

**FISHERY REPORT: *DISSOSTICHUS ELEGINOIDES*
HEARD ISLAND (DIVISION 58.5.2)**

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1. Details of the fishery

1.1 Reported catch

The catch limit of *Dissostichus eleginoides* in Division 58.5.2 for the 2008/09 season was 2 500 tonnes (Conservation Measure 41-08) for the period from 1 December 2008 to 30 November 2009. The catch of *D. eleginoides* reported for this division by October 2009 was 2 177 tonnes. Reported catches along with the respective catch limits and number of vessels active in the fishery are shown in Table 1. In Division 58.5.2, the fishery was a trawl fishery from the 1996/97 to the 2001/02 season. In recent seasons the fishery has been prosecuted by trawl, longline and pot. The longline fishery was active from April to September 2009 and the trawl fishery was active throughout the whole season.

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, WG-FSA-09/5 Rev. 1 and past reports for IUU catch).

Season	Regulated fishery						Estimated IUU catch (tonnes)	Total removals (tonnes)
	Reported effort (number of vessels)	Catch limit (tonnes)	Reported catch (tonnes)					
			Longline	Pot	Trawl	Total		
1989/90	-	-	0	0	1	1	0	1
1991/92	-	-	0	0	0	0	0	0
1992/93	-	-	0	0	0	0	0	0
1994/95	-	297	0	0	0	0	0	0
1995/96	-	297	0	0	0	0	0	0
1996/97	2	3 800	0	0	1 927	1 927	7 117	9 044
1997/98	3	3 700	0	0	3 765	3 765	4 150	7 915
1998/99	2	3 690	0	0	3 547	3 547	427	3 974
1999/00	2	3 585	0	0	3 566	3 566	1 154	4 720
2000/01	2	2 995	0	0	2 980	2 980	2 004	4 984
2001/02	2	2 815	0	0	2 756	2 756	3 489	6 245
2002/03	3	2 879	270	0	2 574	2 844	1 274	4 118
2003/04	3	2 873	567	0	2 296	2 864	531	3 395
2004/05	3	2 787	621	0	2 122	2 744	265	3 009
2005/06	3	2 584	659	68	1 801	2 528	74	2 602
2006/07	2	2 427	601	0	1 787	2 387	0	2 387
2007/08	3	2 500	835	0	1 445	2 280	0	2 280
2008/09*	3	2 500	1 164	13	1 000	2 177	0	2 177

* Catch for 2008/09 not complete. Fishing season ends 30 November.

2. The spatial and temporal structure of the fishing for *D. eleginoides* is summarised in Table 2. The Working Group noted that a minor amount of longline fishing has occurred in trawl ground B to date and that some longline fishing occurs in areas other than the known grounds, and that this has increased with the addition of a second longline fishery in 2007/08. The pot fishery has only been experimental to date (68 tonnes in 2005/06 and 13 tonnes in 2008/09).

Table 2: Spatial and temporal structure of the main areas 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.

Gear type	Season			
	Approximate area (km ²)	Prior to longline	Longline	Post longline
Survey ^a	85 694	-	f1	-
Trawl ground B	442	f2_s1	f2_s2	f2_s3
Trawl ground C	2 033	f3_s1	f3_s2	f3_s3
Longline ground A	16 678	-	f4_s2	-
Longline ground C	2 033	-	f5_s2	-
Longline ground D	90 625	-	f6_s2	-

^a Random stratified trawl survey

1.2 IUU catch

3. There was no evidence of IUU fishing in Division 58.5.2 in 2008/09 (Table 1).

1.3 Size distribution of catches

4. Catch-weighted length frequencies are illustrated in Figures 1 (trawl fishery) and 2 (longline fishery). The Working Group noted that the modal size of fish caught in the longline fishery was greater than that in the trawl fishery. The difference in selectivities between trawl and longline sub-fisheries in Division 58.5.2 was estimated in WG-FSA-09/20, including large amounts of catch-at-age data for the first time (Welsford et al., 2009). This work confirmed previous modelling indicating that pot and longline gear is more able to catch older fish (>20 years) than trawl gear which has high selectivity for 6-year-old fish, effectively declining to zero for fish older than 20 years. The length-frequency distribution for the longline fishery will therefore have larger fish because of gear selectivity, as well as the longline fishery occurring in deeper water where toothfish tend to be larger.

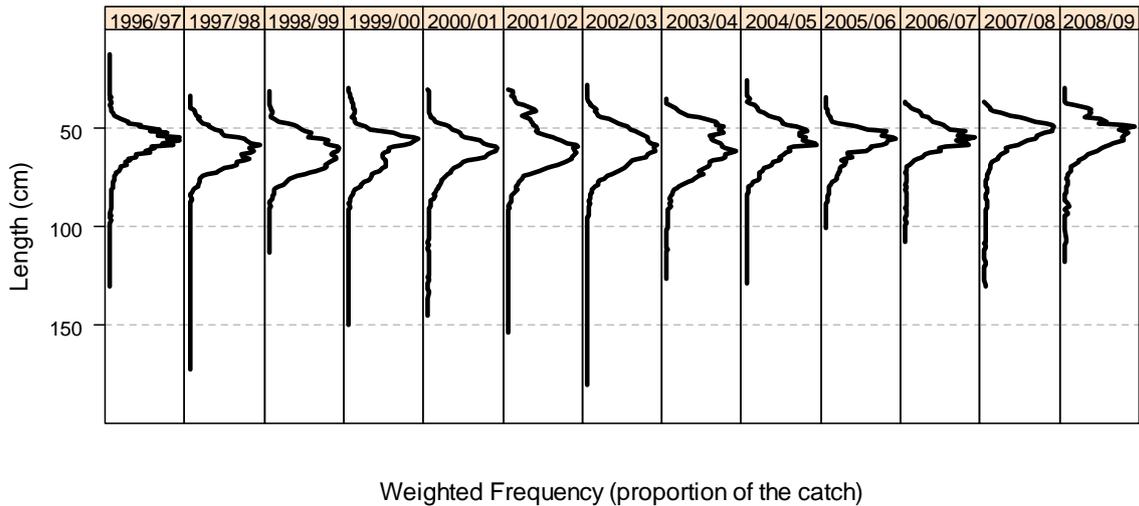


Figure 1: Catch-weighted length frequencies for *Dissostichus eleginoides* caught by trawl in Division 58.5.2 (source: observer, fine-scale and STATLANT data).

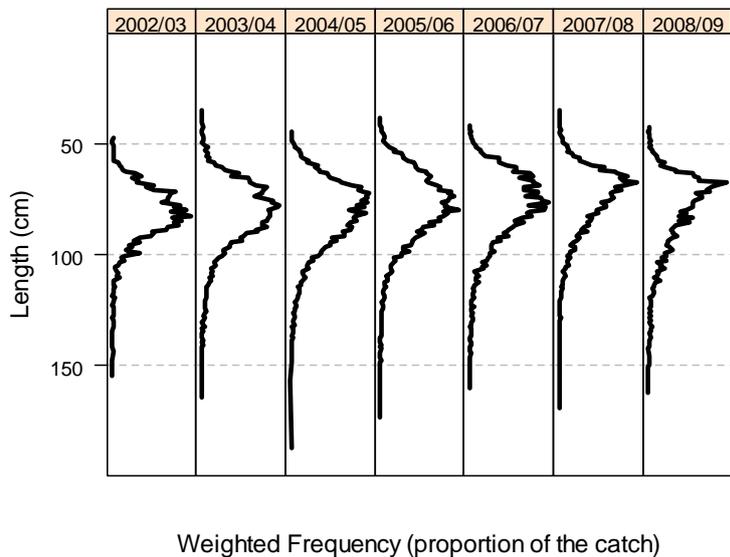


Figure 2: Catch-weighted length frequencies for *Dissostichus eleginoides* caught by longline in Division 58.5.2 (source: observer, fine-scale and STATLANT data).

2. Stocks and areas

5. *Dissostichus eleginoides* occurs throughout the Heard Island and McDonald Islands Plateau, from shallow depths near Heard Island to at least 1 800 m depth around the periphery of the plateau. Random stratified trawl surveys have been conducted since 1990 with survey designs described in detail in WG-FSA-06/44 Rev. 1, and for the 2008 and 2009 surveys in WG-FSA-09/34. Younger fish (less than about 600 mm TL) predominate on the plateau in depths less than 500 m, but no areas of local abundance have been discovered. As fish grow, they move to deeper waters, and are recruited to the trawl fishery on the plateau slopes in depths of 450 to 800 m. Here there are several areas of local abundance that constitute the

main trawling grounds where the majority of fish caught are between 500 and 750 mm TL (Figure 1). Older fish are seldom caught in the trawl fishery, and it is assumed that they move into deeper water (>1 000 m depth) where they are caught by the longline fishery. This fishery mostly operates between 1 000 and 1 800 m depth and catches larger fish than the trawl fishery (Figure 1), but few fish are >1 000 mm TL.

6. Genetic studies have demonstrated that the *D. eleginoides* population at Heard Island and McDonald Islands is distinct from those at distant locations such as South Georgia and Macquarie Island (Appleyard et al., 2002), but that within the Indian Ocean sector there appears to be no distinction between fish at Heard, Kerguelen, Crozet or Marion/Prince Edward Islands based on genetic studies (Appleyard et al., 2004). This, 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), suggests that a metapopulation of *D. eleginoides* may exist in the Indian Ocean sector (WG-FSA-03/72).

3. Parameters and available data

3.1 Parameter values

Fixed parameters

7. No revised parameter estimates were available in 2009. Parameters used in the Division 58.5.2 toothfish assessment are detailed in SC-CAMLR-XXVI, Annex 5, Appendix L and Candy and Constable (2008).

8. A substantial amount of ageing of otoliths from the commercial catch, surveys, and mark-recapture experiments were undertaken in 2008 and 2009 (WG-FSA-09/21; WG-SAM-09/9). 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 given in WG-FSA-09/20.

9. The input parameters used in the assessment are included in Table 3.

10. Recruitment is modelled without assuming a stock-recruitment relationship. Variability in recruitment is estimated from the output of the CASAL integrated assessment and is determined largely from the variability across years in estimated year-class strength.

Table 3: Input parameters for the assessment of *Dissostichus eleginoides* in Division 58.5.2.

Component	Parameter	Value	Units
Natural mortality	M	0.13	y^{-1}
Length-at-age (age in parentheses)	(1) 251.0 (2) 307.5 (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)		(year) mm
CV of length-at-age	CV_{VB}	0.1	
Length-to-mass	' a '	2.59E-09	mm, kg
Length-to-mass	' b '	3.2064	
Maturity (age based)	(11) 0.0 (12) 0.1667 (13) 0.3333 (14) 0.5000 (15) 0.6667 (16) 0.8333 (17) 1.0000		

Recruitment surveys

11. Surveys of young toothfish have been undertaken since 1990 (Table 4). The survey design was consolidated in 2001 with the distribution of stations undertaken during a survey revised in 2003 (WG-FSA-04/74). See also paragraph 5 above for recent survey designs.

Table 4: Details of trawl surveys considered for estimating the abundance of juvenile *Dissostichus eleginoides* in waters less 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	Date	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	July	SC	DT	83 936	83 936	158	12
2008	1	July	SC	DT	83 936	83 936	158	4
2009	1	July	SC	DT	83 936	83 936	161	19

12. Australia undertook trawl surveys of Division 58.5.2 in June–July 2008 and April–May 2009 to estimate the density of juvenile toothfish (WG-FSA-09/34). The survey used the same design as the 2007 survey, with the exclusion of hauls in Shell Bank which are intended for assessing *Champscephalus gunnari* abundance.

13. The allocation of 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, 2004–2009.
- 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.

14. The Working Group confirmed that the bootstrap resampling procedure for estimating annual abundance by length bin and the corresponding coefficients of variation over the Aitchison delta lognormal method (WG-FSA-06/64).

15. Survey abundance (abundance-at-length) was used as observations in the CASAL model for all years except 2006 and 2007 for which there were sufficient aged fish from otoliths collected during the survey 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-09/20.

Tagging studies

16. 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 given in Candy and Constable (2008). It is anticipated that, as the spatial extent of fishing effort is more widely distributed, these data will provide important inputs to future integrated assessments using methods such as CASAL.

17. The Working Group noted that the tagging program has historically been largely restricted to the main trawl ground B and is likely to underestimate the abundance of fish of this age/length range (Candy and Constable, 2008). At present, the assessment is unable to accommodate the small spatial extent of the program and the limited mixing from this ground to the other areas. These data are, therefore, not utilised in the integrated assessment.

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

18. Random length samples were obtained from commercial catches. For use in the assessment, these length-frequency data were aggregated into 100 mm bins. The length distributions are given as a proportion of catch in 100 mm length bins from 200 to 1 900 mm along with the associated sample size. Commercial catch-at-length data was used only for 2009 for each sub-fishery since there were no aged fish available for this latest year. Candy (2008) described the profile maximum likelihood method used for accounting for over-dispersion of the length-frequency data relative to a multinomial distribution by estimating an effective sample size for each distribution.

19. Random length samples were combined with year-specific ALKs to obtain catch-at-age data for input as observations in CASAL for each year prior to 2009 back to 1997. Proportions-at-length, that were combined with ALKs, were calculated specifically for each sub-fishery, fishing season and CASAL period (where more than one period was fished)

(WG-FSA-09/20). The method of calculating effective sample sizes for catch-at-age data was described in WG-SAM-09/8 and tables of effective sample sizes are given in WG-FSA-09/20.

Standardised CPUE series

20. The method for standardising catch-and-effort time series data described in Candy (2004) was used to provide a catch-per-unit-effort (CPUE) series for each of the main trawl grounds (grounds B and C) up to, and including, 2009 and these were used as a series of relative abundance observations in CASAL. The catchability constant (q_{CPUE}), treated as 'relative' observations, is an estimated parameter calculated separately for each of the two CPUE series.

4. Stock assessment

4.1 CASAL model structure and assumptions

21. The CASAL population model used in the assessment of toothfish 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 occurred uniformly over the year. Fisheries were distributed in these seasons according to the spatial and temporal structure of the fisheries in Table 2. Spawning was timed to occur on 1 July. The time series for the assessment was 1982 to 2009 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. All fisheries were modelled with either a double-normal plateau or double-normal age-based selectivity function with the different selectivities for each gear \times 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, s2). In addition, for this fishery separate selectivity parameters were estimated for 2006 and 2007 catches due to the generally smaller size of fish caught in these recent seasons compared to previous seasons. In WG-FSA-SAM-06/14 and WG-FSA-07/64 the coefficient of variation, CV_{VB} , 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-09/9) and was not estimated using CASAL. The updated model to that described in Candy and Constable (2008) is denoted *a2-2009-alkall*.

Model estimation

22. 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). 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. Until improvements can be made in the ability to obtain independent samples from the posterior distribution of the parameters using MCMC, the MVN method is recommended for this assessment. The MVN method is guaranteed to draw independent samples based on the MPD estimates and the Hessian matrix. Additionally, given that uniform priors are used for all parameters, the need to implement an MCMC sampling approach is not obvious since the validity of the quadratic approximation of the likelihood surface for an appropriately parameterised model is well established.

Observation assumptions

23. Numbers-at-length for all survey years except 2006 and 2007 and numbers-at-age for the 2006 and 2007 survey years were used as the primary observations. Observation error was incorporated by using the CV estimates (see paragraph 15). 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 and was assumed to have a catchability $q = 1$. The other survey groups each had a q estimated, with the 1990 and 1993 surveys considered to have the same catchability.

24. The catch and proportions-at-age and proportions-at-length for 2009 were fitted to the model-expected proportions using a multinomial likelihood with effective sample sizes calculated according to the method described in paragraph 19.

25. CPUE indices were assumed to be relative mid-season vulnerable biomass indices 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 GLMM standardisation described in Candy (2004).

Process error and data weighting

26. Observations were primarily weighted using estimates of effective sample sizes and CVs. Process error of 0.1 was added to all surveys other than Survey Group 1 to which it was set to zero, as was the case for the two CPUE series. The use of the iterative CASAL estimation/process error procedure was not used since systematic lack of fit (SLOF) for Survey Group 1 could not be adequately accounted for even after the generic SLOF model was fitted (Candy and Constable, 2008; Candy, 2008). This meant that the iterative process error procedure gave an unacceptably low weight to the Survey Group 1 relative to the catch-at-length data in the fit when lack of fit was attributed as purely process error. Therefore, process error was set to zero with the exception noted above for the survey groups.

Penalties

27. 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 year class strengths deviated from 1.

Priors

28. The parameters estimated by the model, their priors, starting values for the minimisation and their bounds are given in Table 5. In the model presented here, uniform priors were chosen that are non-informative given CASAL's Bayesian implementation.

Yield calculations

29. 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.

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

31. The level of escapement was calculated as the proportion of samples from the Bayesian posterior where the predicted future status of the spawning stock biomass was below 50% of the pre-exploitation median spawning biomass at the end of a 35-year projected period.

32. Random recruitments for the projection begin in 2007 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 MVN sample of historic recruitments (1986 to 2006).

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

34. For removals not included in the 2008/09 season due to unverified catch and catch still to be taken, the anticipated remaining catch for CASAL season 3 was added to that shown in Table 1 to bring total removals to 2 400 tonnes.

Table 5: 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	1		Uniform	50 000	250 000	100 000
YCS	24	1983–2006	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
	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
	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
Survey group q	3	1999 survey 1990/1993 surveys 2003 survey	Uniform	1e-6	1 000	-
CPUE q	2	Trawl ground B Trawl ground C	Uniform	1e-6	1 000	-

35. The future catch was divided amongst the fisheries according to the 2008 catch history as well as consideration of the expected trends in the use of different grounds. The following ratios were used:

Trawl ground B – season 1	0.20
Trawl ground B – season 2	0.03
Trawl ground B – season 3	0.22
Trawl ground C – season 2	0.05
Trawl ground E – season 2	0.14
Longline ground C – season 2	0.14
Longline ground D – season 2	0.14
Longline ground E – season 2	0.03
Longline ground F – season 2	0.05.

4.3 Model estimates

36. MPD estimates of the key parameters for the different scenarios are shown in Tables 6 and 7.

Table 6: 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, SSB status 2009 is the ratio of the CASAL prediction of SSB in 2007 to B_0 , and R_0 is the MPD estimate of mean age-1 recruitment prior to exploitation (1981).

Model	Description	B_0 (SE)	SSB status 2009	R_0 (million)
<i>a2-2009-alkall</i>	Model <i>a2-ess</i> in Candy and Constable (2008) updated to 2009 with catch-at-age and abundance-at-age (2006–2007) data, and addition of sub-fisheries with minor catch prior to 2008	116 379 (2 725)	0.628	4.211

Table 7: 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 (see Candy and Constable, 2008).

Model	Selectivity parameter estimates Survey Group 1 (SE below estimate)				Survey group q - estimate ^a			
					SG3 (1990)	SG5 (1993)	SG2 (1999)	SG7 (2003)
	s_L	s_U	a_1	a_2				
<i>a2-2009-alkall</i>	0.0200 (0.0002)	5.4694 (0.0639)	3.0134 (0.0024)	0.1170 (0.0143)	0.276	0.276	2.401	0.660

^a Catchability q set to 1 for Survey Group 1 (2001, 2002, 2004–2009).

37. Figure 3 shows the fitted selectivity functions for each sub-fishery while for the trawl ground B fishery an extra selectivity function (*Sel_f2_s2r*) was fitted for recent years. These curves show the distinct differences in how the surveys, trawl and longline activities overlap with the stock, notably that the surveys observe the youngest fish (less than age 5), the trawl fishery concentrates on larger but pre-adult fish, and the longline fishery concentrates on larger fish again, 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.

38. Figure 4 shows the fit to the Survey Group 1 (SG1) abundance-at-length data. Fitted values in the figure appear to show a consistent underestimation of abundance for length bins that contain most of the fish compared to observed values, indicating that the abundance of young fish, indicated by other datasets, is not as high as that observed in the surveys. Figure 5 shows the fit in that model for the abundance-at-age data for 2006 and 2007. Figure 6 shows total survey abundance (a) and biomass (b), aggregated over length bins and age classes showing single SE bars and fitted generalised additive model (GAM) curve (obtained using the *gam* function in the *mgcv* library in the R-software package). Note: survey abundances are used in CASAL as abundance-at-length and abundance-at-age as shown in Figures 4 and 5 respectively.

39. Figures 7 to 10 show the fit to the commercial length-frequency data for the main trawl fisheries (grounds B and C) and the two main longline fisheries (grounds C and D) for the main fishing season (s2) for each sub-fishery.

40. Figure 11 shows the standardised CPUE series versus the fitted trend from the CASAL model for the main trawl ground (ground B). Note that the standardised CPUE series was obtained from the haul-by-haul data combined across all three CASAL seasons based on the standardisation model given by Candy, 2004 and updated using data up to, and including, 2009.

41. Figure 12 shows the profile of the objective function value minimised by the fit (i.e. equivalent to twice the negative log-likelihood) across values of the B_0 parameter (i.e. this parameter is held constant at the profiled value while all other model parameters are jointly estimated) for each major source of data. Figure 12 is informative in that it indicates which datasets most contribute to the estimation of the key parameter B_0 . Figure 12 demonstrates that the survey abundance data contrast with the catch-at-age data for the main trawl fishery (ground B, f2) for the two main fishing periods (Table 2), with the survey data indicating a higher value for B_0 than the catch-at-age data. Within the survey data, the abundance-at-age is very useful in that it limits the size of B_0 since the objective increases for B_0 values above 110 000 for this data, while the abundance-at-age data does not provide information on an upper limit for B_0 for the range shown. Therefore, the contrasting signals for these informative data inputs allow CASAL to estimate B_0 with the minimum value of the objective in the range 105 000 to 120 000 with the MPD estimate (i.e. all parameters simultaneously estimated) given in Table 6 as 116 379.

42. Figure 13 shows the estimated Year-class Strengths (YCSs) for the period 1983 to 2006. YCS was fixed at 1 for the remaining years of the historical fishery (i.e. 1981–1982 and 2007–2009) since the data do not allow these year classes to be estimated reliably (or sensibly for the 2007–2009 period). Figure 14 shows the estimated historical recruitment series using year random effect estimates obtained from the fit of the LMM to the log of number of age-1 recruitments for size-1 000 sample from the MVN distribution for the set of

estimated parameters when processed through CASAL’s projection procedure. The estimate of yearly process error CV from the fit of the LMM was 0.530 (SE = 0.085) with autocorrelation parameter estimate of -0.258 (SE = 0.006). For the forward projections using the random lognormal recruitment option in CASAL, a slightly higher CV of 0.6 and autocorrelation of zero was used. Experience with setting the autocorrelation parameter to values other than zero shows that this makes very little difference to the variability of projected spawning stock biomass.

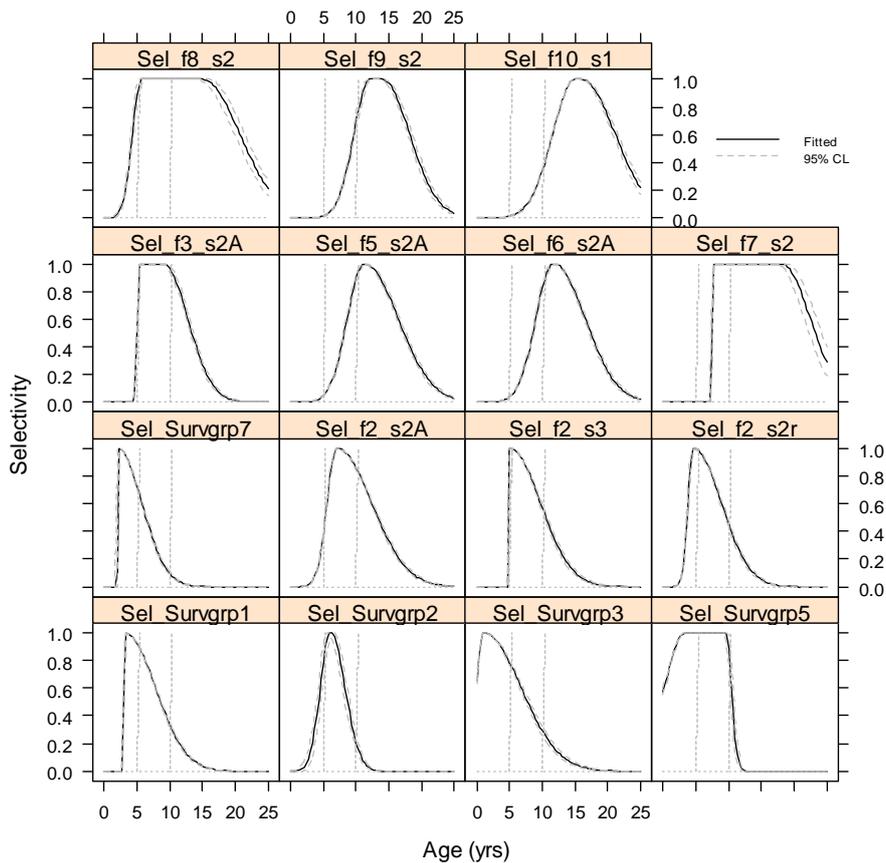


Figure 3: Double-normal-plateau (DNP) and double-normal (DN) fishing selectivity curves from fit of model *a2-2009-alkpool* showing 95% confidence bounds obtained from the MVN sample. Panel headings: Survgrp1 (survey years 2001, 2002, 2004, 2005, 2006, 2007, 2008), Survgrp2 (survey year 1999), Survgrp3 (survey year 1990), Survgrp5 (survey year 1993), Survgrp7 (survey year 2003), f2_s2, f2_s3 (trawl ground B, seasons 1 & 2, season 3), f2_s2r (trawl ground B 2006, 2007 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 & 2). Reference lines are shown at ages 5 and 10.

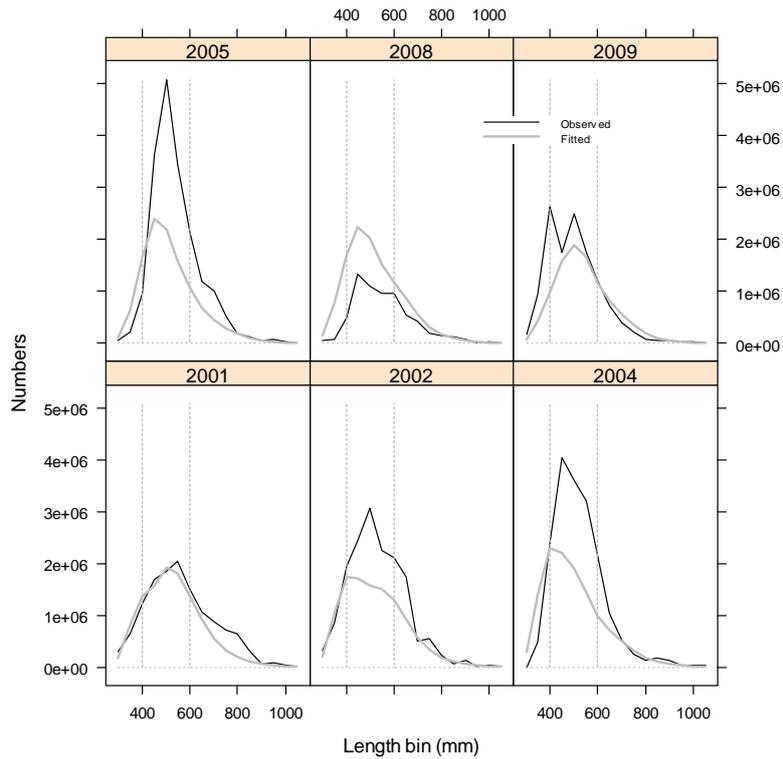


Figure 4: Model fits to Survey Group 1 abundance data with reference lines at 400 and 600 mm.

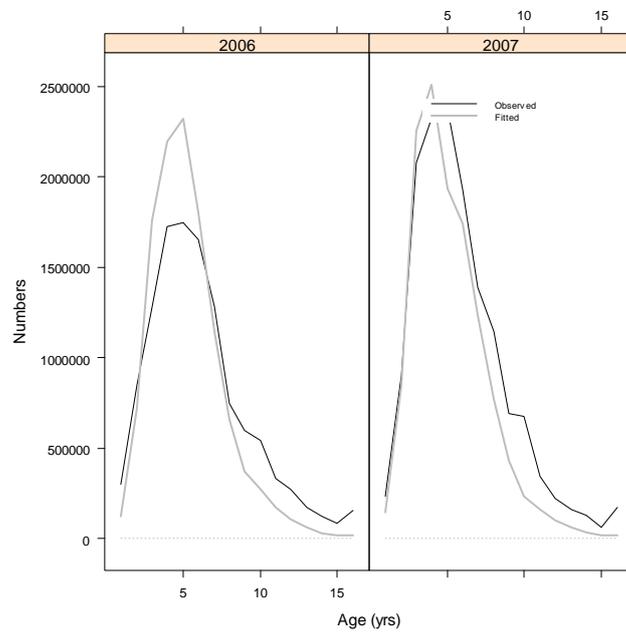


Figure 5: Model fits to Survey Groups 3, 5, 2 and 7 data – comparison of observed (black line) and expected (grey line) numbers-at-length for Survey Groups 3 (1990), 5 (1993), 2 (1999) and 7 (2003).

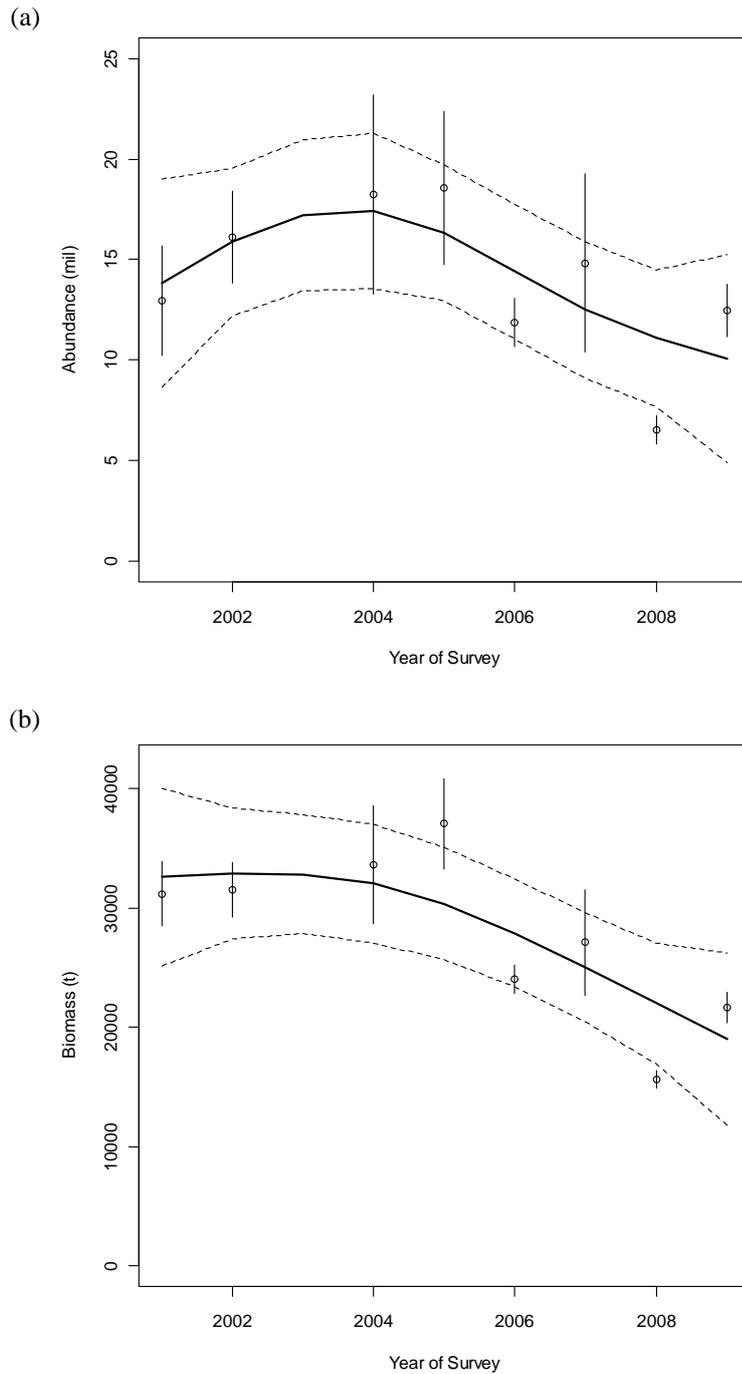


Figure 6: Survey abundance (a) and biomass (b), aggregated over length bins and age classes showing single SE bars and fitted GAM curve (solid line) and $2 \times SE$ bounds for fitted curve. Note: survey abundances are used as observations in CASAL as abundance-at-length and abundance-at-age as shown in Figures 4 and 5 respectively.

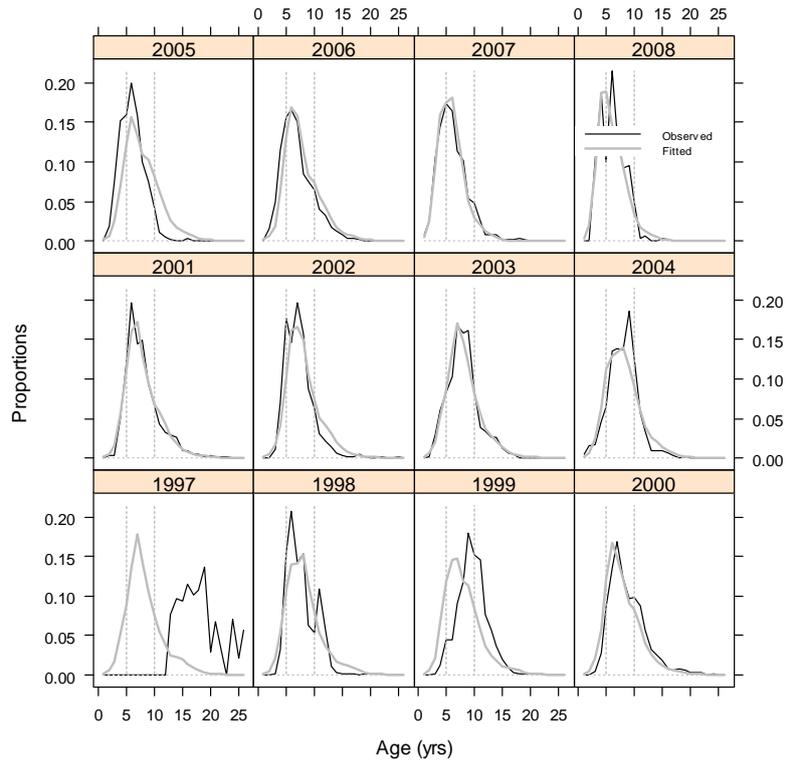


Figure 7: Model fits to catch-at-length proportions for trawl ground B, season 2 (Fishery f2_s2) with reference lines at ages 5 and 10.

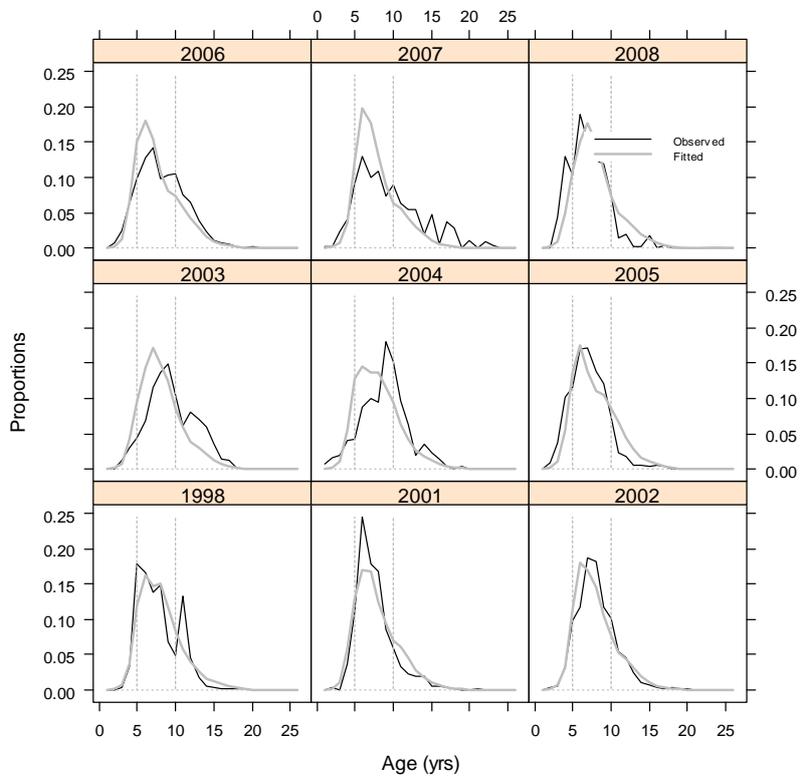


Figure 8: Model fits to catch-at-length proportions for trawl ground C, season 2 (Fishery f3_s2) with reference lines at ages 5 and 10.

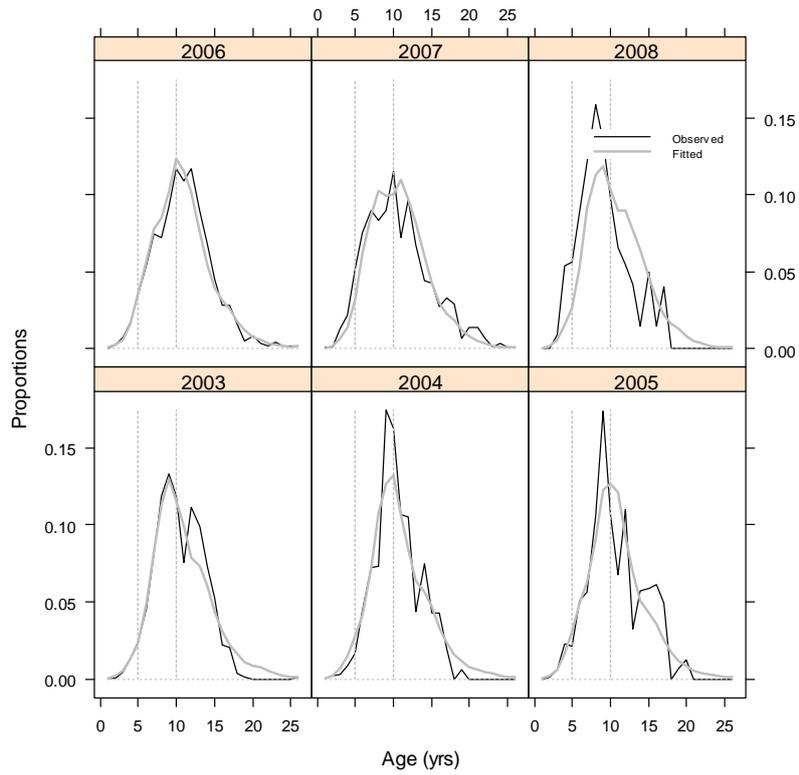


Figure 9: Model fits to catch-at-length proportions for longline ground C, season 2 (Fishery f5_s2) with reference lines at ages 5 and 10.

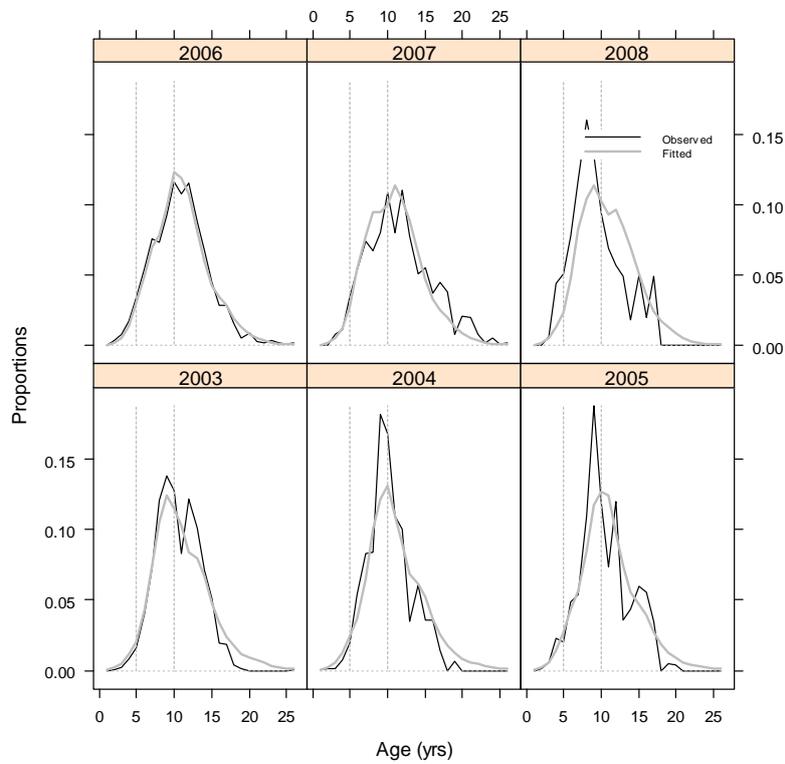


Figure 10: Model fits to catch-at-length proportions for longline ground D, season 2 (Fishery f6_s2) with reference lines at ages 5 and 10.

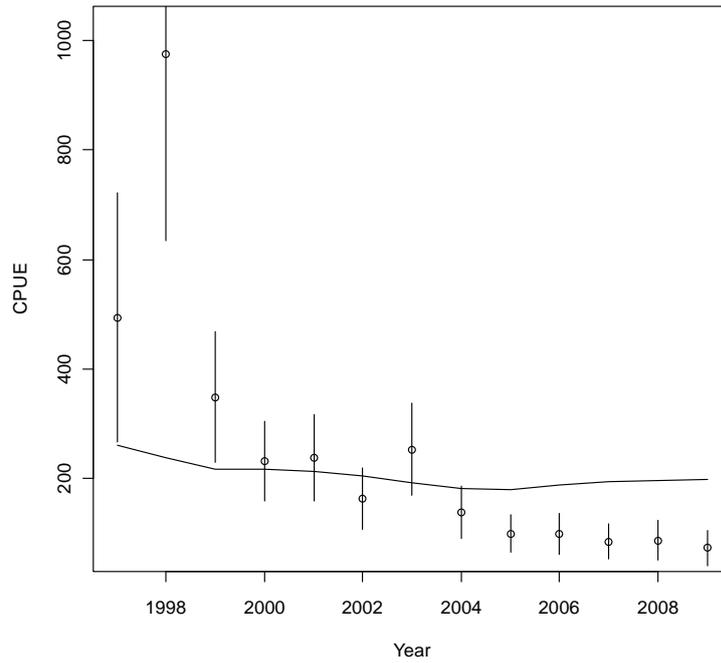


Figure 11: Estimated CPUE series from GLMM model for trawl ground B (f2) (circles) with bars corresponding to +/- one standard error of the estimate and the fitted series (line).

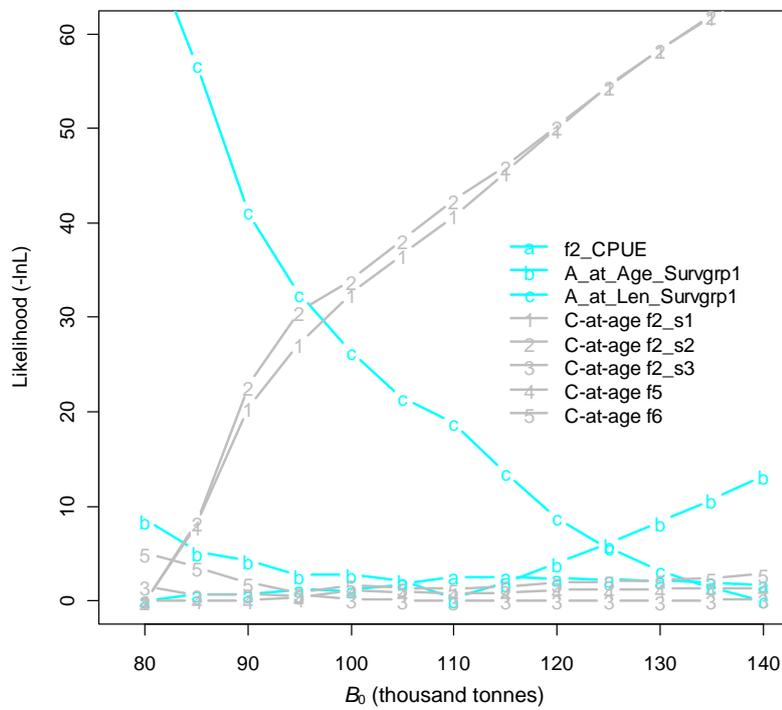


Figure 12: Profile -2log-likelihood for B_0 for major observation datasets.

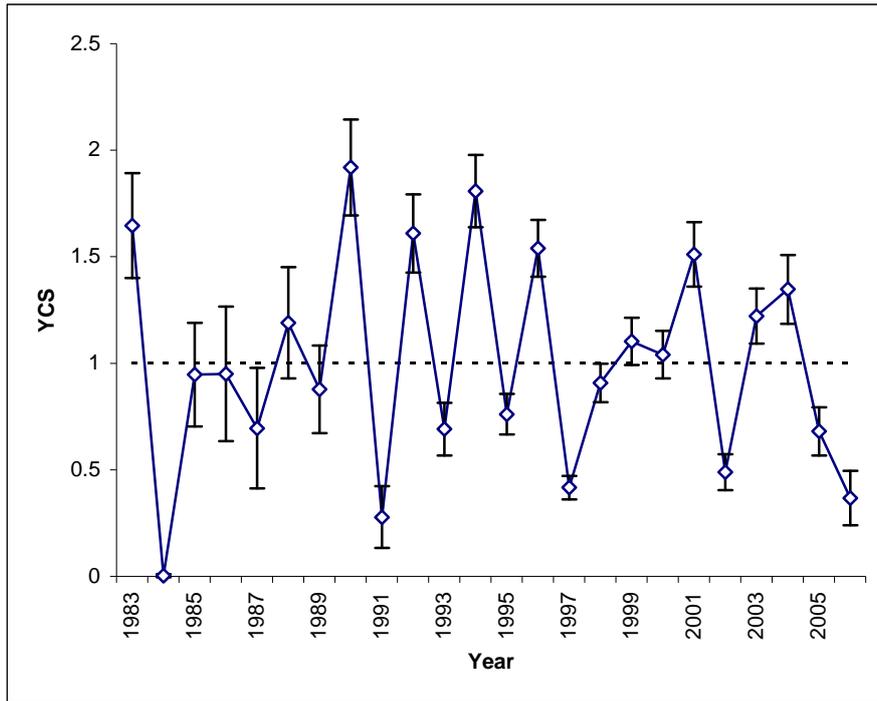


Figure 13: Estimates of Year-class Strength (YCS) estimates (showing +/-SE bars).

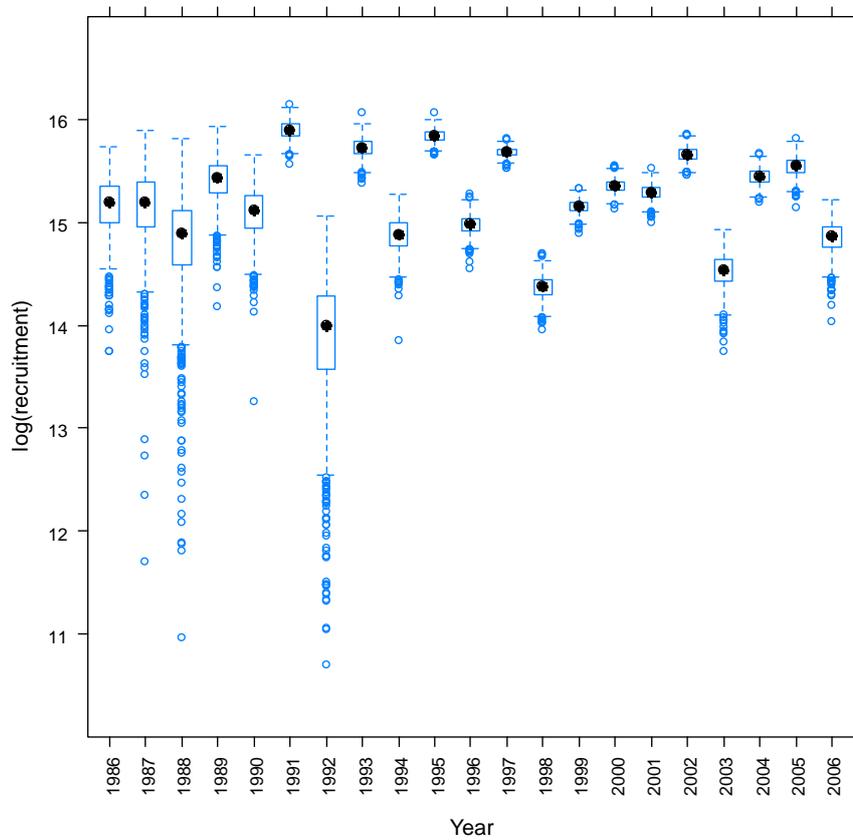


Figure 14: Box plots of age-1 recruitment series on the log scale for the historical period (1986–2006) used to calculate recruitment CV.

4.4 Estimation of yield

43. The estimated long-term yield was 2 550 tonnes with depletion probability of 0.001 and escapement probability of 0.502. Figure 15 shows box and whisker plots of spawning stock biomass (SSB) and status of SSB (i.e. SSB/B_0) under random recruitments from 2007 onwards using the lognormal recruitment variability with a CV of 0.6.

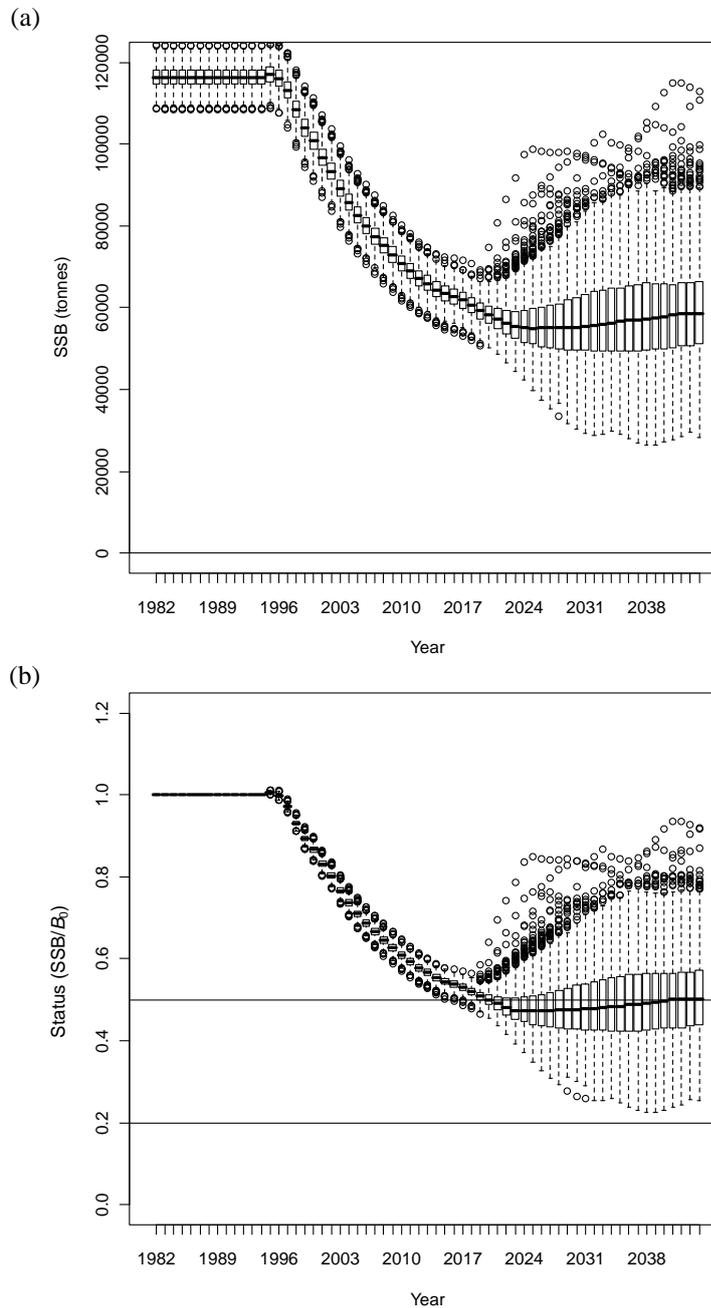


Figure 15: Projection results using future random lognormal recruitment from 2007 with an annual catch of 2 550 tonnes between 2010 and 2044. Each box represents the distribution of the variable across 1 000 projection trials for that year: (a) spawning stock biomass; (b) status of spawning stock biomass in a trial relative to B_0 in that projection trial (used in CCAMLR decision rules – lines show the 50% and 20% status levels for reference).

44. The Working Group agreed that the CASAL assessment provides a foundation for advice on stock status and yield for toothfish in this division. The CASAL assessment using age-classified data in place of length-classified data now allows historical recruitment trends to be more accurately reconstructed with a corresponding large reduction in the estimate of recruitment variability compared to that obtained in previous assessments. As such, the Working Group agreed that the estimate of yield from the CASAL assessment be used as a foundation for advice to the Scientific Committee.

4.5 Future research requirements

45. The Working Group noted the successful progress in developing an integrated assessment of *D. eleginoides* in CASAL. It agreed that further work could be undertaken to refine this assessment, including examining:

- (i) re-estimate the von Bertalanffy growth function using the additional length–age data obtained in 2008 and 2009;
- (ii) investigate possible simplification of the spatial structuring of fishing selectivity functions;
- (iii) the use of aged recaptures and catch-at-age data to estimate natural mortality, M , either independently of CASAL or within the current CASAL estimation framework;
- (iv) whether the model could be developed as a two-sex model;
- (v) whether improvement in the model structure can be made to allow the inclusion of tagging data to assist the estimation of parameters in the model, besides M given in (iii) above, using CASAL.

46. The Working Group encouraged the evaluation of the assessment and harvest strategy in Division 58.5.2 along with the further development and evaluation of management strategies for toothfish fisheries considered in general by the Working Group.

5. By-catch of finfish and invertebrates

5.1 By-catch removals

47. By-catch removals for the toothfish fisheries (longline and trawl) are detailed in Table 8 from fine-scale data. By-catch in the toothfish trawl fisheries is generally low, comprising less than 1% of the total catch. Landed by-catch in the longline fisheries ranged from 6 to 13% of the total catch (~8% in 2008/09), and including cut-offs revised these estimates to between 11 and 26% (21% in 2006/07) of the total catch. No species was caught in quantities approaching the catch limits.

Table 8: Catch history for by-catch species (macrourids, rajids, *Channichthys rhinoceratus*, *Lepidonotothen squamifrons* and other species), catch limits and number of rajids released alive in Division 58.5.2. Catch limits are for the division (see Conservation Measure 33-02 for details). (Source: fine-scale data)

Season	Macrourids				Rajids				Number released
	Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)			
		Longline	Trawl	Total		Longline	Trawl	Total	
1996/97	-	0	0	0	-	0	3	3	-
1997/98	-	0	0	0	120	0	3	3	-
1998/99	-	0	1	1	-	0	2	2	-
1999/00	-	0	4	4	-	0	6	6	-
2000/01	-	0	1	1	50	0	5	5	-
2001/02	50	0	4	4	50	0	4	4	-
2002/03	465	3	1	4	120	7	27	33	-
2003/04	360	42	3	46	120	62	14	76	155
2004/05	360	72	2	74	120	71	8	79	8 412
2005/06	360	26	1	27	120	17	19	36	3 814
2006/07	360	61	5	66	120	8	10	18	7 886
2007/08	360	81	5	86	120	13	9	22	9 799
2008/09	360	110	2	112	120	15	13	28	10 671

Season	<i>Channichthys rhinoceratus</i>				<i>Lepidonotothen squamifrons</i>			
	Catch limit (tonnes)	Reported catch (tonnes)			Catch limit (tonnes)	Reported catch (tonnes)		
		Longline	Trawl	Total		Longline	Trawl	Total
1996/97	-	0	2	2	-	0	0	0
1997/98	80	0	2	2	325	0	3	3
1998/99	150	0	1	1	80	0	0	0
1999/00	150	0	3	3	80	0	0	0
2000/01	150	0	1	1	80	0	4	4
2001/02	150	0	4	4	80	0	1	1
2002/03	150	0	21	21	80	0	0	0
2003/04	150	0	7	7	80	0	3	3
2004/05	150	0	36	36	80	0	2	2
2005/06	150	0	32	32	80	0	5	5
2006/07	150	0	15	15	80	0	10	10
2007/08	150	0	37	37	80	0	20	20
2008/09	150	0	47	47	80	0	18	18

(continued)

Table 8 (continued)

Season	Other species			
	Catch limit (tonnes)	Reported catch (tonnes)		
		Longline	Trawl	Total
1996/97	50	0	6	6
1997/98	50	0	3	3
1998/99	50	0	3	3
1999/00	50	0	5	5
2000/01	50	0	6	6
2001/02	50	0	10	10
2002/03	50	0	10	10
2003/04	50	3	16	19
2004/05	50	3	9	12
2005/06	50	3	7	12
2006/07	50	1	4	5
2007/08	50	2	18	21
2008/09	50	9	17	25

5.2 Assessments of impact on affected populations

48. Updated 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-09/42. Insufficient information was available to update assessments.

49. No stock assessments of individual by-catch species were undertaken in 2009. By-catch limits of *Channichthys rhinoceratus* and *Lepidonotothen squamifrons* are based on assessments carried out in 1998 (SC-CAMLR-XVII, Annex 5, paragraphs 4.204 to 4.206) and by-catch limits of the grenadier *Macrourus carinatus* are based on assessments carried out in 2002 and 2003 (SC-CAMLR-XXII, Annex 5, paragraphs 5.245 to 5.249).

5.3 Mitigation measures

50. The fishery operates under Conservation Measure 33-02.

51. The Working Group recommended that, where possible, all rajids should be cut from the line while still in the water, except on the request of the scientific observers during their sampling period.

6. By-catch of birds and marine mammals

52. One seabird mortality, a Cape petrel, was observed in the trawl fishery in Division 58.5.2 in 2008/09. Seabird/trawl interactions are reported in Table 9. Another Cape petrel mortality was observed in the Division 58.5.2 longline fishery in 2008/09.

Table 9: Seabird mortality totals and rates (BPT: birds/trawl) and species composition of by-catch, recorded by observers in Division 58.5.2 trawl fisheries over the last nine seasons. DIM – black-browed albatross; PRO – white-chinned petrel; DAC – Cape petrel (data from SC-CAMLR-XXVIII, Annex 7, Table 5).

Season	Target species	BPT	Dead			Total dead	Alive (all species combined)
			DIM	PRO	DAC		
2000/01	<i>D. eleginoides</i>	<0.10				0	0
2001/02	<i>D. eleginoides</i>	<0.10				0	1
2002/03	<i>D. eleginoides</i>	<0.10	2	2	2	6	11
2003/04	<i>D. eleginoides</i>	<0.10				0	13
2004/05	<i>D. eleginoides</i>	<0.11	5	3		8	0
2005/06	<i>D. eleginoides</i>	0.00				0	0
2006/07	<i>D. eleginoides</i>	<0.10			2	2	0
2007/08	<i>D. eleginoides</i>	0.00				0	1
2008/09	<i>D. eleginoides</i>	0.002			1	1	0

53. WG-IMAF assessed the level of risk of incidental mortality of seabirds in Division 58.5.2 as category 4 (average-to-high) (SC-CAMLR-XXVIII, Annex 7, Table 14 and Figure 2).

54. No instances of marine mammal mortalities or entanglements were observed in the trawl fishery in Division 58.5.2 in the 2008/09 season (Table 10). However, there were two observed Elephant seal mortalities in the longline fishery in Division 58.5.2 in 2008/09 (WG-IMAF-09/6 Rev. 2, Table 2).

Table 10: Seal mortality totals and rates (SPT: seals/trawl) and species composition of by-catch, recorded by observers in Division 58.5.2 trawl fisheries over the last nine seasons. SLP – leopard seal; SEA – Antarctic fur seal; SES – southern elephant seal (data from SC-CAMLR-XXVIII, Annex 7, Table 7).

Season	Target species	SPT	Dead			Total dead	Alive (all species combined)
			SLP	SEA	SES		
2000/01	<i>D. eleginoides</i>	0.001		1		1	2
2001/02	<i>D. eleginoides</i>	0.001		1		1	0
2002/03	<i>D. eleginoides</i>	0.003		2	2	4	2
2003/04	<i>D. eleginoides</i>	0.002		3		3	0
2004/05	<i>D. eleginoides</i>	0.00				0	1
2005/06	<i>D. eleginoides</i>	0.00	1			1	0
2006/07	<i>D. eleginoides</i>	0.00				0	0
2007/08	<i>D. eleginoides</i>	0.00		1		1	0
2008/09	<i>D. eleginoides</i>	0.00				0	0

6.1 Mitigation measures

55. Longline fishing is conducted in accordance with Conservation Measures 24-02 and 25-02 and the special requirements outlined in Conservation Measure 41-08, paragraph 3; trawl fishing in accordance with Conservation Measure 25-03.

7. Ecosystem implications/effects

56. 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 in an IUCN category Ia marine reserve (SC-CAMLR-XXI/BG/18). The marine reserve and associated conservation zone comprises around 17% of the area of the Australian EEZ around Heard Island and McDonald Islands and falls entirely within CCAMLR Division 58.5.2.

57. 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.

8. Harvest controls and management advice

8.1 Conservation measures

58. The limits on the fishery for *D. eleginoides* in Division 58.5.2 are defined in Conservation Measure 41-08. The limits in force applied to 2007/08 and 2008/09 and the Working Group's advice to the Scientific Committee are summarised in Table 11.

Table 11: Limits on the exploratory fishery for *D. eleginoides* in Division 58.5.2 in force in 2007/08 and 2008/09 (Conservation Measure 41-08) and advice to the Scientific Committee.

Element	Limit in force	Advice
Access (gear)	Trawls or longlines or pots	
Catch limit	2 500 tonnes west of 79°20'E (see CM 32-14)	Revise to 2 550 tonnes
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 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.	Carry forward
Mitigation	In accordance with CMs 24-02, 25-02 and 25-03.	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 Annex 42-02/B. 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 <i>Dissostichus eleginoides</i> and the by-catch is any species other than <i>D. eleginoides</i> .	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

8.2 Management advice

59. The Working Group recommended that the catch limit for *D. eleginoides* in Division 58.5.2 west of 79°20'E should be 2 550 tonnes for the 2009/10 fishing season.

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. 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.
- 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.
- 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.