for the assessment was 1982 to 2011 with future projections for another 35 years. The initial age structure assumed in the assessment was for a constant recruitment at equilibrium. No stock-recruitment relationship was assumed.

A17. Fisheries were distributed in these seasons according to the spatial and temporal structure of the fisheries in Table A1. All fisheries were modelled with either a double-normal plateau (DNP) or double-normal (DN) age-based selectivity function with the different selectivities for each gear × area combination. Selectivities were assumed to remain constant across seasons with the exception of the trawl ground B fishery, which was estimated to have different selectivity parameters for the late season (s3) compared to the combined early seasons (s1 and s2). In addition, for this fishery, separate selectivity parameters were estimated for 1997–2006 and 2007–2011 catches due to the generally smaller size of fish caught in these recent seasons compared to previous seasons. The DNP function used previously for the main survey group (Group 1, years 2001, 2002, 2004–2011) was replaced by a DN function since the plateau length, parameter a_2, was typically estimated to be very small (~ 0.1 yr), thus collapsing to a DN function. The reduction in goodness of fit to the survey abundance data was not detectable when this parameter was dropped (i.e. set to zero) by fitting the DN function.

A18. The coefficient of variation, CV, for the normal distribution for length at age, required to convert length frequencies to age frequencies in CASAL, was obtained independently of CASAL from the fit of the von Bertalanffy growth model to length-at-age data (Candy et al., 2007; WG-SAM-09/09) and not estimated using CASAL. CASAL allows a single ageing error matrix (AEM) as input that is used to 'smudge' predicted catch-at-age proportions in order to compare these to observed values. WG-FSA-09/21 described the method used to construct the AEM.

Model estimation

A19. Analyses were undertaken using a point estimate Bayesian analysis (MPD: maximum posterior density). Exploration of uncertainty in parameter estimates, and its impacts on estimates of yield, used a multivariate normal (MVN) approximation based on the covariance matrix (e.g. WG-FSA-07/53 Rev. 1). Non-informative (i.e. uniform) priors were used for all parameters. The MCMC method was not adopted for this assessment due to the problems identified in WG-FSA-SAM-06/14 of unacceptably high autocorrelation in MCMC samples even after a long burn-in and very heavy 'thinning' of the sequence of MCMC samples which has continued in subsequent revisions of the model.

Observation assumptions

A20. Numbers at length for all survey years up to 2005 and numbers at age for 2006–2011 survey years were used as the primary observations. Observation error was incorporated by using CV estimates. These were applied as lognormal errors in the likelihood. Survey Group 1 was assumed to be the most accurate in estimating abundance of young fish with an assumed catchability $q = 1$. Catchability for the other survey groups was estimated, with the 1990 and 1993 surveys considered to have the same catchability.

A21. The catch proportions at age for 1997–2008 and proportions at length for 2009–2011 were fitted to the model-expected proportions using a multinomial likelihood with ESS calculated according to the method described in paragraph A13.

A22. CPUE indices were assumed to be relative indices of mid-season vulnerable biomass with an associated catchability constant q. A lognormal likelihood was used for the CPUE indices. Observation error was accounted for by using the CV estimates from the generalised linear mixed model (GLMM) standardisation described in Candy (2004).

Process error and data weighting

A23. Observations were primarily weighted using estimates of ESS and CVs. The ESS for catch-at-age and catch-at-length proportions were further adjusted (i.e. reduced) through a number of iterations by accounting for process error until ESS values converged (Candy, 2008). For a small number of fishing years the ESS values could not be determined due to insufficient data, so a value of either 200 or 400 was assigned. Process error for catch-rate data was calculated using the method described in Appendix 2 of Candy and Constable (2008). The process error was estimated to be greater than zero only for the f2 CPUE series, and at the final iteration the process error CV estimate (i.e. 'cv_process_error' for lognormal distributed data) was 0.147. No process error component was calculated for the abundance-at-age and abundance-at-length data to give extra statistical weight to the survey data (Francis, 2011).

Penalties

A24. 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. Second, an increasing penalty was applied according to the degree to which the mean of the vector of estimated YCS deviated from 1.

Priors

A25. The parameters estimated by the model, their priors, starting values for the minimisation and their bounds are given in Table A4. In the model presented here, uniform priors were chosen that are non-informative given CASAL's Bayesian implementation.

Yield calculations

A26. 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.

A27. 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.

A28. 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.

Table A4: Number (*N*), start values, priors and bounds for free parameters estimated for *Dissostichus eleginoides* in Division 58.5.2.

Parameter		*N*	Description	Prior	Lower bound	Upper bound	Start values
B_0 (tonnes)		1		Uniform	50 000	250 000	100 000
YCS		24	1983–2007	Uniform	0.001	100	1
Selectivities – surveys	S_L	15	Survey Groups 1, 2, 3, 5, 7 Fisheries f2, f2_s3, f2_s2r, f3, f5, f6, f7, f8, f9, f10	Uniform	1	10	1, 1, 1, 1, 1 1, 1, 1, 1, 3, 3, 3, 3, 3, 3
	a_1	15	Survey Groups 1, 2, 3, 5, 7 Fisheries f2, f2_s3, f2_s2r, f3, f5, f6, f7, f8, f9, f10	Uniform	2	20	4, 4, 4, 4, 4 4, 4, 4, 3, 6, 6, 6, 6, 6, 6
	a_2	10	Survey Groups 1, 2, 5 Fisheries f3, f5, f6, f7, f8, f9, f10	Uniform	0.02	20	2, 4, 4 4, 7, 7, 7, 7, 7, 7
	S_U	15	Survey Groups 1, 2, 3, 5, 7 Fisheries f2, f2_s3, f2_s2r, f3, f5, f6, f7, f8, f9, f10	Uniform	1	12	6, 4, 7.5, 4, 7.5 7.5, 7.5, 7.5, 4, 8, 8, 8, 8, 8, 8
Survey group *q*		3	1999 survey 1990/1993 surveys 2003 survey	Uniform	1e-6	1 000	-
CPUE *q*		3	Trawl ground B Trawl ground C Longline ground D	Uniform	1e-6	1 000	-

A29. Random recruitments for the projection begin in 2009 and are derived from a lognormal recruitment function where mean recruitment is R_0 for the trial, and recruitment variability was estimated from the fit of a linear mixed model (LMM) to the multivariate normal (MVN) sample of historic recruitments (1986 to 2008).

A30. For a given trial, the pre-exploitation median SSB is derived as the median of spawning biomass derived from 1 000 age structures drawn from the lognormally distributed recruitments derived above.

A31. For removals not included in the 2011 season due to catch still being taken, the anticipated remaining catch for CASAL season 3 was added to that shown in Table 1 to bring total removals to 2 550 tonnes.

A32. For the projections, future catches were allocated in the following proportions reflecting an expected shift away from trawl towards longline as the predominant capture method:

Trawl ground B – season 1	0.055
Trawl ground B – season 2	0.055
Trawl ground B – season 3	0.088
Trawl ground C – season 2	0.037
Trawl ground E – season 2	0.062
Longline ground C – season 2	0.198
Longline ground D – season 2	0.201
Longline ground E – season 2	0.201
Longline ground F – season 2	0.055
Pot – season 1	0.048.

Model estimates

A33. MPD estimates of the key parameters for the different scenarios are shown in Tables A5 and A6.

Table A5: Results of assessments of stock status of *Dissostichus eleginoides* in Division 58.5.2 using CASAL. B_0 is the MPD estimate of the pre-exploitation median spawning biomass (tonnes) with standard error (SE), SSB status 2011 is the ratio of the CASAL prediction of SSB in 2011 to B_0, R_0 is the MPD estimate of mean age-1 recruitment prior to exploitation (1981), and CV_R is the coefficient of variation of the annual recruitment series (1996–2008).

Model	B_0 (SE)	SSB status 2011	R_0 (million)	CV_R
a2-2011-alkall-PE	86 400 (1 915)	0.629	5.765	0.78

Table A6: Estimates of selectivity parameters in Survey Group 1 and catchability of the other survey groups in assessments of stock status of *Dissostichus eleginoides* in Division 58.5.2 using CASAL. Catchability q set to 1 for Survey Group 1 (2001, 2002, 2004–2011).

Model	Selectivity parameter estimates Survey Group 1 (SE)			Survey group (SG) estimate of q			
	s_L	s_U	a_1	SG3 (1990)	SG5 (1993)	SG2 (1999)	SG7 (2003)
a2-2011-alkall-PE	0.9449 (0.1006)	4.8183 (0.0908)	3.8640 (0.1290)	0.187	0.187	1.982	0.748

A34. The fitted selectivity functions for each sub-fishery show the distinct differences in how the survey, trawl and longline activities overlap with the stock (Figure A1). Notably, the surveys observe the youngest fish (less than age 5), the trawl fishery concentrates on larger pre-adult fish, and the longline fishery concentrates on larger fish, including mature fish. The notable exception is for the last two fishing seasons in trawl ground B for which the fitted selectivity function (Sel_f2_s2r) indicates that fish younger than 5 years have been selected.

A35. Model fits to the Survey Group 1 (SG1) abundance-at-length (Figure A2) and abundance-at-age (Figure A3) data from the RSTS often underestimated observed abundance numbers for length and age bins that contain most of the fish compared to observed values. This indicates that the model-estimated abundance of young fish, as indicated by other datasets, is not as high as that observed in the surveys.

A36. Figures A4 to A7 show the fit to the commercial length-frequency data for the main trawl fisheries on grounds B and C, and the two main longline fisheries on grounds C and D, for the main fishing season (s2) for each sub-fishery.

A37. The model fitted poorly to the standardised catch rates from the trawl fishing grounds, where the initial decline in observed catch rates was not replicated by the models (Figure A8). However, due to the very high uncertainty in the annual estimates, all three standardised CPUE series made a negligible contribution to model parameter estimation (see Figure A9).

A38. The contributions to the likelihood and the likelihood profiles are shown in Figure A8. Likelihood profiles were well defined and the MPD estimate (corresponding to the minimum negative log likelihood estimate) of B_0 was at the minimum points of the profile. This indicates that the estimation was well behaved with respect to B_0, with the MPD estimate at 86 400 tonnes.

A39. Figure A10 shows the estimated YCS for the period 1982 to 2007. YCS was fixed at 1 for the remaining years of the historical fishery (i.e. 1981–1983 and 2008–2010) since the data do not allow these year classes to be estimated reliably (or sensibly for the 2008–2010 period). The respective estimated time series for age-1 recruitment using year random-effect estimates obtained from the fit of the LMM to the log of numbers of age-1 recruitments and drawn from 1 000 MVN samples for the set of estimated parameters is shown in Figure A11. The estimate of yearly process error CV from the fit of the LMM was 0.78. This value was used for the forward projections using the random lognormal recruitment option in CASAL.

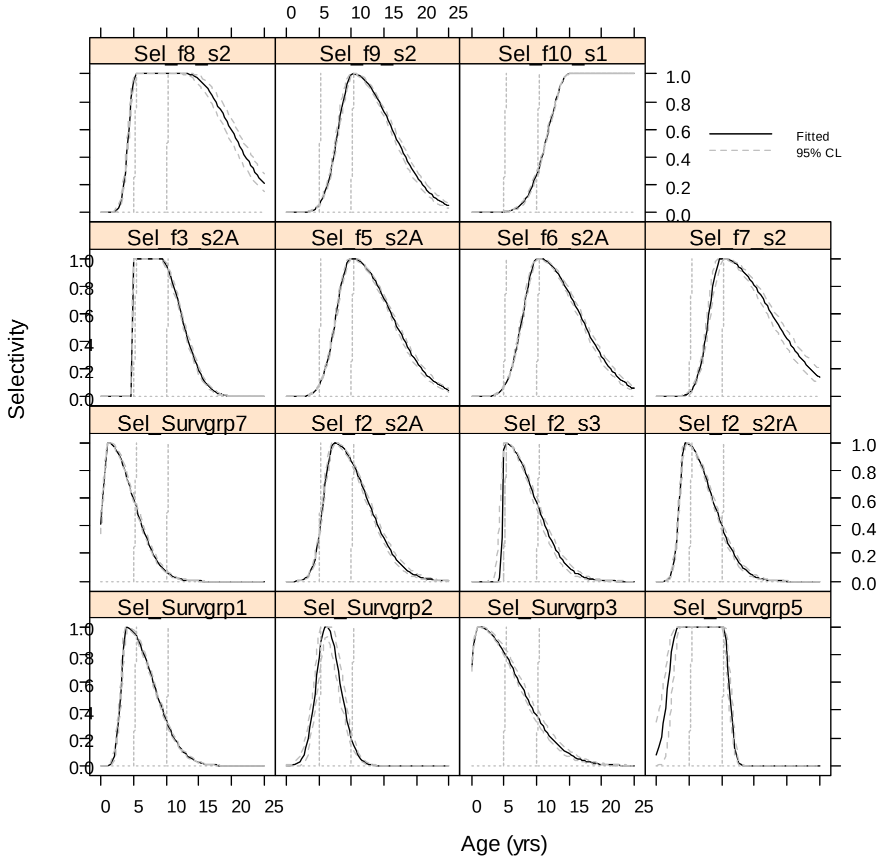


Figure A1: Double-normal-plateau (DNP) and double-normal (DN) fishing selectivity curves from fit of model a2-2011-alkpool-PE showing 95% confidence bounds obtained from the MVN sample. Panel headings: Survgrp1 (survey years 2001, 2002, 2004–2011), Survgrp2 (survey year 1999), Survgrp3 (survey year 1990), Survgrp5 (survey year 1993), Survgrp7 (survey year 2003), f2_s2 and f2_s3 (trawl ground B, 1997–2006, seasons 1 and 2, season 3), f2_s2r (trawl ground B, 2007–2011, all seasons), f3_s2 (trawl ground C, all seasons), f5_s2 (longline ground C, season 2), f6_s2 (longline ground D, season 2), f7_s2 (longline ground E, season 2), f8_s2 (trawl ground E, all seasons), f9_s2 (longline ground F, season 2), f10_s1 (pot, seasons 1 and 2). Reference lines are shown at ages 5 and 10.

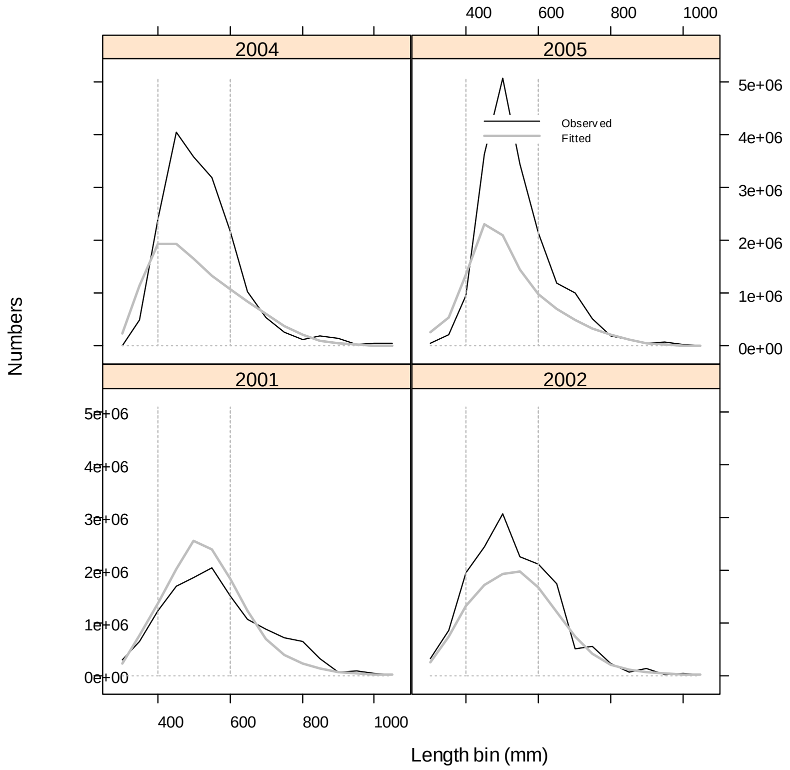


Figure A2: Model fits to Survey Group 1 abundance-at-length data from the random stratified trawl survey with observed (black line) and expected numbers (grey line) and reference lines at 400 and 600 mm.

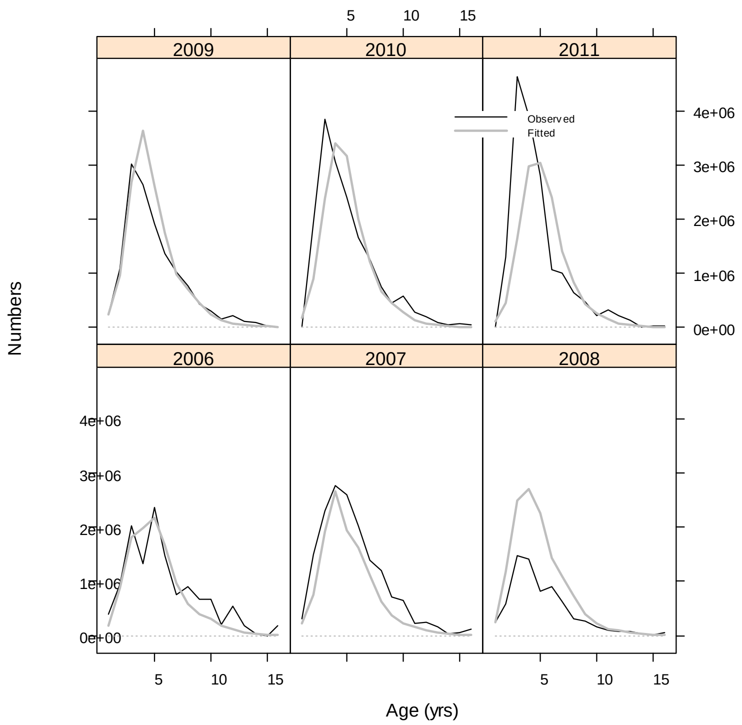
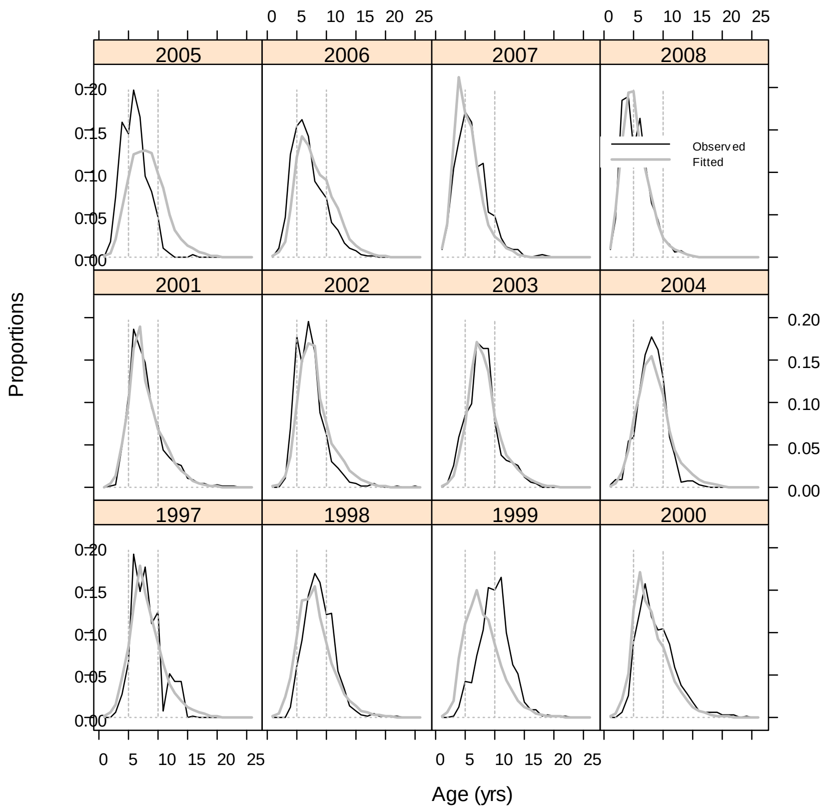


Figure A3: Model fits to Survey Group 1 abundance-at-age data from random stratified trawl survey (black lines: observed; grey lines: fitted).

(a)



(b)

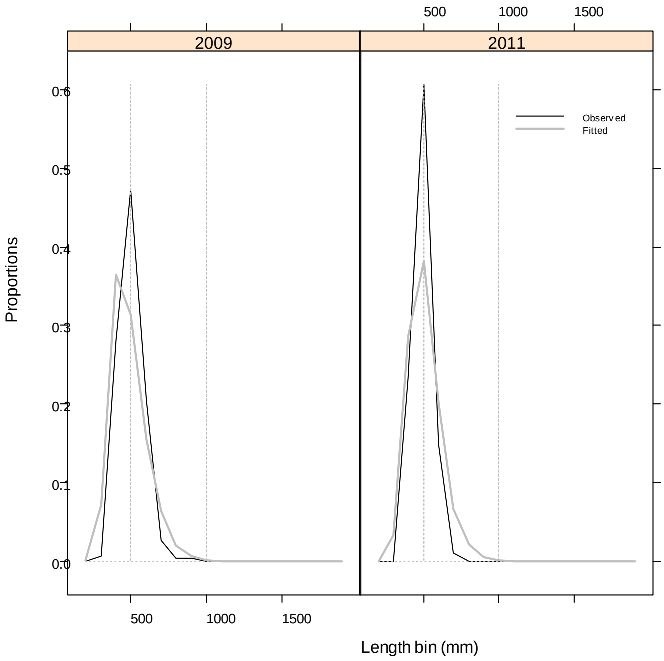


Figure A4: (a) Catch-at-age proportions with reference lines at ages 5 and 10 years, and (b) catch-at-length proportions with reference lines at 500 and 1 000 mm, for f2_s2 on trawl ground B, season 2 (black lines: observed; grey lines: fitted).

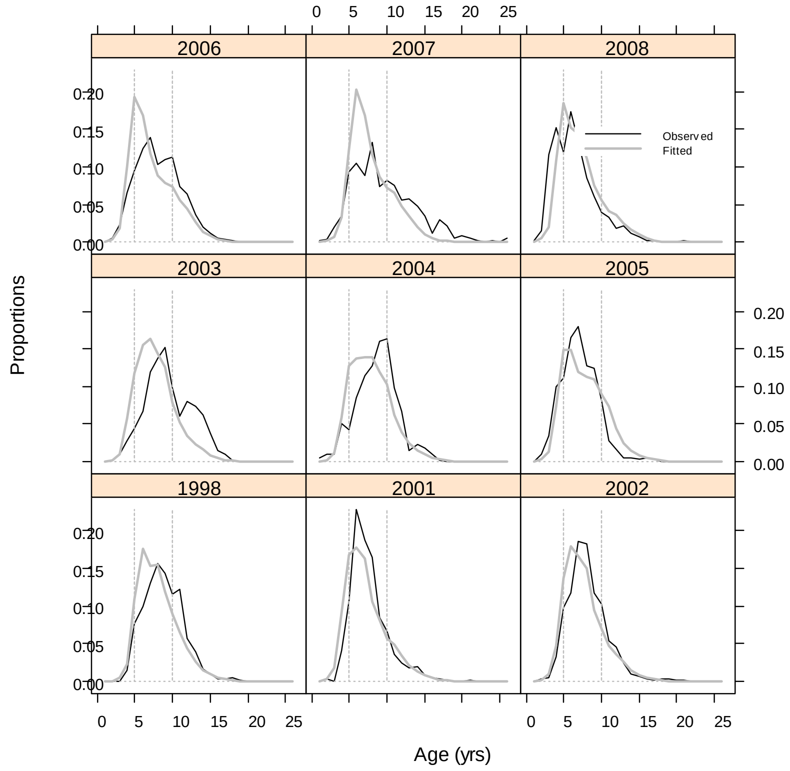
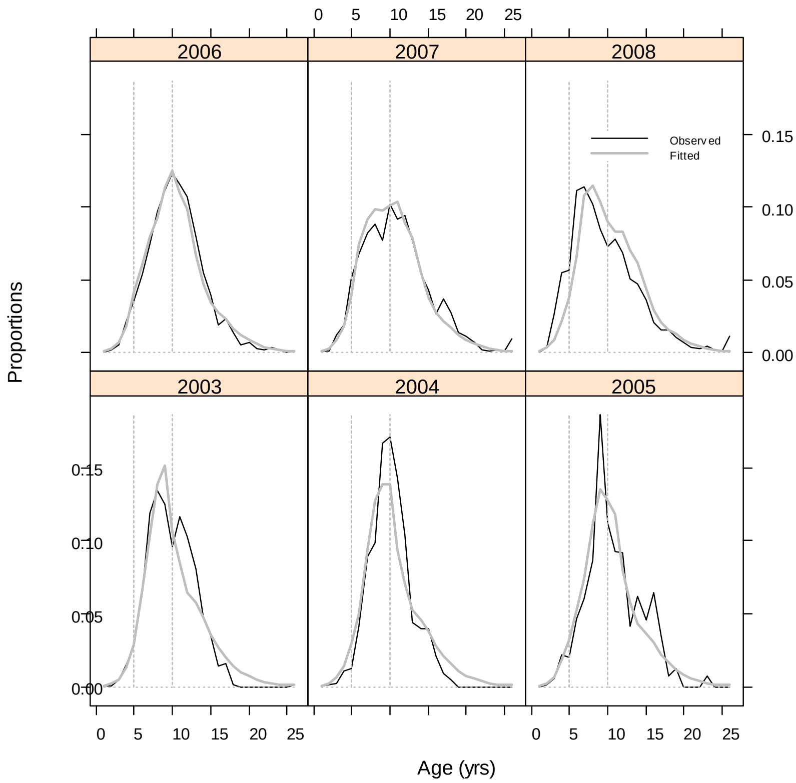


Figure A5: Catch-at-age proportions with reference lines at ages 5 and 10 years, for f3_s2 on trawl ground C, season 2 (black lines: observed; grey lines: fitted).

(a)



(b)

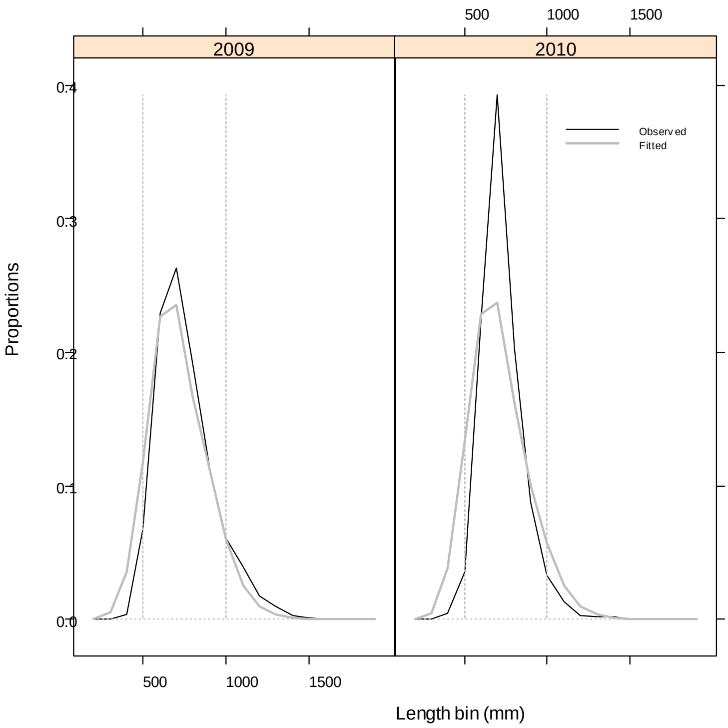
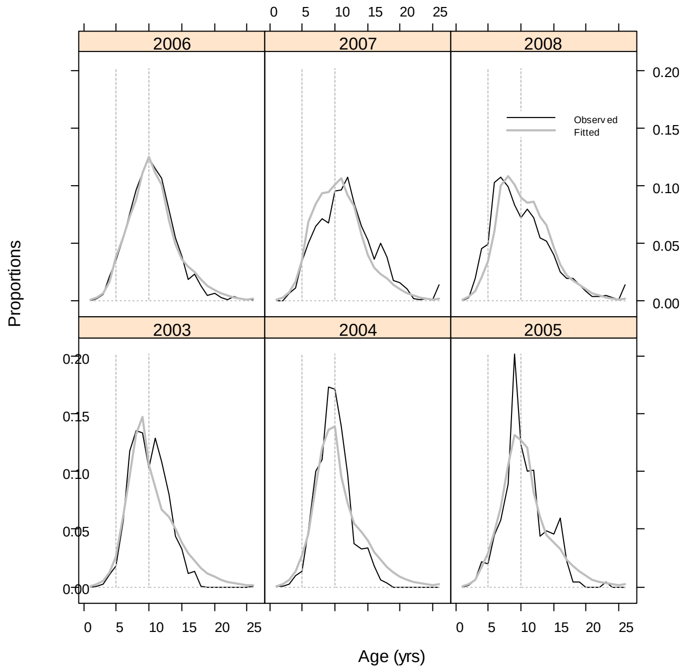


Figure A6: (a) Catch-at-age proportions with reference lines at ages 5 and 10 years, and (b) catch-at-length proportions with reference lines at lengths 500 and 1 000 mm, for f5_s2 on longline ground C, season 2 (black lines: observed; grey lines: fitted).

(a)



(b)

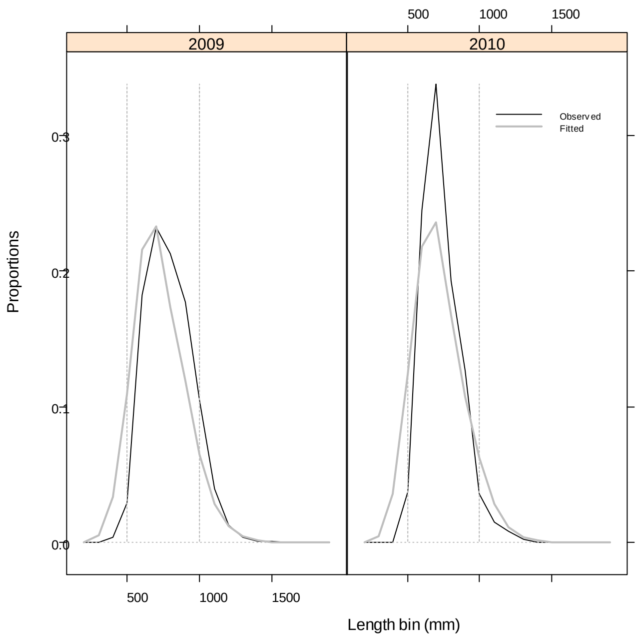


Figure A7: (a) Catch-at-age proportions with reference lines at ages 5 and 10 years, and (b) catch-at-length proportions with reference lines at lengths 500 and 1 000 mm, for f6_s2 on longline ground D, season 2 (black lines: observed; grey lines: fitted).

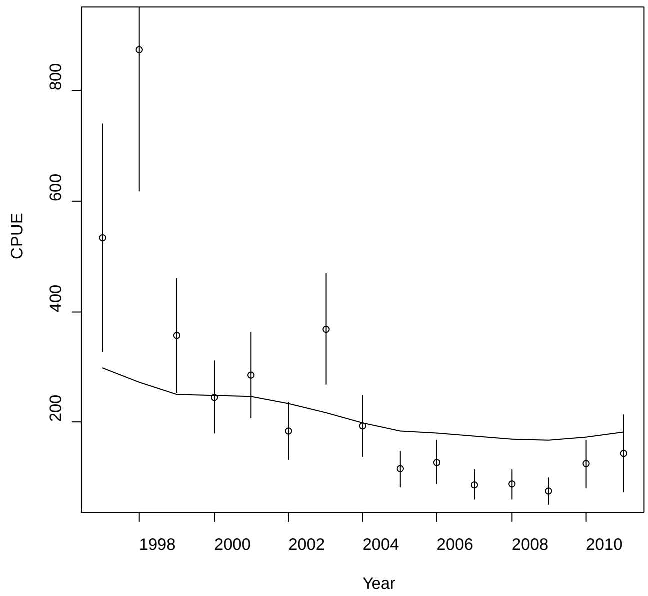


Figure A8: Estimated CPUE series from GLMM model for trawl ground B (f2) (circles) with bars corresponding to ± one standard error of the estimate and the fitted series (line).

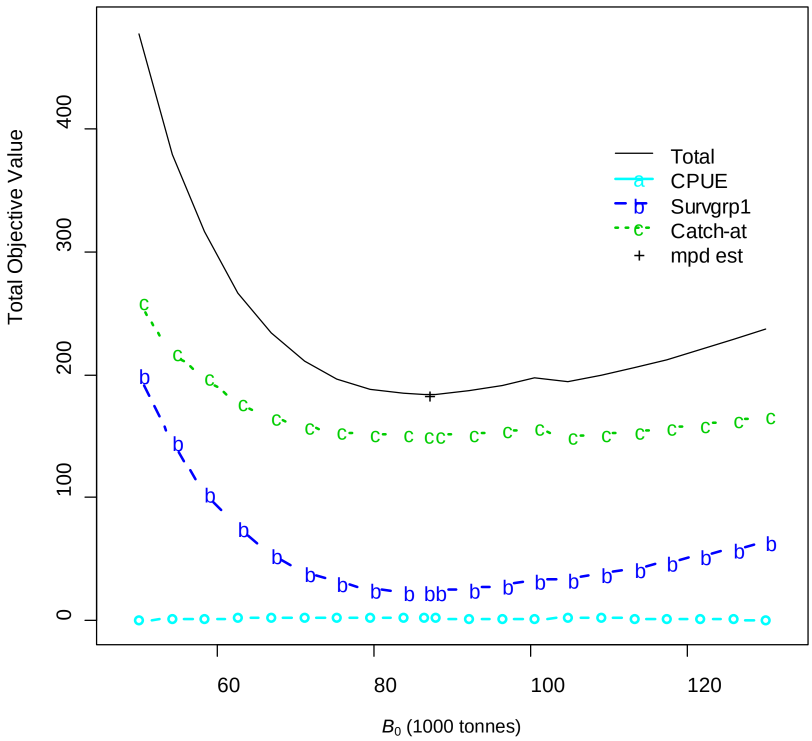


Figure A9: Likelihood profiles (–2 log-likelihood) across a range of B_0 values. To create these profiles, B_0 values were fixed while only the remaining parameters were estimated.

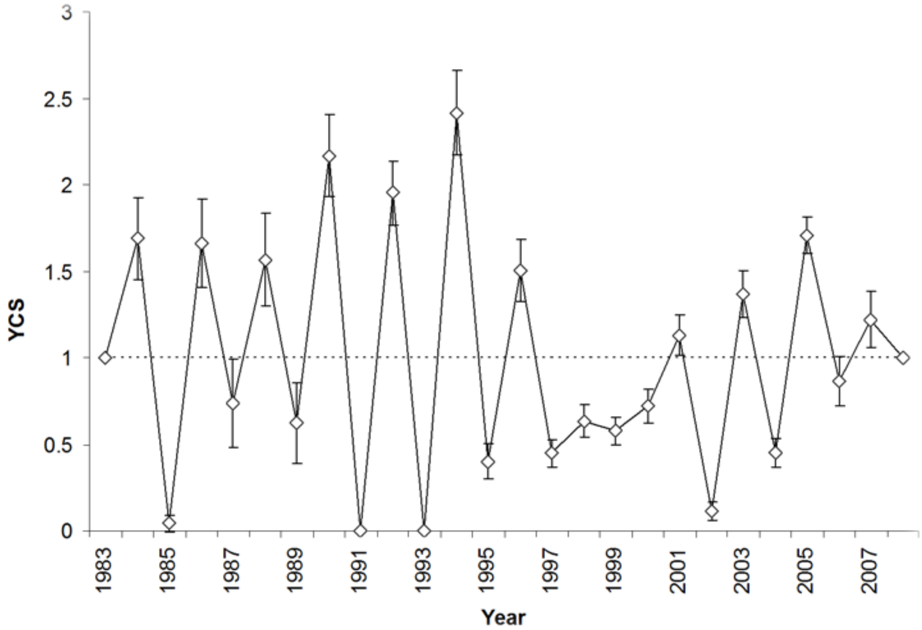


Figure A10: Estimates of year-class strength (YCS) with SE. YCS parameters were fixed to 1.0 for the periods 1981–1983 and 2008–2010.

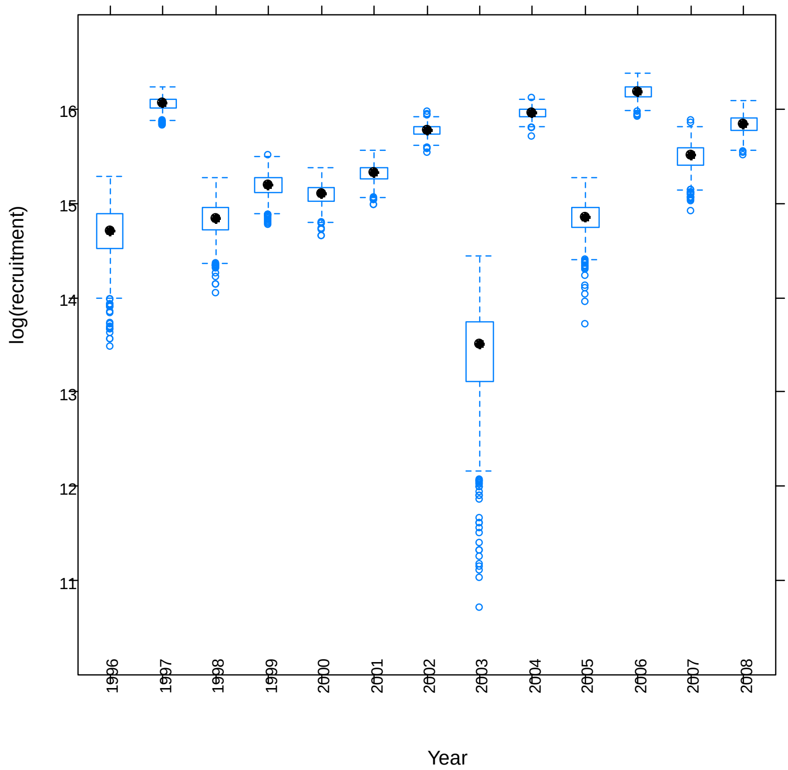
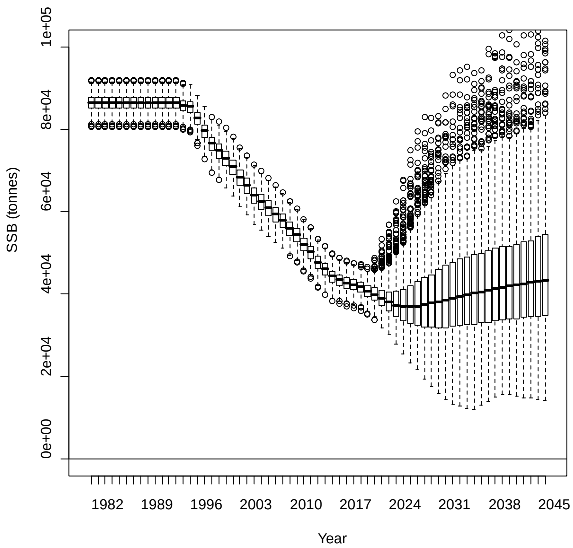


Figure A11: Box plots of age-1 recruitment series on the log scale for the historical period (1996–2008) with variability generated using 1 000 multivariate normal samples to calculate recruitment CV.

Estimation of yield

A40. Using the lognormal recruitment variability with a CV of 0.78, the estimated long-term yield that satisfies the CCAMLR harvest control rules was 2 730 tonnes with depletion probability of 0.001 and escapement probability of 0.501 (Figure A12).

(a)



(b)

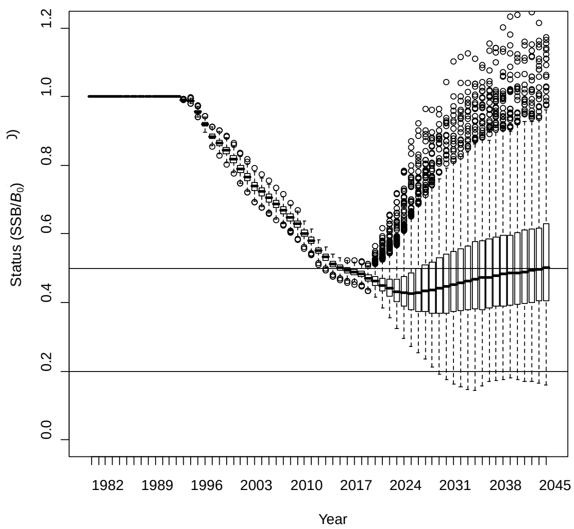


Figure A12: (a) Projected spawning stock biomass (SSB) in tonnes and (b) SSB status relative to B_0 in that projection trial, using future random lognormal recruitment from 2009 to 2046 with an annual constant catch of 2 730 tonnes in 1 000 projection trials. The lines show the 50% and 20% status levels for reference.