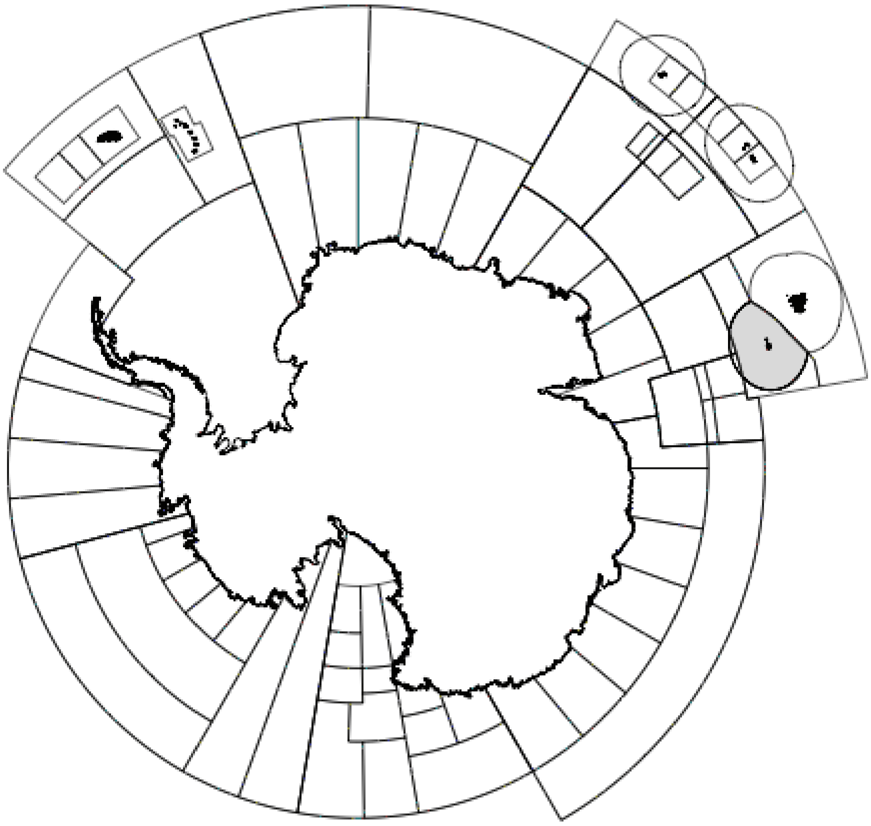
Commission for the Conservation of Antarctic Marine Living Resources
Commission pour la conservation de la faune et la flore marines de l'Antarctique
Комиссия по сохранению морских живых ресурсов Антарктики
Comisión para la Conservación de los Recursos Vivos Marinos Antárticos

Fishery Report 2018: *Dissostichus eleginoides* Heard Island Australian EEZ (Division 58.5.2)

FISHERY REPORT



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

Fishery Report 2018: *Dissostichus eleginoides*
Heard Island, Australian EEZ (Division 58.5.2)

Introduction to the fishery

1. This fishery 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 to be used, with an increasing proportion of longline fishing in each year. Since 2015 almost the entire catch has been taken by longline.

3. The fishery is managed by the Australian Fisheries Management Authority (AFMA) in accordance with the conservation measures adopted by CCAMLR and Australian law. 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 2018, the longline fishery was active from 1 April and the trawl fishery was open throughout the whole season. Four vessels participated in the fishery in 2018: three vessels fished using longlines only and one vessel fished using both longlines and trawls.

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 ranged from 2 427 tonnes in 2007 to 4 410 tonnes in 2015.

7. The reported catch of *D. eleginoides* in 2018 was 3 127 tonnes.

Illegal, unreported and unregulated (IUU) fishing

8. No illegal, unreported and unregulated (IUU)-listed vessels were sighted in Division 58.5.2 inside the Heard Island and McDonald Islands exclusive economic zone (EEZ) during the period from 2006 to 2016. However, surveillance reports indicate that IUU fishing activities did occur in Division 58.5.2 outside the Heard Island and McDonald Islands EEZ, and therefore brief fishing forays into the EEZ cannot be discounted. IUU fishing gear was also recovered in 2006 and 2011, indicating IUU fishing activities have potentially occurred in the region. Information from satellite surveillance trials indicated the presence of unidentified vessels in this division outside the Heard Island and McDonald Islands EEZ in 2016. In May 2017, a section of gillnet was recovered during fishing operations in Division 58.5.2 (see COMM

CIRC 17/74). 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	2863	531
2005	2787	621	0	2122	2743	265
2006	2584	659	68	1801	2528	74
2007	2427	601	0	1787	2388	0
2008	2500	835	0	1445	2280	0
2009	2500	1168	10	1286	2464	0
2010	2550	1213	30	1215	2458	0
2011	2550	1383	34	1148	2565	*
2012	2730	1356	0	1361	2717	*
2013	2730	2074	40	563	2677	*
2014	2730	2642	0	108	2750	*
2015	4410	4021	0	205	4226	*
2016	3405	2619	0	156	2775	*
2017	3405	3343	0	24	3367	*
2018	3525	3083	0	44	3127	*

* 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 50 years of age have been found (Welsford et al., 2011; WG-FSA-15/55). Fifty percent of fish are estimated to be mature at around 14 years of age (WG-FSA-17/P04). *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 spawning locations, with tagging studies showing occasional migrations of more than 2 500 km to the deeper slopes around 1 400–1 800 m depth (Welsford et al., 2011).

10. *Dissostichus eleginoides* at Heard Island and McDonald Islands as well as Kerguelen and Crozet Islands appear to have a high level of genetic homogeneity and are distinctly different from those at more distant locations such as South Georgia and Macquarie Island (Toomey et al., 2016). 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 some level of stock linkages of *D. eleginoides* exists in the Indian Ocean sector.

Data collection

11. Catch limits for CCAMLR's fisheries for Antarctic toothfish (*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-17/14 for the 2017 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 a small number of 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). Larger fish are seldom caught by trawling and there is evidence from tag recaptures and size distribution of the catch by depth that fish, as they grow, move into deeper water (>1 000 m depth) where they are caught by longline.

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 >500 000 fish have been measured in this division.

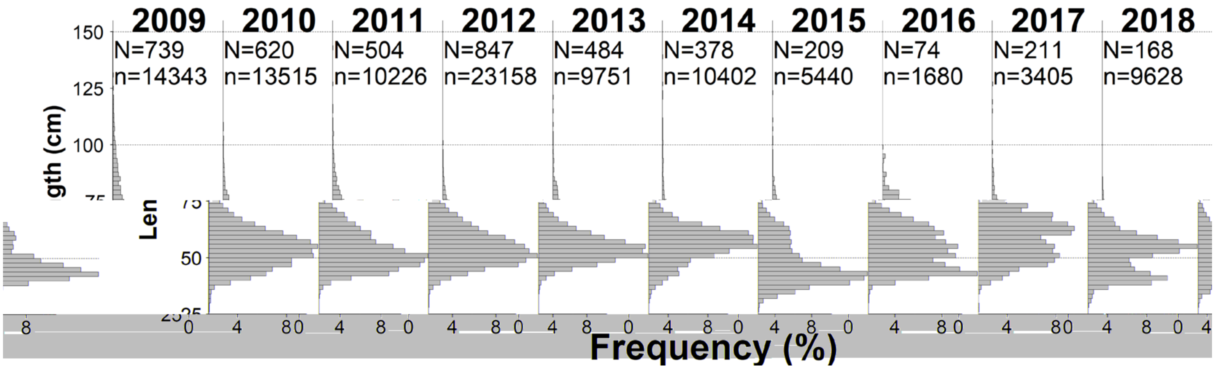


Figure 1: Annual length-frequency distributions of *Dissostichus eleginoides* caught by trawl in the Australian EEZ in Division 58.5.2 since 2009. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided.

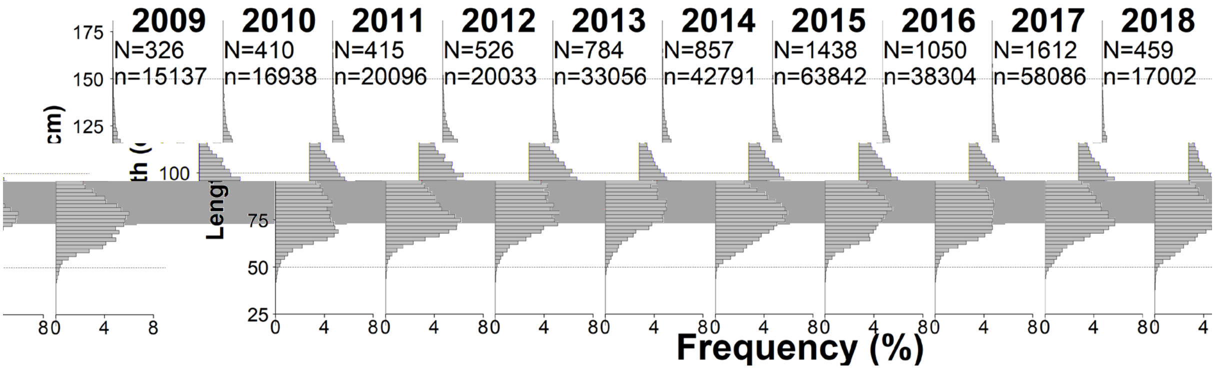


Figure 2: Annual length-frequency distributions of *Dissostichus eleginoides* caught by longline in the Australian EEZ in Division 58.5.2 since 2009. The number of hauls from which fish were measured (N) and the number of fish measured (n) in each year are provided.

15. The majority of *D. eleginoides* caught by trawl measured between 30 and 100 cm with a mode around 50–60 cm, while those caught by longline measured between 50 and 125 cm with a mode around 70–80 cm. 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 2015 are provided in WG-FSA-15/55. By 2015, there had been 32 934 releases of tagged fish in Division 58.5.2 of which 5 101 were recaptured within Division 58.5.2 and 247 were recaptured in Division 58.5.1 (WG-FSA-15/55).

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; WG-FSA-14/43). 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 has 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 from 2012 to 2015 were incorporated into the stock assessment in 2017 (see Appendix 1).

Stock assessment

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

19. The assessment model in 2017 was a single-sex, single-area, age-structured population model including age classes from 1 to 35 years.

20. Data from the RSTS, tag-recapture data, commercial catch and length data, and biological data provided input to the assessment model for this fishery. The fisheries structure comprised one survey group from the RSTS, and the commercial sub-fisheries of trawl from 1997 to 2004 and trawl from 2005 to 2017, pot, longline from <1 500 m and longline from >1 500 m depth.

21. Compared to the 2015 assessment, the 2017 assessment took into account (i) new fishery observations up to the end of 2016 including new ageing data from the RSTS and commercial fishery from 2015/16, (ii) updated growth parameters, (iii) updated maturity parameters (WG-FSA-17/P04), (iv) updated tag-loss estimates (WG-FSA-17/21), (v) a bias correction for fish emigrating out of Division 58.5.2 (WG-SAM-17/11), (vi) survey biomass and catch proportions instead of survey abundance numbers, and (vii) iterative data weighting using the Francis method (2011a and 2011b).

22. The 2017 assessment model estimated a virgin spawning stock biomass B_0 of 77 286 tonnes (95% CI: 71 492–84 210 tonnes) and an estimated *SSB* status in 2017 of 0.61 (0.58–0.64). The estimated long-term yield from this projection was 3 525 tonnes with a depletion probability of 0.0 and an escapement probability of 0.503 (Figure 3).

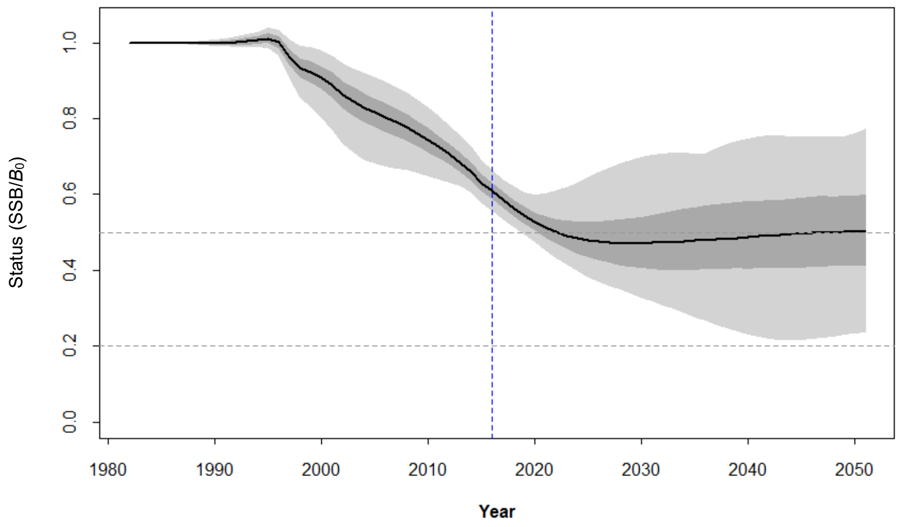


Figure 3: Projected SSB status relative to B_0 using MCMC samples and future random lognormal recruitment from 2012 to 2051 with annual constant catches. Shown are median (black line), 100% confidence bounds (light grey) and 80% confidence bounds (dark grey). Horizontal dotted lines show the 50% and 20% status levels used in the CCAMLR decision rules, the vertical blue line indicates the current year.

By-catch of fish and invertebrates

Fish by-catch

23. 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.

24. Catch limits for by-catch species groups (macrourids, rajids and other species) are defined in CM 33-02 and provided in Table 2.

25. A quantitative risk assessment of the Caml grenadier (*Macrourus caml*) was undertaken in 2015 and WG-FSA-15 recommended a catch limit of 409 tonnes for *M. caml* and Whitson's grenadier (*M. whitsoni*) combined based on the risk assessment in WG-FSA-15/63, and a catch limit of 360 tonnes for bigeye grenadier (*M. holotrachys*) and ridge-scaled grenadier (*M. carinatus*) combined based on the previous assessment from 2003. These by-catch limits were introduced in 2016 and are reflected in Table 2.

26. 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, when including by-catch that was caught on the longlines but cut-off before being landed, estimates ranged from 11% to 26% of the total catch. No by-catch species was caught in quantities approaching the catch limit.

27. An analysis of the by-catch species unicorn icefish (*Channichthys rhinoceratus*) and grey rockcod (*Lepidonotothen squamifrons*) indicated that both species are widespread over the plateau in depths of <1 000 m (WG-FSA-15/50). Up to 2015, the catch limits of *C. rhinoceratus* and *L. squamifrons*, 150 tonnes and 80 tonnes respectively, were based on assessments carried out in 1998 (SC-CAMLR-XVII, Annex 5). Catches of each of these species since 2004 have been well below the limits set by CCAMLR (Table 3). A quantitative risk assessment of *C. rhinoceratus* was undertaken in 2015 and WG-FSA-15 recommended a by-catch limit of 1 663 tonnes for *C. rhinoceratus*.

28. Length–weight relationships, length-at-maturity data and estimates of abundance from survey data for rajids were presented in WG-FSA-05/70. An analysis of the skate tagging program (WG-FSA-13/22) indicated a recapture rate of <1% and an average distance between release and recapture of 4 n miles. An analysis of catch rates from 1997 to 2014 of the three skate species (Nowara et al., 2017) shows little evidence of depletion on the main trawl grounds, except for a decrease in the average total length of Eaton's skate (*Bathyraja eatonii*). One of the skate species Kerguelen sandpaper skate (*B. irrasa*), shows a slight decline in catch rates in the deeper waters around Heard Island and McDonald Islands where the longline fishery operates. This study also calculated a growth rate of ~20 mm per year, and a maximum age >20 years for *B. eatonii*, estimated from tag returns.

Table 2: 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 all targeted fishing in Division 58.5.2 (see CM 33-03 for details). From 1997 to 2015, all macrourids were reported as a single taxon for the purpose of by-catch limits. (Source: fine-scale data.)

Season	*Macrourus caml* and *M. whitsoni*				*Macrourus holotrachys* and *M. carinatus*				Rajids				
	Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)			Number released
		Longline	Trawl	Total		Longline	Trawl	Total		Longline	Trawl	Total	
1997	-	0	<1	<1					-	0	2	2	-
1998	-	0	<1	<1					120	0	2	2	-
1999	-	0	1	1					-	0	2	2	-
2000	-	0	4	4					-	0	6	6	-
2001	-	0	1	1					50	0	4	4	-
2002	50	0	3	4					50	0	3	3	-
2003	465	3	1	4					120	5	7	12	-
2004	360	42	3	46					120	62	11	73	155
2005	360	72	2	74					120	70	3	73	8412
2006	360	26	<1	27					120	17	12	29	3814
2007	360	61	5	66					120	8	10	18	7882
2008	360	81	5	86					120	13	8	21	9155
2009	360	110	2	112					120	15	9	24	10291
2010	360	100	3	103					120	11	6	17	10382
2011	360	147	4	151					120	11	3	14	6938
2012	360	89	3	92					120	7	3	10	8484
2013	360	154	3	157					120	13	11	24	12605
2014	360	175	1	176					120	16	<1	16	19565
2015	360	288	4	292					120	19	5	24	37863
2016	409	78	<1	79	360	220	0	220	120	20	1	21	32287
2017	409	89	1	90	360	235	0	235	120	30	2	32	43848
2018	409	95	0	95	360	241	0	241	120	20	1	21	28141

Table 3: 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	1	1	80	0	3	3	50	3	48	51
2005	150	0	3	3	80	0	2	2	50	3	7	10
2006	150	0	3	3	80	0	5	5	50	3	8	11
2007	150	0	12	12	80	0	10	10	50	1	4	5
2008	150	0	29	29	80	0	20	20	50	2	12	14
2009	150	0	46	46	80	0	26	26	50	9	10	19
2010	150	0	26	26	80	0	48	48	50	6	10	16
2011	150	0	23	23	80	0	26	26	50	11	4	15
2012	150	0	42	42	80	0	34	34	50	7	10	17
2013	150	0	25	25	80	0	44	44	50	9	65	74
2014	150	0	<1	<1	80	0	2	2	50	12	1	13
2015	150	0	1	1	80	0	2	2	50	38	2	40
2016	1663	0	9	9	80	<1	3	3	50	21	20	41
2017	1663	0	2	2	80	<1	2	2	50	27	19	46
2018	1663	0	1	1	80	<1	4	4	50	27	10	37

Incidental mortality of seabirds and marine mammals

Incidental mortality

29. A summary of the bird mortality by longline in the Australian EEZ in Division 58.5.2 since 2004 is presented in Table 4. The three most common species injured or killed in the fishery were the Cape petrel (*Daption capense*) white-chinned petrel (*Procellaria aequinoctialis*).

Table 4: Number of seabird mortalities in the longline fishery in the Australian EEZ in Division 58.5.2.

Season	*Daption capense*	*Procellaria aequinoctialis*	*P. cinerea*	Other
2008				
2009	1			
2010	3			
2011				
2012				
2013				
2014				
2015	1			2
2016		5		2
2017		1	1	
2018			1	

30. In 2018, there was one grey petrel (*P. cinerea*) mortality observed inside the Australia EEZ in Division 58.5.2.

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

32. There were seven southern elephant seal (*Mirounga leonina*) mortalities reported in the longline fishery in Division 58.5.2 during 2017 and two reported from 2018.

Depredation

33. Low levels of sperm whale depredation have been observed in Division 58.5.2 since 2011 (WG-FSA-15/53). Sperm whale sightings occur exclusively in the April–June period.

Mitigation measures

34. CM 25-03 is in force to minimise the incidental mortality of birds and 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 birds so that hook lines sink beyond the reach of birds 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. A core fishing season and season extensions are specified in CM 41-08. If three seabirds are caught during the season extension by a vessel, 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, an IUCN Category 1a reserve where fishing is prohibited (SC-CAMLR-XXI/BG/18). The marine reserve covers a total area of 71 000 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 benthos by-catch 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 5.

Table 5: 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	3 525 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 1 to 30 April and 15 September to 30 November each season for any vessel that has demonstrated full compliance with CM 25-02 in the previous season.

(continued)

Table 5 (continued)

Element	Limit in force
By-catch	Fishing shall cease if the by-catch limit of any species, as set out in CM 33-02, is reached: *Channichthys rhinoceratus* 1 663 tonnes *Lepidonotothen squamifrons* 80 tonnes *Macrourus carinatus* and *M. holotrachys* 360 tonnes *Macrourus caml* and *M. whitsoni* 409 tonnes Skates and rays 120 tonnes
Move-on-rule	If the catch limits for any one haul, as set out in CM 33-02, are reached, the vessel must not fish using that method within 5 n miles of the location for at least 5 days: *Channichthys rhinoceratus* 5 tonnes *Macrourus* spp. combined 3 tonnes *Lepidonotothen squamifrons* 2 tonnes *Somniosus* spp. 2 tonnes Skates and rays 2 tonnes Other by-catch species 1 tonne
Mitigation	In accordance with CMs 24-02, 25-02 and 25-03, minimisation of risk of the incidental mortality of birds and 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 Annex 41-08/A. Reported in accordance with the CCAMLR Scheme of International Scientific Observation
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 2017

A1. The Heard Island and McDonald Islands fishery for Patagonian toothfish (*Dissostichus eleginoides*) in Division 58.5.2 was assessed in 2017 with an integrated stock assessment using CASAL (WG-FSA-17/19).

Model data

A2. The historical catches of *D. eleginoides* in Division 58.5.2 are provided in Table 1.

A3. A large number of toothfish have been measured annually for length in the surveys and the commercial fishery (Table A1). Over 17 000 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 Heard Island and McDonald Islands assessment for surveys and commercial fisheries. Where numbers are in bold, the ages have been used to calculate age–length keys (ALKs). RSTS – random stratified trawl survey.

Year	Length			Age		
	RSTS	Commercial	Total	RSTS	Commercial	Total
1997	0	11387	11387	0	**55**	55
1998	169	11229	11398	0	**286**	286
1999	2294	14623	16917	2	**623**	625
2000	2258	20483	22741	20	**807**	827
2001	2505	27079	29584	2	**909**	911
2002	2965	18476	21441	4	**829**	833
2003	2301	27298	29599	13	**675**	688
2004	2462	33509	35971	4	**336**	340
2005	2355	28899	31254	1	**370**	371
2006	2081	31427	33508	**119**	**1100**	1219
2007	2050	22843	24893	**547**	**588**	1135
2008	1281	31475	32756	**652**	**107**	759
2009	1922	44342	46264	**642**	**77**	719
2010	5893	30485	36378	**918**	**129**	1047
2011	2484	35568	38052	**520**	**142**	662
2012	6062	37026	43088	**549**	**140**	689
2013	2912	42736	45648	**266**	**1249**	1515
2014	2769	50417	53186	**571**	**526**	1099
2015	3869	18661	22530	**656**	**559**	1215
2016	5630	57078	62708	**315**	**537**	852
Total	54262	650779	705041	5801	11533	17334

Random stratified trawl surveys

A4. Random stratified trawl surveys (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 2017. 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 2004–2017 (WG-FSA-17/14).

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*, AC – FV *Atlas Cove*, DT – demersal trawl. Note: surveys from 2007 to 2013 exclude Shell Bank.

Survey year	Month	Vessel	Gear	Original design area (km^2)	Area following reassignment (km^2)	Hauls	Catch (tonnes)
1990	May	AA	DT	97106	53383	59	16
1992	Feb	AA	DT	55817	38293	49	3
1993	Sep	AA	DT	71555	53383	62	12
1999	Apr	SC	DT	84528	80661	139	93
2000	May	SC	DT	39839	32952	103	9
2001	May	SC	DT	85170	85694	119	45
2002	May	SC	DT	85910	85694	129	35
2003	May	SC	DT	42280	42064	111	13
2004	May	SC	DT	85910	85694	145	65
2005	May	SC	DT	85910	85694	158	21
2006	May	SC	DT	85694	85694	158	12
2007	Jul	SC	DT	83936	83936	158	12
2008	Jul	SC	DT	83936	83936	158	4
2009	Apr–May	SC	DT	83936	83936	161	19
2010[a]	Apr	SC	DT	83936	83936	134	6
2010	Sep	SC	DT	83936	83936	158	9
2011	Mar–May	SC	DT	83936	83936	156	7
2012	Mar–May	SC	DT	83936	83936	174	15
2013	Apr	SC	DT	83936	83936	158	8
2014	Jun	SC	DT	83936	83936	163[b]	14
2015	May	AC	DT	83936	83936	163	27
2016	April	AC	DT	83936	83936	163	14
2017	April	AC	DT	83936	83936	163	21

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

A5. For the assessment, observations from the survey years 2001–2002 and 2004–2016 were used. The annual survey biomass and coefficient of variation (CV) for these survey years was estimated as the sum of biomass estimates in each surveyed stratum which were derived from a stratified bootstrap of the estimated fish density in survey hauls. Based on simulations by de la Mare et al. (WG-SAM-15/34) and a recommendation by WG-SAM-15 (SC-CAMLR-XXXIV, Annex 5, paragraph 2.10), a uniform-log prior for survey catchability q with parameter bounds from 0.1 to 1.5 was used.

A6. For all survey years 2006–2015, catch-at-length data were used to estimate proportions at length, weighted by stratum–area. These were then converted to proportions at age using age–length keys (ALKs). The initial effective sample size(s) (ESS) were derived by assuming a relationship between the observed proportions-at-age, O_j, and their CVs, c_j, as estimated from bootstrap sampling that accounted for haul-specific proportions at length, the ALK and random ageing error. The estimated effective sample size was then derived using a robust non-linear least squares fit of $\log(c_j) \sim \log(O_j)$ assuming a multinomial distribution.

A7. The fishery structure was evaluated following the method developed by Candy et al. (WG-SAM-13/18) and consisted of sub-fisheries for trawl from 1997 to 2004 (Trawl1), trawl from 2005 to 2016 (Trawl2), pot, longline in <1 500 m depth (LL1), and longline in >1 500 m depth (LL2). The illegal, unreported and unregulated (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.

A8. For all years with commercial fishing from 1997 to 2016, catch-at-length data were used to estimate catch proportions at length and converted to proportions at age using commercial ALKs. Similarly to the survey data, initial ESS for all years and sub-fisheries, except pot, were estimated by fitting a robust non-linear least squares model to the observed proportions at age against their CVs assuming a multinomial distribution. For pot fisheries, ESS was set to 1 to allow for the estimation of pot selectivity while the information content of the data was considered to be poor due to high interannual variability in areas and depths fished.

Tagging data

A9. Longline tag releases from 2012 and 2015 and their subsequent recaptures were incorporated into the assessment model (Table A3). Within-season recaptures were not used in the analysis. The model assumed that tag-release mortality was 0.1, the no-growth period after tagging was 0.5 years and tag-detection rate was 100%. Tag-shedding rates in CASAL's single-tag model were estimated as l = 0.021 (WG-FSA-17/21). Tag-dispersion φ was estimated at 1.228 following the method in Mormede et al. (WG-FSA-13/51).

Table A3: Numbers of tag releases, tag recaptures and scanned fish that were used in the 2017 assessment. Data for 2015 is incomplete.

Releases		Recaptures				
Year	Numbers	2013	2014	2015	2016	Total
2012	1433	22	40	39	21	122
2013	1467	-	52	94	37	183
2014	1799	-	-	77	58	135
2015	7631	-	-	-	261	261
Total	12330	22	92	210	377	701
Scanned fish:		357576	412287	635104	459684	1864651

Biological parameters

A10. Natural mortality was assumed to be 0.155 (Candy et al., 2011) and constant across all age classes. Fish growth using a von Bertalanffy growth function was estimated following the approach of Candy et al. (2007). An ageing error matrix (AEM) was estimated following the method by Burch et al. (WG-FSA-14/46).

CASAL model structure and parameter estimates

A11. The CASAL population model used for 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. The model parameters and data are detailed in Table A4. CASAL version 2.30-2012-03-21 rev 4648 was used following the recommendation of WG-SAM-14.

A12. The assessment model was run for the period from 1982 to 2016. The annual cycle was divided into three time steps or seasons during which (i) fish recruitment, the first half of natural mortality, and fishing, (ii) the second part of natural mortality and spawning, and (iii) ageing occurred. The models estimated B_0, annual year-class strength (YCS) from 1986 to 2011, the parameters for the selectivity functions of the survey group and all commercial sub-fisheries, and survey catchability q.

A13. Either double-normal (DN) or double-normal-plateau (DNP) fishing selectivity functions were fitted for the survey group and each commercial sub-fishery (Bull et al., 2012). 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-fisheries, while all longline and the pot sub-fisheries were fitted with DNP functions.

Model fitting procedure

A14. Priors were defined for all free parameters in the models. Penalties were included for YCS to force the average of estimated YCS towards 1 and catch to prevent the model from estimating a fishable biomass for which the catch of each sub-fishery in any given year would exceed the maximum exploitation rate set at $U = 0.995$.

Table A4: Population parameters, their values and data used in the assessment for *D. eleginoides* in Division 58.5.2 in 2015.

Parameters	Values	Data	Values
Assessment period	1982–2016	RSTS:	Survey
B_0 and recruitment:		Biomass index	2001–2016
B_0	Estimated	Survey numbers at age	2006–2016
Mean recruitment R_0	Derived from B_0	Commercial sub-fisheries:	Trawl1, Trawl2, LL1, LL2, Pot
Period of estimated YCS	1986–2011	Proportions at age	1997–2016
σ_R for projections	Calculated from YCS 1992–2011	Estimated sample size (ESS)	Estimated, except set to 1 for Pot
Stock–recruitment and steepness *h*	Beverton-Holt $h = 0.75$	Tagging data	
Age classes	1–35 y	Tag-releases	
Length classes	300–2000 mm	Sub-fisheries	LL1, LL2
Size-at-age:	von Bertalanffy	Years	2012–2015
L_∞	1605		
K	0.049		
t_0	–3.64		
CV	0.131		
Ageing error matrix	Burch et al. (WG-FSA-14/46)	Tag-recaptures	
Weight at length *L* (mm to t)	$c = 2.59\text{E-}12$, $d = 3.2064$	Sub-fisheries	LL1, LL2
Maturity: Range 5–95%	11–17 y	Years	2013–2016
Natural mortality *M*	0.155		
Survey *q*	Estimated		
Tagging data			
Tag detection	1.00		
Tag shedding	0.016		
Tag-release mortality	0.1		
No-growth period	0.5 y		
Priors and bounds			
B_0	Prior: uniform		
Starting value	90 000		
Bounds	30 000–250 000		
Survey *q*	Prior: uniform-log Bounds: 0.1–1.5		
YCS	Prior: lognormal		
Starting value	$\mu = 1$, CV = 0.6		
Bounds	0.001–200		
Fishing selectivities:			
Double-normal:	Prior: uniform		
Sub-fisheries	Survey, Trawl1, Trawl2		
Starting values (bounds)	a_1: 4 (1–20) σ_L: 1 (0.1–20) σ_R: 7 (0.1–20)		
Double plateau normal:	Prior: uniform		
Sub-fisheries	LL1, LL2, Pot		
Starting values (bounds)	a_1: 10 (1–20) a_2: 6 (0.1–20) σ_L: 1 (0.1–20) σ_R: 3 (0.1–20) a_{max}: 1 (1–1)		
Number of parameters	48		

A15. When fitting the assessment models, excluding the effect of process error by using the initial 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 following the method TA1.8 described by Francis (2011a and 2011b). The reweighting was applied first to the commercial catch composition data of all sub-fisheries, then to the survey composition data, and lastly to the tag-recapture data.

A16. 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 Markov Chain Monte Carlo (MCMC) sampling. For the MCMCs, the first 500 000 iterations were dismissed (burn-in), and every 1 000th sample taken from the next 1 million iterations. MCMC trace plots were used to determine evidence of non-convergence.

Yield calculations

A17. 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 2012, corresponding to YCS estimates from 1986 to 2011. The median of the square root of the variance of the yearly numbers of these age-1 recruits from 1992 to 2012 provided a robust estimate of the CV_R for recruitment required for the lognormal random recruitment generation.

A18. The estimated CVs were used to generate the random recruitment from 2012 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.

A19. The depletion probability was calculated as the proportion of samples from the Bayesian posterior where the projected future spawning stock biomass (SSB) was below 20% of the pre-exploitation median spawning biomass in any one year, for each year over a 35-year projected period. 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.

A20. Catch limit estimates were based on the assumption of constant annual catches. Future surveys were assumed to be conducted every year with a catch of 20 tonnes. The entire remaining future catch was assumed to be taken by longline, with a catch split based on the catch distribution of longline sub-fisheries in the last three years. This meant that 50% of the total catch was attributed to LL1 and 50% to LL2.

Model estimates

A21. The 2017 assessment model estimated a virgin SSB (B_0) of 77 286 tonnes (95% CI: 71 492–84 210 tonnes) and an estimated SSB status in 2017 of 0.61 (0.58–0.64) (Table A5; Figure A1).

A22. The trace plots of the MCMCs for all free parameters showed little evidence of non-convergence (Figures A2 and A3).

Table A5: MCMC estimates of median SSB_0 and SSB status in 2017 with 95% confidence intervals.

B_0 (95% CI)	SSB status 2017 (95% CI)
77 286 (71 492–84 210)	0.61 (0.58–0.64)

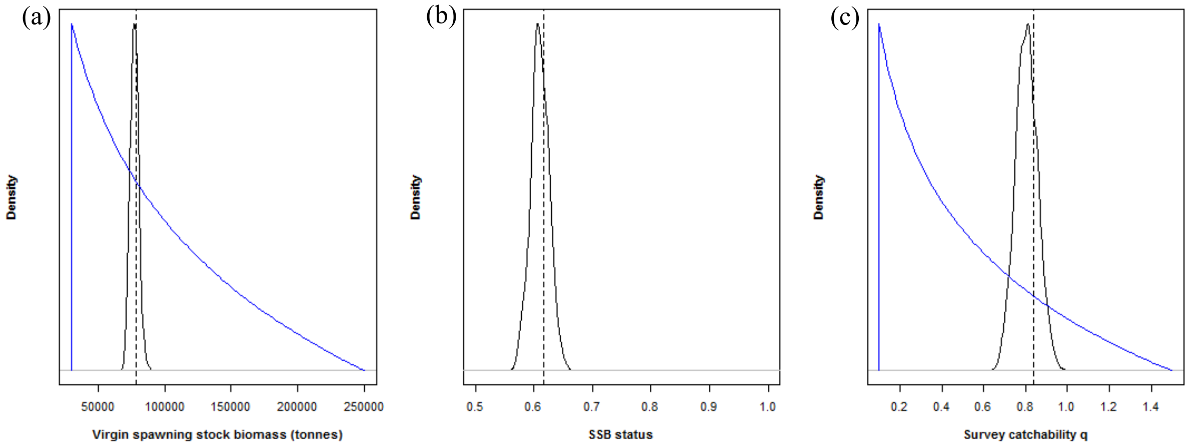


Figure A1: MCMC posterior distribution of (a) B_0, (b) SSB status in 2017, and (c) survey catchability q (black) and prior distributions (blue). Vertical dashed lines indicate the MPD estimates.

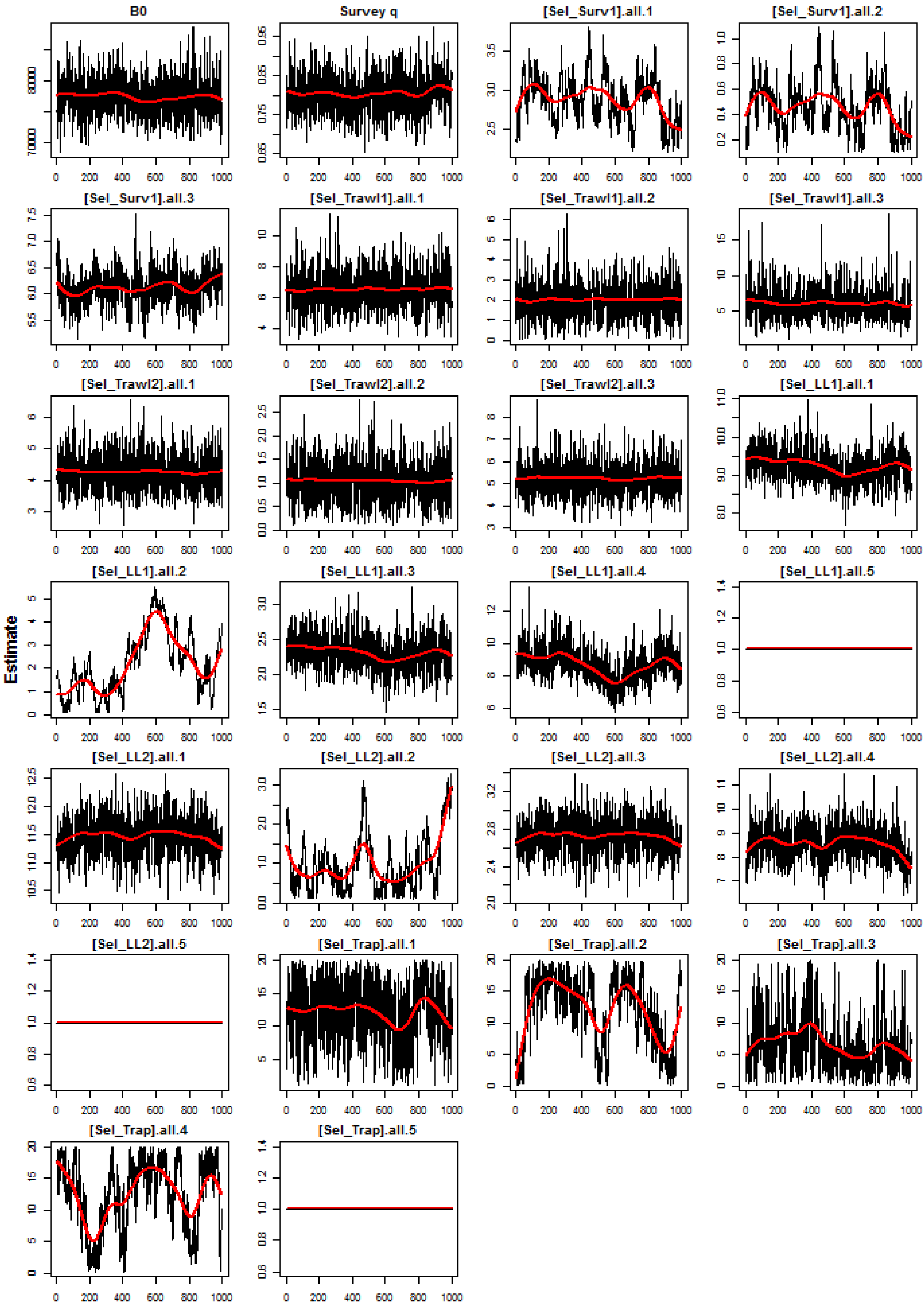


Figure A2: MCMC posterior trace plots for B_0, survey catchability q and all selectivity parameters.

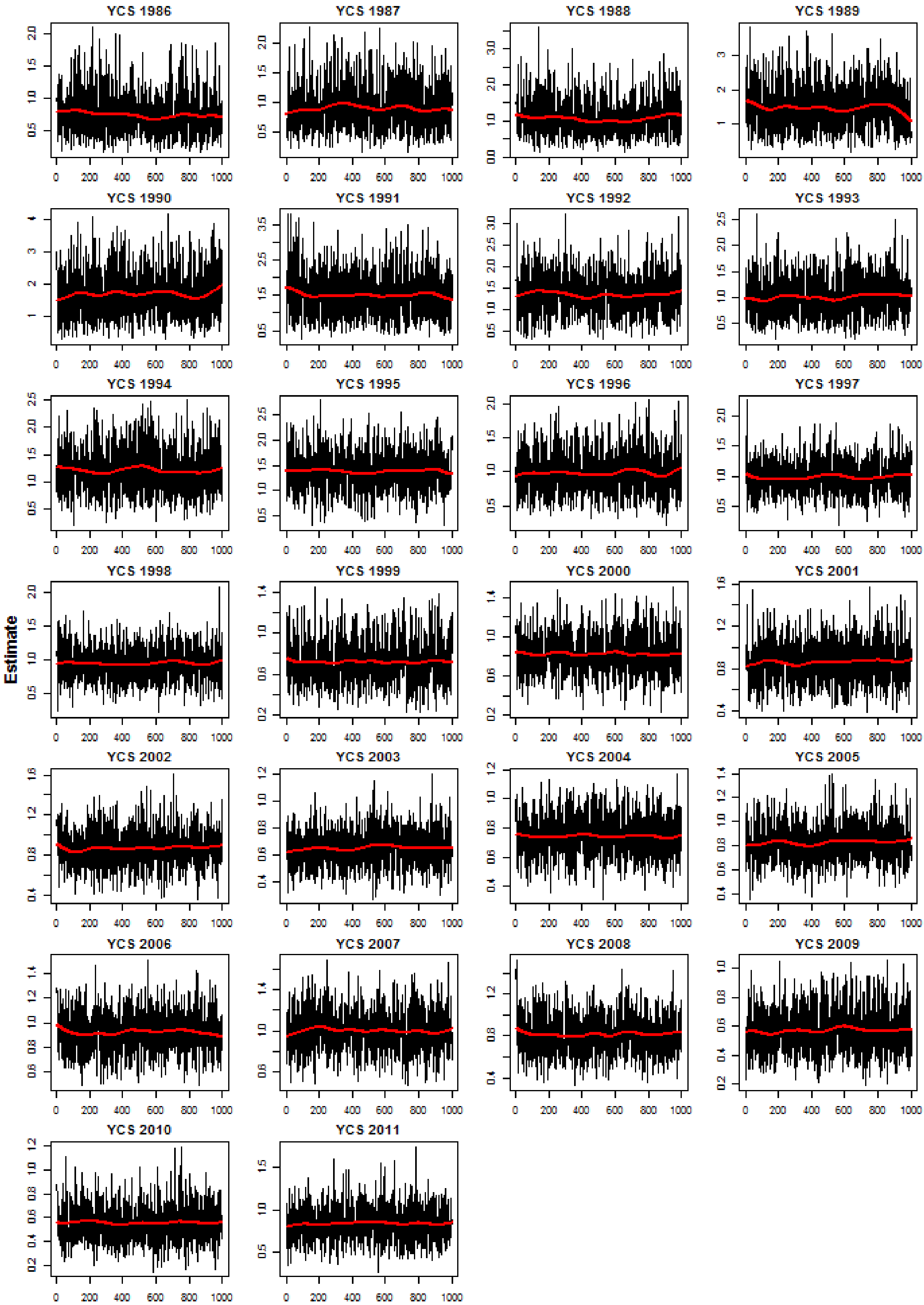


Figure A3: MCMC posterior trace plots for all estimated YCS parameters.

A23. Estimates of YCS and selectivity functions are shown in Figures A4 and A5. The selectivity functions showed distinct differences between the survey, 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.

A24. The median CV estimated for the YCS period from 1992 to 2011 was used to generate the random recruitment from 2012 to 2016 and the 35-year projection period from 2017 to 2051 ($\sigma_R = 0.39$). The maximum catches that satisfy the CCAMLR harvest control rules based on the assumption of future constant annual catches taken entirely by an annual survey of 20 tonnes and by longline (50% LL1 and 50% LL2) was estimated at 3 525 tonnes (Table A6 and Figure A4).

Table A6: Estimates of catch limits in tonnes based on MCMC sampling that satisfy the CCAMLR harvest control rules, with (i) a median escapement of the spawning biomass at the end of the 35-year projection period of at least 50% of the median pre-exploitation level ('Target'), and (ii) a less than 10% risk of the spawning biomass dropping below 20% of its median pre-exploitation level at any time over the 35-year projection period ('Depletion').

Model	Catch limit	Target	Depletion
2017 Assessment	3525	0.503	0.00

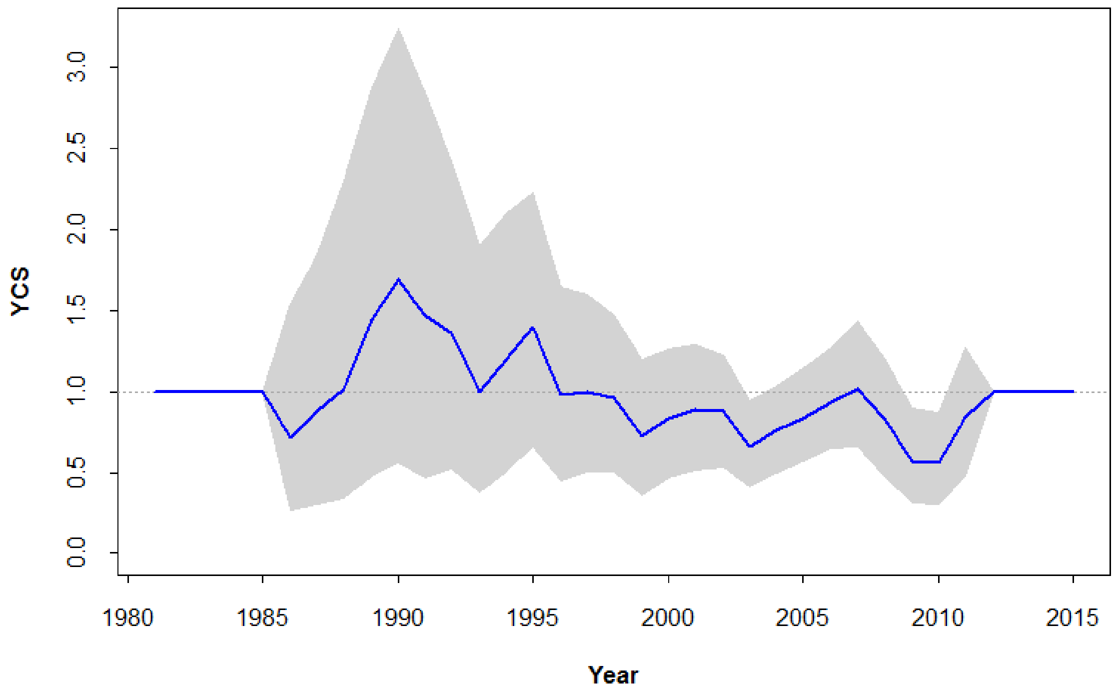


Figure A4: Year-class strength (YCS) estimates with 95% confidence bounds obtained from the MCMC samples.

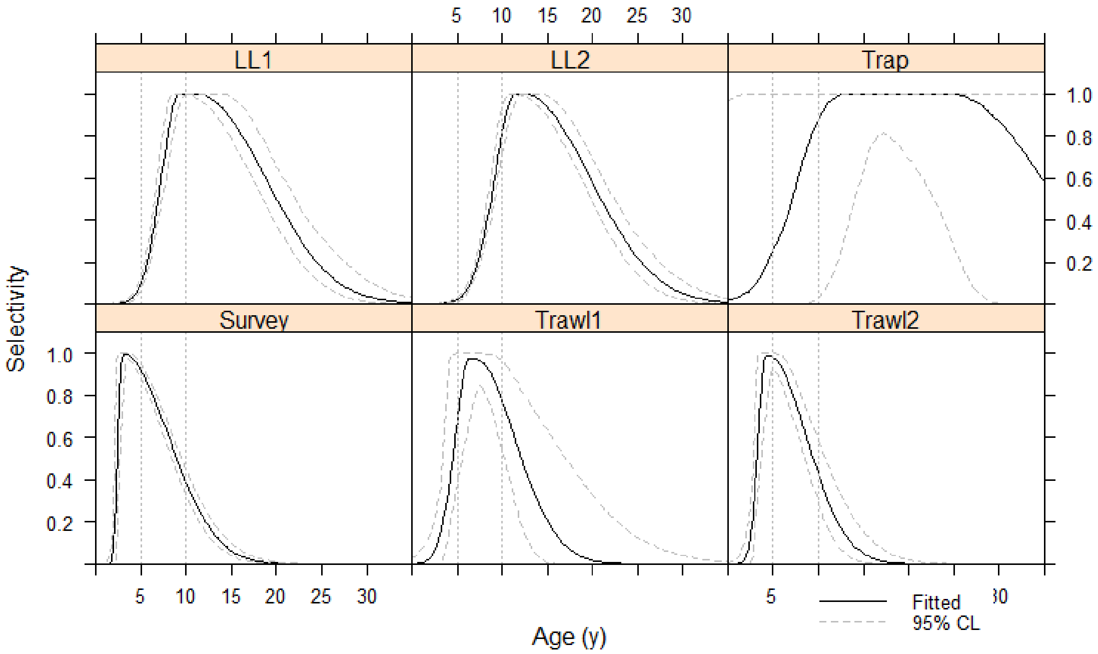


Figure A5: Estimated double-normal-plateau and double-normal fishing selectivity functions for the survey (Surv1) and commercial sub-fisheries, showing 95% confidence bounds obtained from the MCMC samples. Trawl1 is trawl from 1997 to 2004, Trawl2 is trawl from 2005 to 2016, LL1 and LL2 are longline in <1 500 m and >1 500 m depth respectively. Vertical reference lines are shown at ages 5 and 10.

Likelihood profile

A25. The likelihood profile is shown in Figure A6. While tag releases from 2014 and 2015 were in agreement and indicated that a B_0 of around 80 000 tonnes was most likely, tag-releases from 2012 and 2013 were in diametrical disagreement indicating that either a much larger or much smaller B_0 was most likely. The survey data indicated that a B_0 below 70 000 tonnes was most likely.

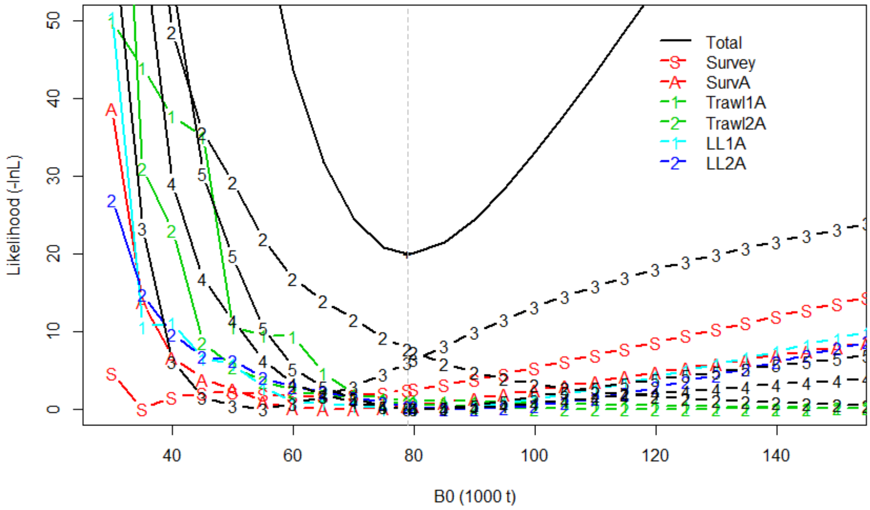
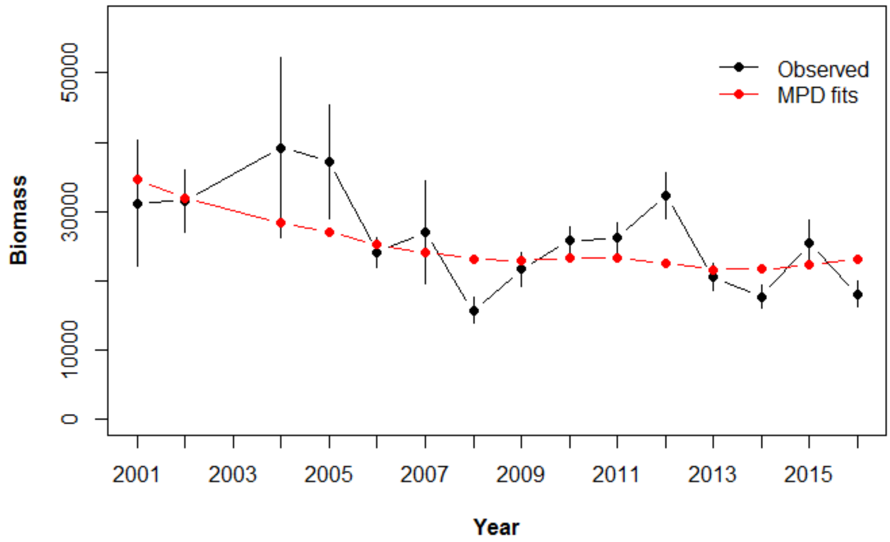


Figure A6: Likelihood profiles (–2 log-likelihood) across a range of B_0 values. To create these profiles, B_0 values were fixed while only the remaining parameters were estimated. Values for each dataset were rescaled to have a minimum of 0, while the total objective function was rescaled to 20. The dotted grey line indicates the MPD estimate. The solid grey lines indicate the total objective function and the 95% confidence intervals for both likelihood profiles. '2' is tag releases from 2012, '3' is tag releases from 2013, '4' is tag releases from 2014, and '5' is tag releases from 2015.

Model fits

A26. The MPD 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 A7 to A14.

(a)



(b)

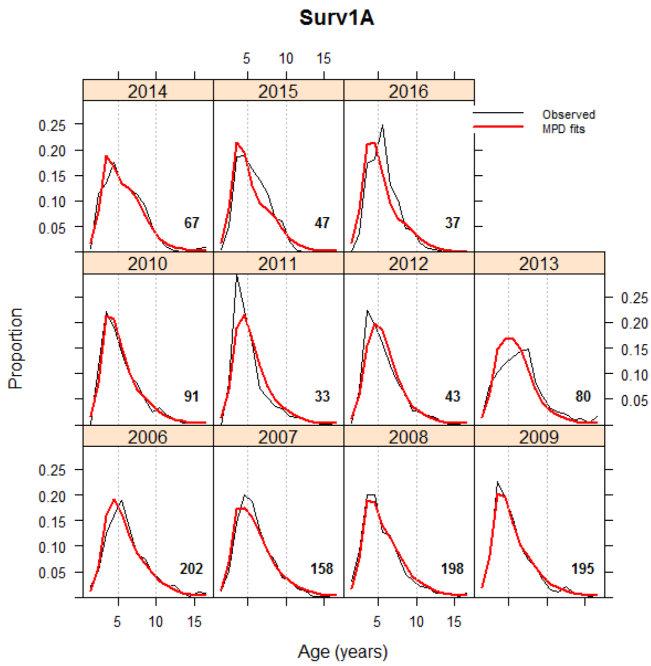
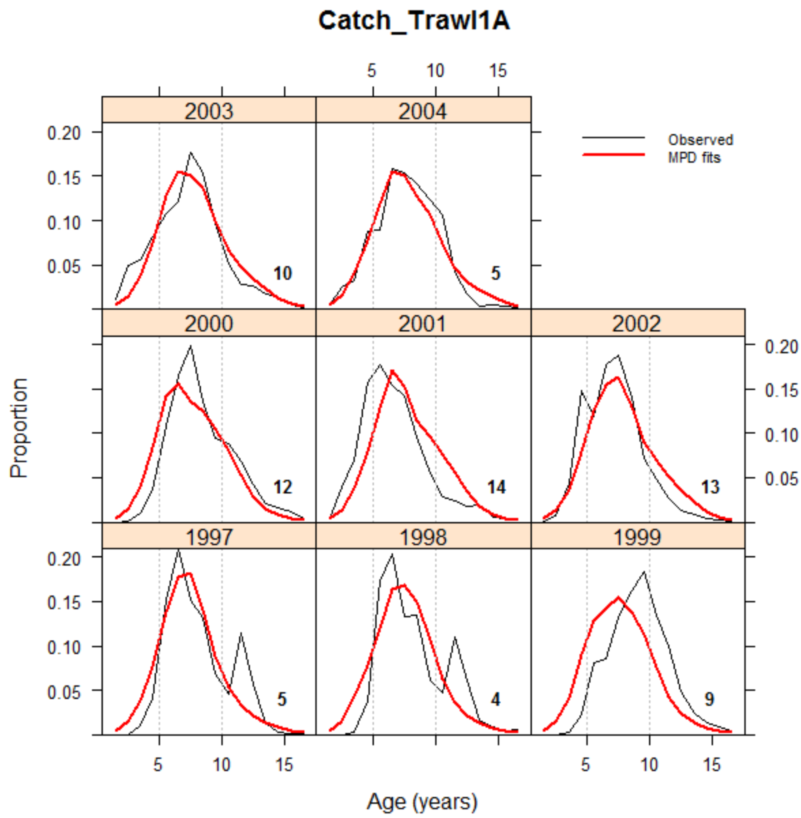


Figure A7: (a) Observed (black line with 95% CI) and predicted (red line) survey biomass and (b) observed (black) and predicted (red) proportions at age for the survey. Numbers indicate the effective sample size.

(a)



(b)

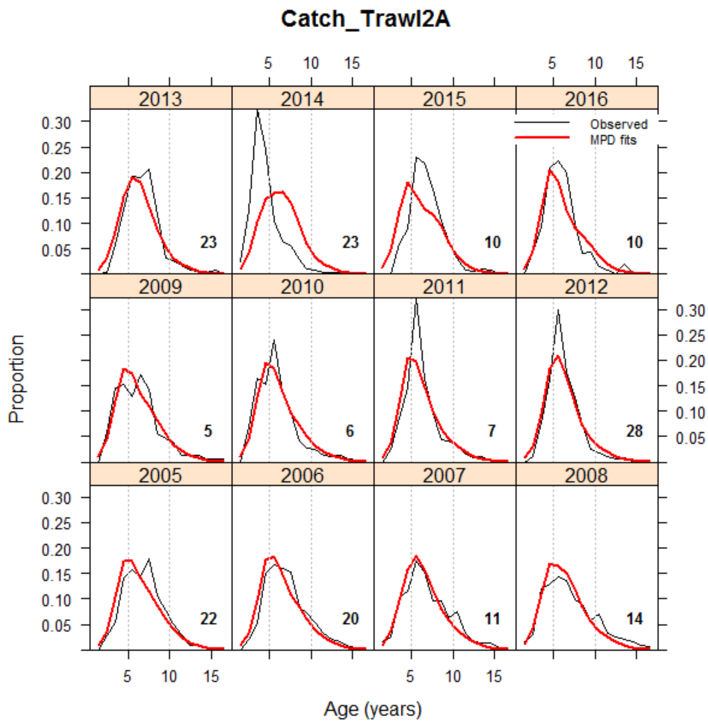
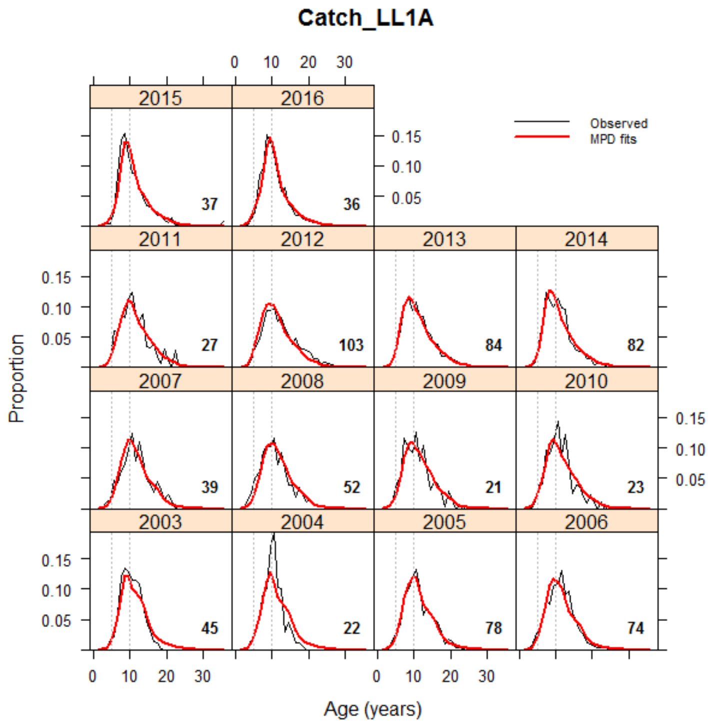


Figure A8: Observed (black lines) and expected (red lines) proportions at age for (a) Trawl1 and (b) Trawl2. Numbers indicate the effective sample size.

(a)



(b)

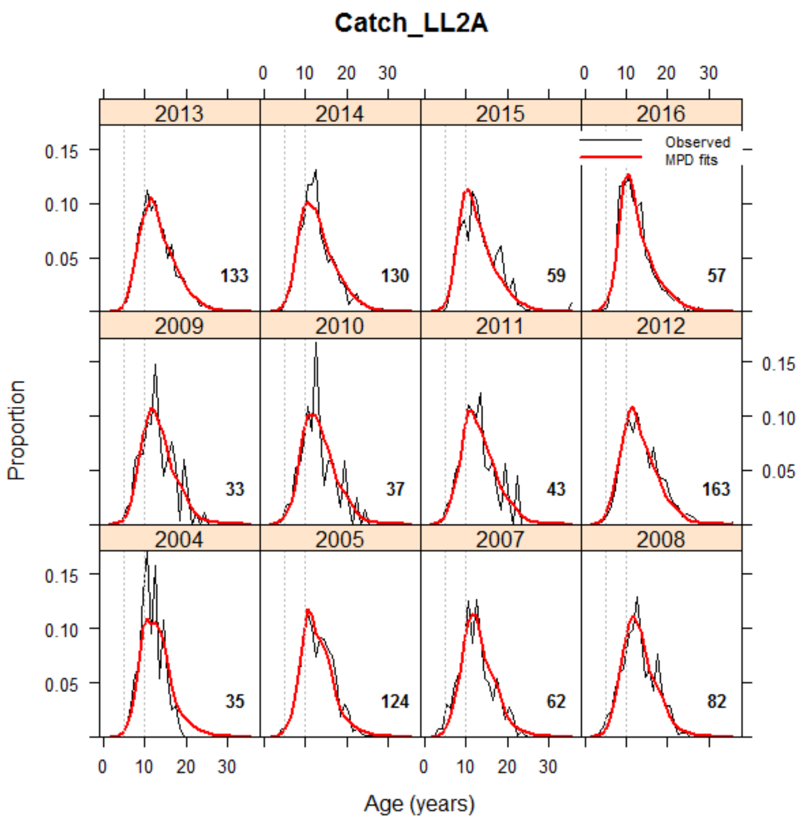


Figure A9: Observed (black lines) and expected (red lines) proportions at age for (a) LL1 and (b) LL2. Numbers indicate the effective sample size.

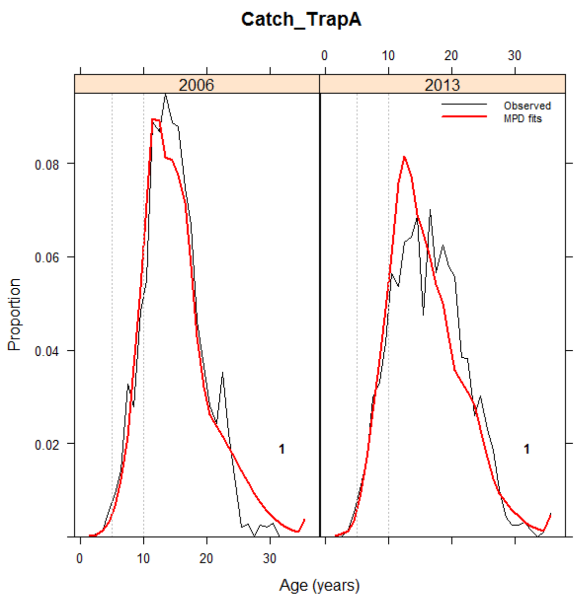


Figure A10: Observed (black lines) and expected (red lines) proportions at age for pot. Note that years are not consecutive. Numbers indicate the effective sample size.

(a)

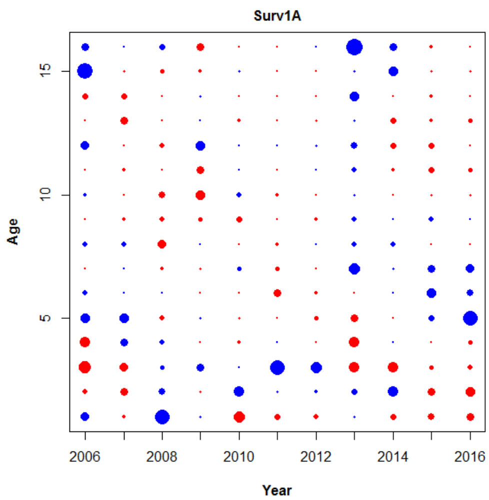


Figure A11: Pearson's residuals of MPD fits by age and year for the (a) survey, (b) commercial trawl and (c) longline sub-fisheries.

(continued)

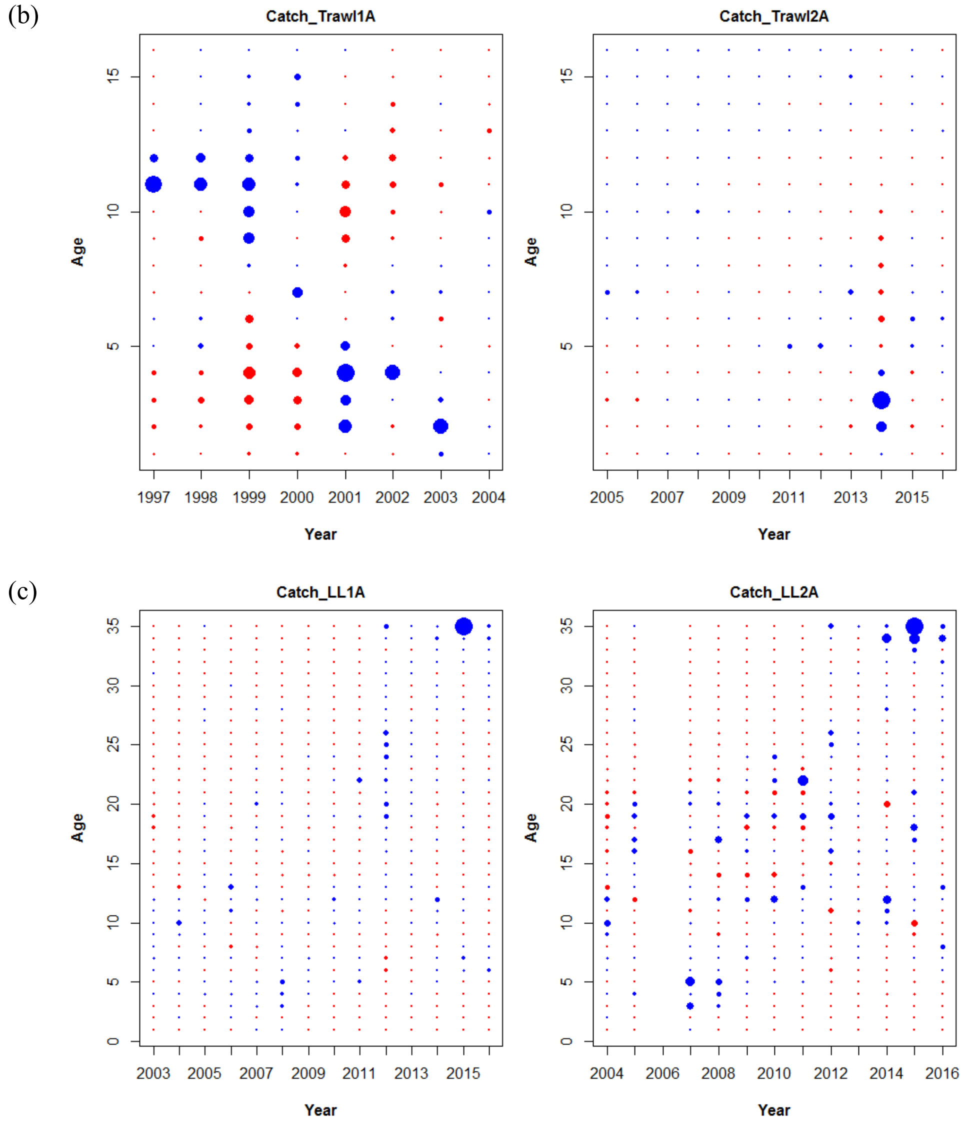


Figure A11 (continued): Pearson's residuals of MPD fits by age and year for the (a) survey, (b) commercial trawl and (c) longline sub-fisheries.

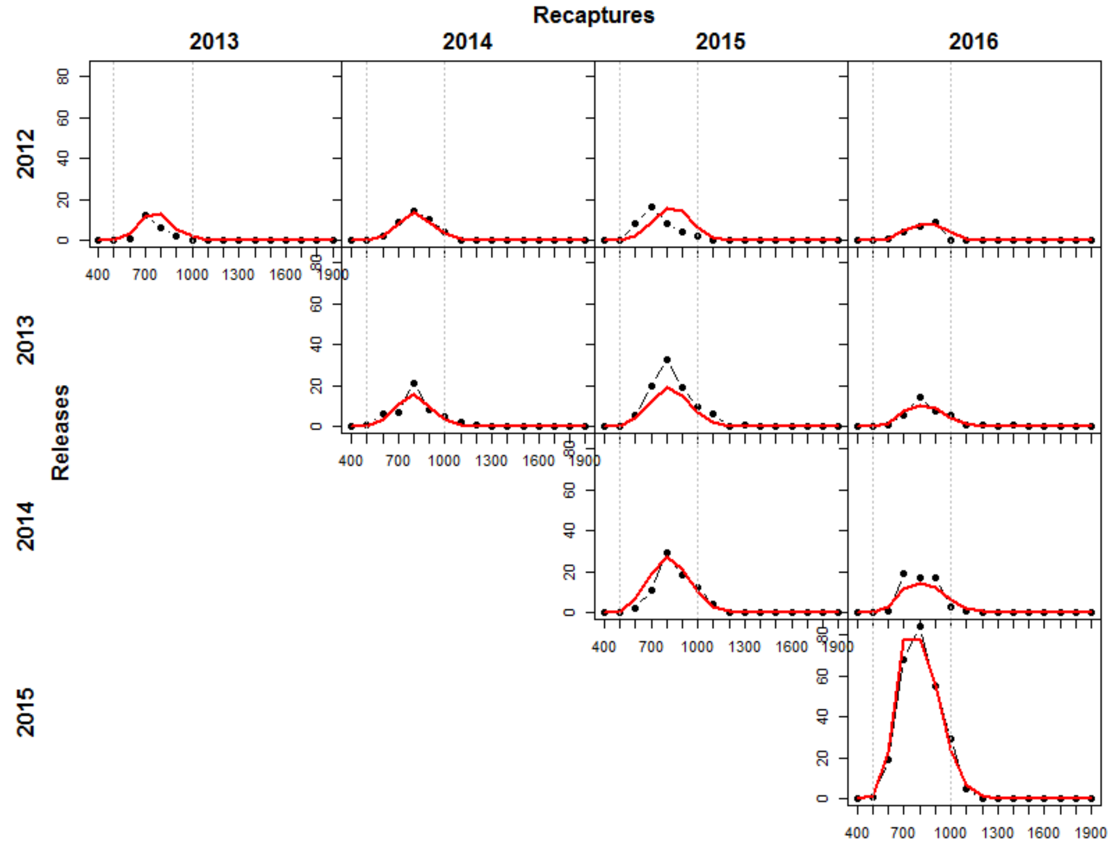


Figure A12: Observed (black lines) and expected (red lines) tag recaptures by 100 mm length for tag releases in 2012–2015 and tag recaptures in 2013–2016.

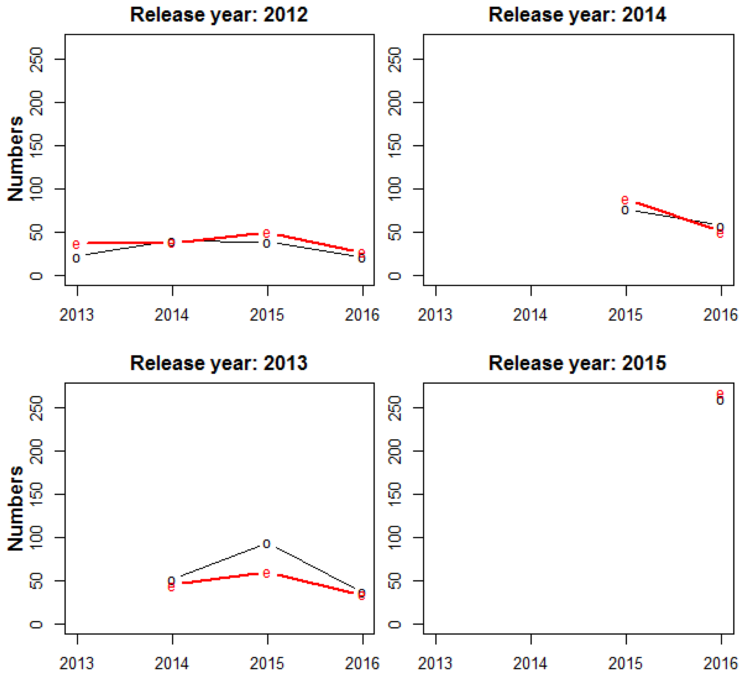


Figure A13: Observed (black lines) and expected (red lines) total tag recaptures by recapture year for tag releases in 2012–2015 and tag recaptures in 2013–2016.

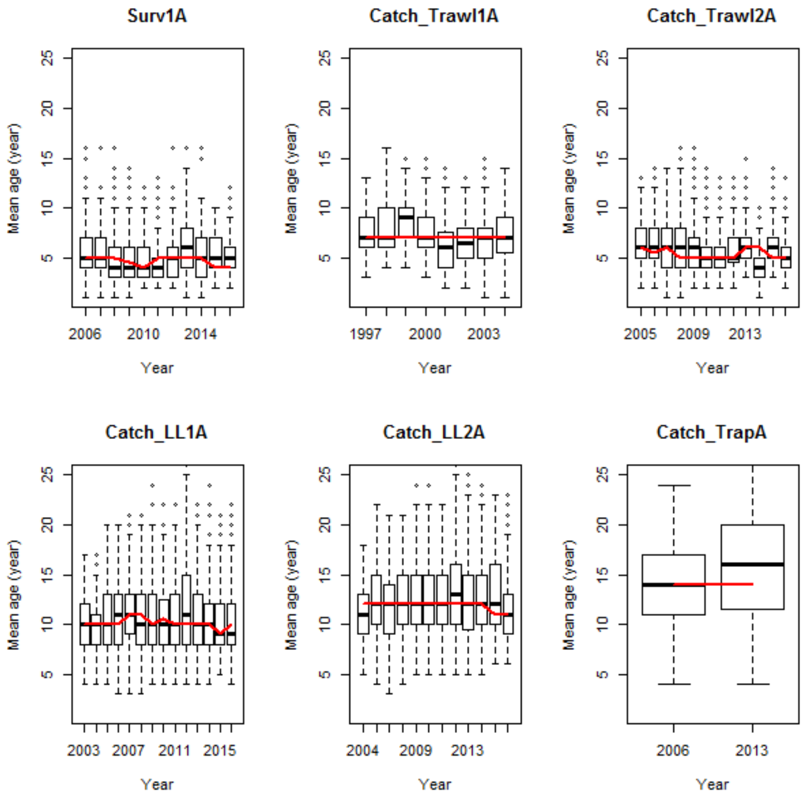


Figure A14: Boxplots of observed age by sub-fishery and expected median age (red line).

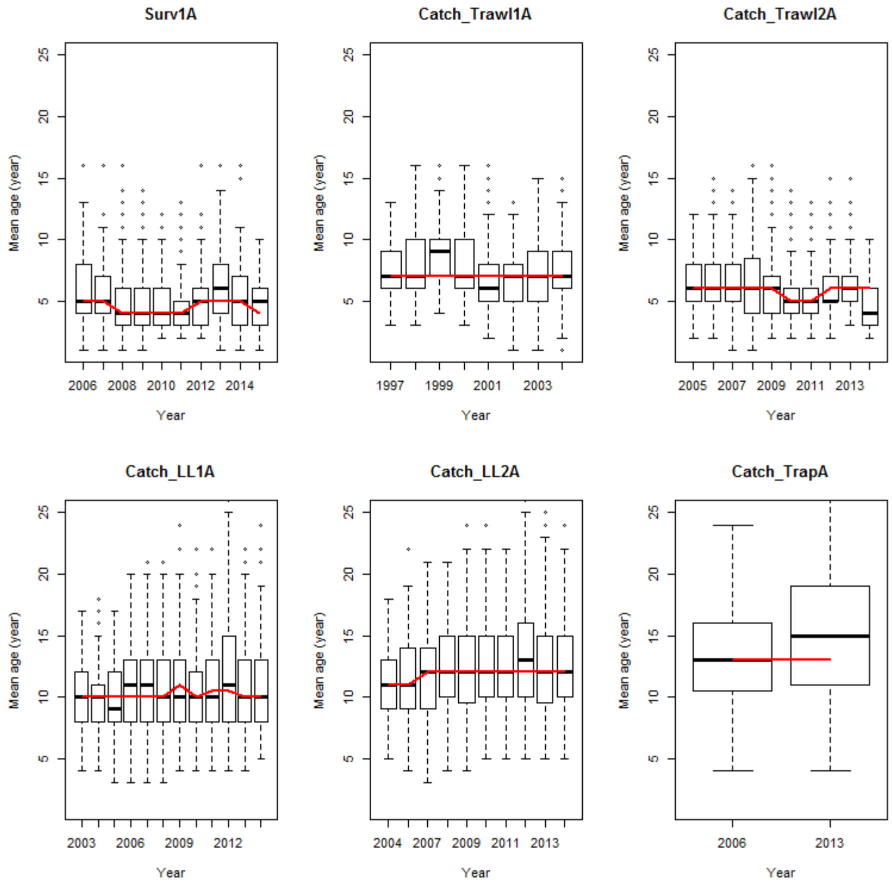


Figure A15: Boxplots of observed age by sub-fishery and expected median age (red line).