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Title **REVISED ESTIMATES OF THE BIOLOGICAL PARAMETERS FOR ANTARCTIC TOOTHFISH (*DISSOSTICHUS MAWSONI*) IN THE ROSS SEA**

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ABSTRACT

This report updates the estimates of the biological parameters for Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea (Subareas 88.1 and SSRUs 88.2A–B). We present revised estimates of the von Bertalanffy growth curves, length weight relationship, and natural mortality based on CCAMLR observer data collected from commercial fishing operations in the Ross Sea. In addition, we review meta-data for plausible estimates of the steepness parameter of the stock-recruitment relationship and recruitment variability of Antarctic toothfish.

SUMMARY OF FINDINGS AS RELATED TO NOMINATED AGENDA ITEMS

<i>Agenda Item</i>	<i>Findings</i>
2.4.1	We recommend separate age-length keys are used for Antarctic toothfish in the north and slope/shelf areas of the Ross Sea.
2.5.1	We recommend new von Bertalanffy growth parameters and length-weight parameters for Antarctic toothfish.
2.5.2	We recommend using a value of $M = 0.13 \text{ y}^{-1}$ for Antarctic toothfish.
2.5.3	We recommend values of $\sigma_R = 0.60$ and $h = 0.75$ for Antarctic toothfish.

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1. INTRODUCTION

Toothfish are large Nototheniids endemic to Antarctic and sub Antarctic waters. There are two common species of toothfish; Antarctic toothfish (*Dissostichus mawsoni*) and Patagonian toothfish (*Dissostichus eleginoides*). Their distribution is circumpolar, although *D. mawsoni* has a more southern distribution and is found in latitudes south of the Antarctic Convergence (Hanchet et al. 2003).

Finfish fisheries in Antarctic waters are largely managed under CCAMLR jurisdiction. The Convention area covers roughly the area south of the Antarctic Convergence (varying from 60° S in the Pacific Sector to 45° S in the western Indian Ocean Sector). Within the Convention area some fisheries are managed by CCAMLR member countries, which have exclusive economic zones (EEZ) around their sub Antarctic Islands. Unlike Patagonian toothfish, Antarctic toothfish appear to be restricted to waters managed solely by CCAMLR. To date, the main fishery for this species has taken place in Subarea 88.1 (the western Ross Sea) and to a much lesser extent in Subarea 88.2 (the eastern Ross Sea) (Figure 1), as well as Divisions 58.4.1 and 58.4.2.

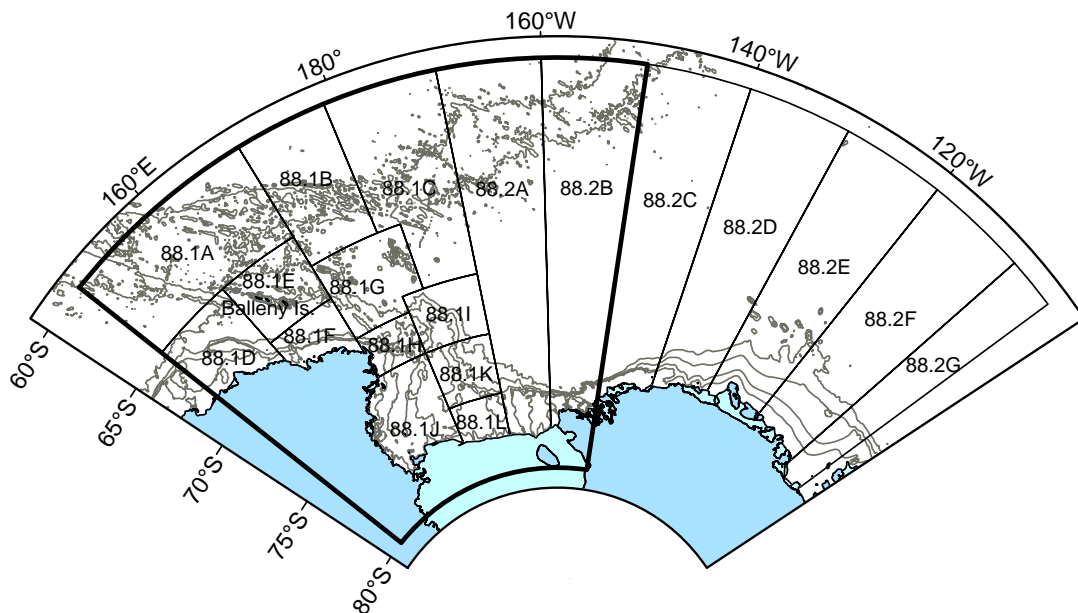


Figure 1: CCAMLR Subareas 88.1 and 88.2, small scale statistical areas (SSRUs), and the Ross Sea (bounded region). Depth contours plotted at 500, 1000, 2000, and 3000 m.

Estimates of natural mortality, growth, and the length-weight parameters provide an important input into the stock assessment models for Antarctic toothfish in the Ross Sea. Previous estimates of the key biological parameters used in the most recent stock assessment of Antarctic toothfish in the Ross Sea are reported in Dunn et al. (2005). Estimates of Antarctic toothfish natural mortality, growth, and weight-at-length were based on data collected from New Zealand vessels fishing in Subarea 88.1 between 1998–2002¹, and summarised by Hanchet et al. (2003).

This paper updates the previous estimates, and uses data collected between 1998 and 2005 from all vessels, and New Zealand vessels in 2006 that fished in the Ross Sea (Subareas 88.1

¹ Note that this report uses the CCAMLR split year that is defined from 1 December to 30 November. Hence, the term “year” refers to the fishing season in which most fishing occurs, e.g., the period 1 December 2004 to 30 November 2005 is labelled the 2005 year.

and SSRUs 88.2A–B). In addition, where possible, estimates are presented for data collected from vessels in SSRU 88.2E and compared with estimates for the Ross Sea. The previously assumed parameters are given in Table 1.

To be consistent with the assessment of the Ross Sea by Dunn et al. (2005) data from the Ross Sea fishery were divided into three regions, defined as ‘shelf’, ‘slope’, and ‘north’. The definitions of the areas that comprised the fisheries were based on stratifications derived from the tree based regression analysis of the commercial catch-at-length data used to stratify the commercial catch-at-age data by Hanchet et al. (2005) using the tree based regression method of Phillips et al. (2005). The shelf fishery was defined as the SSRUs 88.1E–F, 88.1H–I, & 88.1K at a depth of less than 761 m plus 88.1J, 88.L & 88.2A–B; Slope was defined as the SSRUs 88.1E–F, 88.1H–I, & 88.1K at a depth of greater than or equal to 761 m; and North was defined as SSRUs 88.1A–88.1C, and 88.1G.

Table 1: Previously assumed biological parameters (natural mortality, growth, length-weight relationship, and stock-recruitment relationship) for Ross Sea Antarctic toothfish.

Relationship	Parameter (units)	Group	Value	Source
Natural mortality	M (y^{-1})	All	0.15	(Hanchet et al. 2003)
Von Bertalanffy	t_0 (y)	Male	0.31	(Horn 2002)
		Female	0.50	(Horn 2002)
	k (y^{-1})	Male	0.102	(Horn 2002)
		Female	0.095	(Horn 2002)
	L_∞ (cm)	Male	170.3	(Horn 2002)
		Female	184.5	(Horn 2002)
	c.v.	All	0.08	(Dunn et al. 2004)
Length-weight	a ($t.cm^{-1}$)	Male	9.86e-09	(Hanchet et al. 2001)
		Female	6.17e-09	(Hanchet et al. 2001)
	b	Male	3.0335	(Hanchet et al. 2001)
		Female	3.1383	(Hanchet et al. 2001)
Stock recruitment relationship	h	All	0.75	(Dunn et al. 2004)
	σ_r	All	0.70	(Dunn et al. 2004)

2. METHODS AND RESULTS

2.1 Natural mortality

Natural mortality was assumed to be constant across age and sex classes. Hanchet et al. (2003) discussed possible values for the natural mortality of Antarctic toothfish, and reported values of $0.19 y^{-1}$ for males and $0.18 y^{-1}$ for females, with a range of 0.15 to $0.22 y^{-1}$ using the maximum age method of Hoenig (1983). Hanchet et al. (2003) also states that “... the longline fishery is unlikely to provide an unbiased estimate of population numbers at age, so these estimates must be considered to be very uncertain.” Previous yield calculations by CCAMLR for Antarctic toothfish have assumed a range of 0.15 – $0.22 y^{-1}$ (SC-CAMLR-XX 2001, p.371). The stock assessment of Antarctic toothfish summarised by Dunn et al. (2005) assumed $M = 0.15 y^{-1}$ but considered a sensitivity where $M = 0.1 y^{-1}$. In previous assessments of the related species, Patagonian toothfish, a range of 0.132 – $0.198 y^{-1}$ was assumed (SC-CAMLR-XXIII 2004). However, at the 2005 CCAMLR meeting, this value was revised to $0.13 y^{-1}$ for Patagonian toothfish in Subarea 48.3 and to a range of 0.13 – $0.165 y^{-1}$ for Division 58.5.2 (SC-CAMLR-XXIV 2005).

Sets of catch-at-age data by year since 1998, and by fishery (i.e., ‘shelf’, ‘slope’, and ‘north’) were available. They had been derived by applying the length data from all vessels fishing in

the Ross Sea area to an age-length key based on aged otoliths collected from New Zealand vessels. Estimated total numbers at age in the catch were summed across each age class to produce a single distribution for each sex in each fishery (Figure 2). Where several years of data are combined in this way it has the effect of smoothing the data and reducing the influence of any particularly weak or strong year classes.

For each distribution, an estimate of instantaneous natural mortality (M) was derived using the Chapman-Robson (1960) equation,

$$M = \log_e \left(\frac{1 + a - 1/n}{a} \right)$$

where a is the mean age above recruitment age (A_r) and n is estimated number of fish in the catch that are aged A_r or older (Chapman & Robson 1960). For this estimator, age at recruitment (A_r) should be the age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment). For each distribution, A_r was derived from Figure 2. The resulting estimates of M for each area and sex are listed in Table 2.

In addition, alternative estimates of M were also derived using the methods of Hoenig (1983)

$$\log_e M = 1.46 - 1.01 \times \log_e A_{1\%}$$

and Punt et al. (2005)²

$$\log_e M = 0.97 - 0.822 \times \log_e A_{1\%}$$

where $A_{1\%}$ is the minimum age of the oldest 1% of fish in the commercial catch. These estimates are also listed in Table 2.

Table 2: Estimates of instantaneous natural mortality (M) for Ross Sea Antarctic toothfish, by sex and fishery area. For the Chapman-Robson method, $A_x = A_r$; for the Hoenig and Punt methods, $A_x = A_{1\%}$.

Sex	Method	Shelf		Slope		North		All areas	
		A_x	M	A_x	M	A_x	M	A_x	M
Male	Chapman-Robson	8	0.17	13	0.18	16	0.15	14	0.16
	Hoenig	29	0.14	33	0.13	37	0.11	35	0.12
	Punt	29	0.17	33	0.15	37	0.14	35	0.14
Female	Chapman-Robson	8	0.14	15	0.18	19	0.17	17	0.18
	Hoenig	32	0.13	34	0.13	36	0.12	35	0.12
	Punt	32	0.15	34	0.15	36	0.14	35	0.14

² The equations listed in Table 14 of Punt et al. (2005) appear incorrect, in that they describe the relationship as a function of \log_{10} rather than (as described in Figure 11 of that report) \log_e . The relationships calculated here use \log_e .

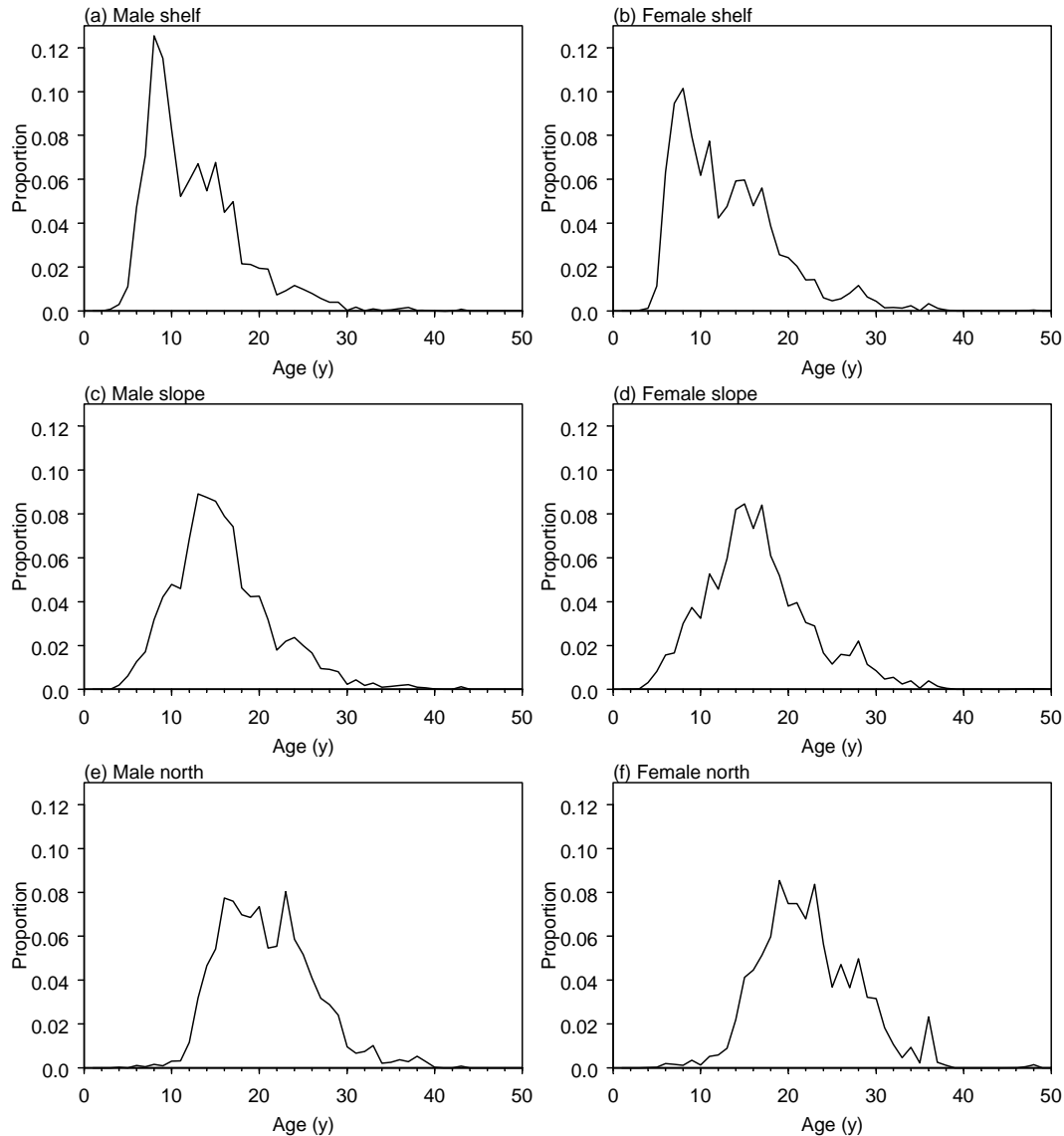


Figure 2: Estimated distributions of Antarctic toothfish catch at age in the Ross Sea, by sex and fishery, for all fishing years combined (i.e., 1998–2005).

2.2 Growth parameters

The von Bertalanffy growth equation (von Bertalanffy 1938) was used to derive the mean length at age relationship. Previously, Horn (2002) estimated age and growth from a sample of 1520 otoliths collected in Subarea 88.1 during 1998, 1999, and 2000, to produce the parameters in Table 1. The ageing method used (counts of zones in cross-sectioned, baked otoliths) has since been partially validated (Horn et al. 2003). Within the Ross Sea assessment model, Dunn et al. (2005) assumed variability in the length at age relationship that was parameterised by a constant normally distributed c.v. (with c.v. as a function of age), with c.v. arbitrarily set at 0.08.

Annual ageing of Antarctic toothfish samples has continued, and a significant volume of data is now available (Table 3). All available data from the Ross Sea were used to re-estimate the von Bertalanffy parameters using maximum likelihood, where growth curves were fitted assuming normally distributed errors with a constant c.v. parameterised as a function of mean length (i.e., the c.v. increased as a function of mean length at age rather than as a function of

age). Here, we assume that the length-at-age data consisting of length L and age t observations for n fish is partitioned into i groups by sex. Then we can describe the likelihood function of the parameters θ_{mj} in growth model m for the i th group, assuming normally distributed errors parameterised with a constant coefficient of variation c that is assumed to be the same for all i groups, as,

$$L_i(\theta_{m,i}, c; \mathbf{L}_i, \mathbf{t}_i) = \prod_{j=1}^{n_i} \left(2\pi \left[c\mu_m(\theta_{m,i}, t_{ij}) \right]^2 \right)^{1/2} \times \exp \left(-\frac{1}{2 \left[c\mu_m(\theta_{m,i}, t_{ij}) \right]^2} \left[L_{ij} - \mu_m(\theta_{m,i}, t_{ij}) \right]^2 \right)$$

Revised von Bertalanffy growth parameters are listed in Table 4, and the curves and raw data are plotted in Figure 3. Von Bertalanffy parameters were not calculated for the three areas separately. Because there are very few small fish caught in the northern area, and very large fish are uncommon on the shelf, it is likely that any growth curves calculated for these areas would not be representative of the entire population.

A comparison of the median age at length, by sex, from the three fishery areas is shown in Figure 4. There were no apparent between-area differences for males up to about 110 cm or for females up to about 120 cm. But for longer fish, median age at length was greater in the ‘north’ area, i.e., large fish in the north have, on average, experienced a slower growth rate than similar sized fish in the slope. This growth difference between slope and north fish persists until fish from both areas reach a size near L_∞ . Male fish on the shelf have a similar mean age at length to those from the slope, but females larger than 150 cm appear to be more similar to those from the north.

Table 3: Numbers of available length at age data points for Ross Sea Antarctic toothfish, by sex and year.

Year	Male	Female	Total
1998	268	227	495
1999	287	214	501
2000	309	220	529
2001	472	417	889
2002	309	267	576
2003	276	261	537
2004	303	245	548
2005	239	255	494
Total	2 463	2 106	4 569

Table 4: Revised growth parameters for Ross Sea Antarctic toothfish.

Parameter (units)	Male	Female
t_0 (y)	-0.256	0.021
k (y ⁻¹)	0.093	0.090
L_∞ (cm)	169.07	180.20
c.v.	0.102	0.102

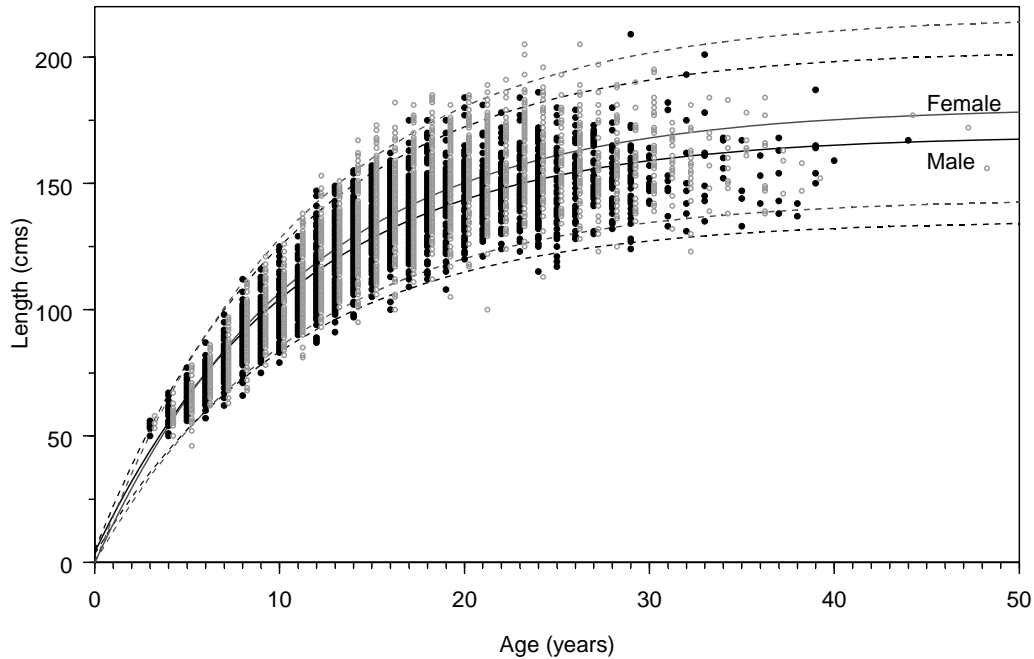


Figure 3: Revised von Bertalanffy growth curves for males (black lines) and females (grey lines) for Antarctic toothfish in the Ross Sea, with points showing the observations of age at length for males (filled circles) and females (open grey circles). Dashed lines show 95% C.I.s.

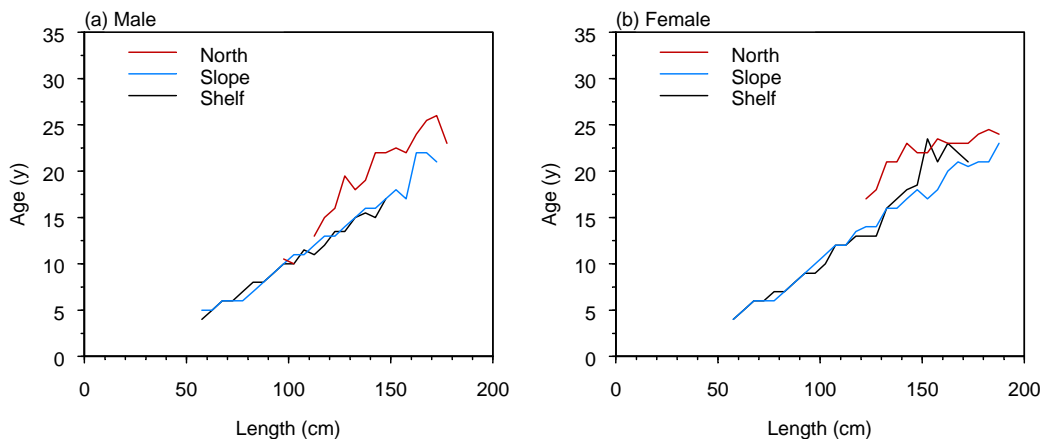


Figure 4: Median age at length (5 cm bins) for (a) Ross Sea Antarctic toothfish males and (b) females, in the shelf (black), slope (blue), and north (red) fisheries (bins of less than 5 fish are ignored).

2.3 Length-weight relationship

Length-weight parameters used previously in stock assessment of Dunn et al. (2005) were reported by Hanchet et al. (2001), and are reproduced above in Table 1. For that analysis, data from 2001 ($n = 10\,280$) were checked for obvious errors, outliers were removed, and the data were log-transformed and geometric mean regressions calculated.

The continued annual sampling of Antarctic toothfish has resulted in a significant volume of length-weight data now being available (Table 5), and these were used to re-estimate the length-weight relationships for Antarctic toothfish by sex. The data set comprised length-weight records from all longline vessels fishing in the Ross Sea up to end of 2005, plus all

New Zealand vessels fishing in 2006. Data from the FV *San Aspiring* in 2005 (CCAMLR trip number 298) were excluded from analysis, because a large proportion of the recorded fish weights from this trip were clearly erroneous.

The revised length-weight parameters are listed in Table 6, and the curves and raw data are plotted in Figure 5. Length-weight relationships were also investigated for the three areas separately owing to a perception that fish in poor condition, often referred to as ‘axe handles’, were relatively more abundant in the north. Parameters for the shelf, slope, and north fisheries are listed in Table 6 and plotted in Figure 6.

Table 5: Numbers of available weight at length data points for Ross Sea Antarctic toothfish, by sex and year.

Year	Male	Female	Total
1998	257	228	485
1999	2 013	1 597	3 610
2000	6 122	4 817	10 939
2001	4 512	4 029	8 541
2002	9 461	7 066	16 527
2003	7 649	8 462	16 111
2004	20 063	16 031	36 094
2005	14 831	12 454	27 285
2006	6 558	5 266	11 824
Total	71 466	59 950	131 416

Table 6: Revised length-weight parameters for Ross Sea Antarctic toothfish.

Group	Parameter (units)	Male	Female
Shelf	a ($t.cm^{-1}$)	5.324e-9	5.381e-9
	b	3.173	3.171
Slope	a ($t.cm^{-1}$)	4.606e-9	3.923e-9
	b	3.205	3.238
North	a ($t.cm^{-1}$)	3.035e-8	1.696e-8
	b	2.774	2.906
Ross Sea	a ($t.cm^{-1}$)	1.387e-8	7.154e-9
	b	2.965	3.108

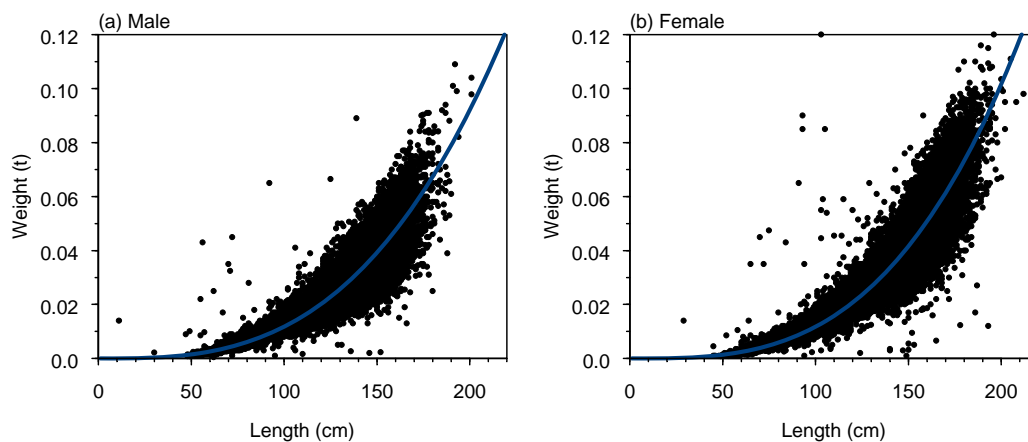


Figure 5: Revised length-weight curves (grey lines), by sex, for Ross Sea Antarctic toothfish, with points showing the observations of weight at length.

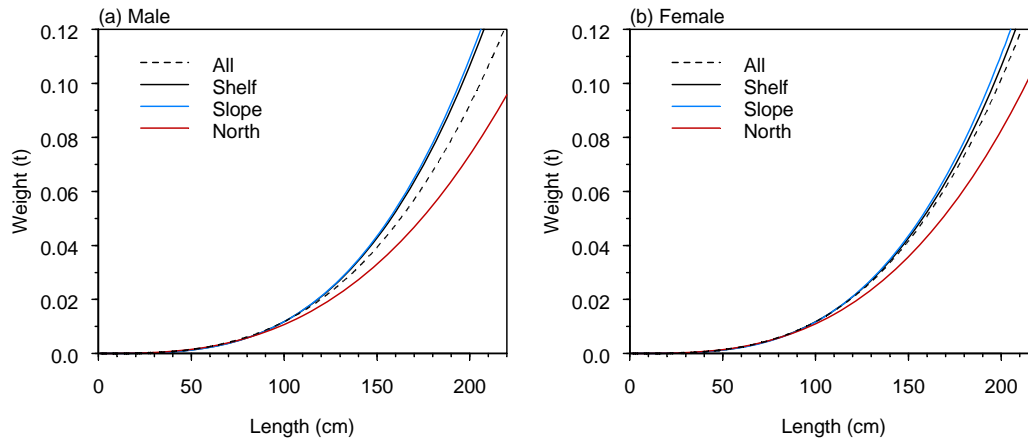


Figure 6: Length-weight curves, by sex, for Ross Sea Antarctic toothfish in the shelf, slope, and north sections of the Ross Sea, with the ‘all Ross Sea’ curves provided for comparison.

2.4 Stock-recruitment relationship and recruitment parameters

In the stock assessments of Antarctic toothfish in the Ross Sea and SSRU 88.2E, the spawning stock-recruitment relationship was assumed to be a Beverton-Holt relationship with steepness (h) equal to 0.75 (Dunn et al. 2005). In those models, variability in future recruitment was assumed to be lognormally distributed, with $\sigma_R = 0.7$. However, these values were chosen arbitrarily, and little empirical data exist for Antarctic toothfish on which to base these values.

In recent GY assessments for Patagonian toothfish h has been assumed equal to 1 and σ_R has been estimated in the model from recruitment survey data (SC-CAMLR-XXIV 2005). In recent CASAL assessments of Subarea 48.3, h was assumed equal to 0.8 and σ_R was assumed to be 0.7 for MCMC projections, whilst in ASPM assessments for Subarea 58.6 (South African EEZ) h was assumed equal to 0.6 and σ_R was assumed to be 0.5 (SC-CAMLR-XXIV 2005).

Three publications provide information based on meta-analyses recruitment variability. Myers et al. (1995) tabulated values of recruitment variability (σ_R) and first order autocorrelation in σ_R (see Table 1 in Myers et al. 1995) for a range of species. Myers et al. (1999) estimated a steepness parameter (h) for a range of species using a meta-analysis approach, and Punt et al. (2005) analysed a wide range of stock and recruitment data to determine if these could lead to a choice of default values of priors for assessments of data-poor assessments, including h and σ_R .

Table 1 in Myers et al. (1995) details the σ_R and first order autocorrelation of estimated recruitment for a wide variety of international fisheries. We use these values to derive plausible values of σ_R and autocorrelation, using those stocks with more than 10 years data, for species selected from the orders Gadiformes (including cods and hakes), Lophiiformes (monkfish), Ophidiiformes (lings), and Scorpaeniformes (perch, rockfish), and *Anoplopoma fimbria* (sablefish). Summary values derived from those fish are given in Table 7.

Table 1 in Myers et al. (1999) summarises estimates of h for a wide variety of international fisheries. We use these values to derive plausible values of h for individual species selected from the orders Gadiformes (including cods and hakes), Lophiiformes, Perciformes (Lutjanidae and Percichthyidae, Sparidae, and Xiphiidae only), Pleuronectiformes (halibut

only), Salmoniformes (pike only), Scorpaenidae, and *Anoplopoma fimbria* (sablefish). Summary values derived from those fish are given in Table 7.

Punt et al. (2005) analysed stock and recruitment data to estimate priors for the steepness of the stock-recruitment relationship. Their recommendations were based on the median posteriors of estimated values of steepness. They recommended that "... if a single default point estimate of steepness be used in a stock assessment, then the default should be $h=0.907$ for Clupeiformes, Gadiformes, and Pleuronectiformes, and $h=0.757$ for other species" (i.e., Aulopiformes, Perciformes, Salmoniformes, and Scorpaeniformes). Further, they recommended that the default choice for σ_R was 0.615 (median, with 90% intervals 0.232–1.525), and "... that this value provides a default value of σ_R ".

Table 7: Summary statistics for \log_e transformed recruitment, for included fisheries with data series greater than 10 years (Table 1 in Myers et al. 1995) and h for included fisheries (Table 1 in Myers et al. 1999).

Parameter	Lower 90% percentile	Lower quartile	Median	Upper quartile	Upper 90% percentile
σ_R	0.23	0.37	0.60	0.83	1.45
First order autocorrelation	-0.16	0.15	0.35	0.63	0.83
h	0.32	0.46	0.73	0.83	0.94

Note: The summary statistics presented by Myers et al. (1995) involved \log_{10} transformations. These have been converted to \log_e in this table as to allow direct comparison with values used within the Antarctic toothfish stock assessment models.

3. DISCUSSION

3.1 Natural mortality

It is clear that the mean age of the catch increases from the shallow (shelf) to the deeper (north) waters (Figure 2), and the sections of the population exploited by the line fishery are different in each of the three areas. Very old fish are less common on the shelf, and young fish are very uncommon in the north. These spatial differences in the population structure confound the estimation of natural mortality. In addition, the use of a single age-length key for Antarctic toothfish in the Ross Sea, where there is a clear difference in mean age at length, may have introduced a bias into estimates of the North (and a lesser extent, the Shelf and Slope) age structure.

There is no clear evidence that M for Antarctic toothfish differs between sexes (although it is relatively common for teleosts to have an M for females being slightly lower than that for males). In Table 2, a lower female M is apparent for the shelf population, but there are no differences on the slope, and a reverse trend is apparent in the northern fishery.

The Chapman-Robson method technically estimates the total instantaneous mortality (Z) rather than M . However, the Ross Sea fishery has been in progress for less than 8 years (the lowest A_r used in the calculations is 8) and total extractions have probably been low relative to total biomass (Dunn et al. 2005). However, the Chapman-Robson values can be used to infer a likely maximum value of M . Both the Shelf and Slope distributions have an under-representation of very old fish when compared to the North. Hence, they may underestimate the true mean age above recruitment for the population, and so overestimate M .

Estimates of M derived using the methods of Hoenig (1983) and Punt et al. (2005) ranged from 0.11 to 0.17 y^{-1} , but those from the northern area are from 0.11 to 0.14 y^{-1} . For

Patagonian toothfish (*D. eleginoides*) estimates of M were revised to 0.13 y^{-1} for Subarea 48.3, and to the range $0.13\text{--}0.165 \text{ y}^{-1}$ for Division 58.5.2 (SC-CAMLR-XXIV 2005).

Clearly, there is still considerable uncertainty about M for Antarctic toothfish. Based on Hoenig and Punt equations estimates of M ranged from $0.11\text{--}0.17 \text{ y}^{-1}$, and had a median estimate of 0.14 y^{-1} overall, and 0.13 y^{-1} in the North. The Chapman-Robson Z had range $0.14\text{--}0.18 \text{ y}^{-1}$. Assuming the average effective fishing mortality (F) over the period of the fishery was 0.02 , suggests that M was between $0.12\text{--}0.16 \text{ y}^{-1}$. Here, the median (adjusted) estimate was 0.15 overall, and 0.14 y^{-1} in the North.

We propose that the value of 0.13 y^{-1} be used in stock modelling of Antarctic toothfish for both males and females (see Table 8), but that the values of natural mortality be re-estimated once revised age-length keys and hence age frequencies are developed for the Ross Sea. In addition, consideration might be given to using values in the range $0.11\text{--}0.15 \text{ y}^{-1}$ for both sexes as a sensitivity. We note that further research is required on values of M and on possible changes of M with age.

Table 8: Proposed biological parameters (natural mortality, growth, length-weight relationship, and stock-recruitment relationship) for use in assessments of Ross Sea Antarctic toothfish.

Relationship	Parameter (units)	Male	Female	All
Natural mortality	$M (\text{y}^{-1})$	0.13	0.13	
Von Bertalanffy	$t_0 (\text{y})$	-0.256	0.021	
	$k (\text{y}^{-1})$	0.093	0.090	
	$L_\infty (\text{cm})$	169.07	180.20	
	c.v.	0.102	0.102	
Length-weight	$a (\text{t.cm}^{-1})$	1.387e-8	7.154e-9	
	b	2.965	3.108	
Stock recruitment relationship	h			0.75
	σ_r			0.60

3.2 Growth parameters

The newly calculated relationships appear to fit the raw data well. As found by Horn (2002), females are, on average, larger at age than males from about age 10. The new values (Table 8) are only slightly different to those originally estimated by Horn (2002) despite a three-fold increase in available data. For both sexes, the new estimates of L_∞ and k are lower than the previous estimates. The values of t_0 are very close to zero for both sexes, despite the scarcity of fish younger than 4 years old. Hence, it is likely that the derived curves provide a good model of Antarctic toothfish growth over the full range of ages.

The apparent differences between areas in mean age at length are problematical. There is no reason to believe that more than one Antarctic toothfish stock exists in the area. Differentiation begins at about the length at 50% maturity (Hanchet et al. 2003), so a trade-off between somatic growth and reproductive productivity may be an influential factor. Fish in the north are generally more sexually mature than those on the shelf and slope, and it has been hypothesised Antarctic toothfish migrate to the northern areas to spawn (Patchell 2002, Fenaughty 2005). If fish remaining on the shelf and slope expend less energy on reproduction then they are likely to be, on average, longer at age than those reproducing in the north. The gradual convergence of the median age at length from all areas in larger fish as they approach L_∞ suggests gradual mixing of fish between areas over time. This is supported by the relatively slow rate of mixing shown by the tagging experiments (Dunn & Hanchet 2006). It is uncertain how the large ($>150 \text{ cm}$), slower growing female fish in the shelf population fit

into this scenario. One hypothesis to explain them would be that they may comprise the return from the north of post-reproductive (senescent) fish.

It is not practical or logical to use two different growth equations when modelling fish from a presumed single stock, hence we suggest that the revised relationship (Table 8) be used for stock assessment modelling. However, it may be prudent to create two age-length keys each season, i.e., one for the north area, and another for the shelf and slope combined, for estimating the age-frequencies for use in the stock assessment models.

3.3 Length-weight relationship

The newly calculated relationships appear to fit the raw data well. The new values differ from those originally estimated by Hanchet et al. (2001) (i.e., the b values are lower and the a values are higher), but when plotted together there was little apparent difference between the old and new curves.

The finding that toothfish in the north area are, on average, lighter at length than those on the shelf and slope is in line with previous observations (Fenaughty 2005). It is likely that the northern fish have deteriorated in condition following spawning (and possible migration from the southern regions). It is not practical to use multiple length-weight equations in the stock modelling, hence we suggest that the revised relationship (Table 8) be used for stock assessment modelling.

There are two methods that could be used to create the scaled length-frequency distributions (and hence age frequencies) for each fishery in each season. The method previously used for the Ross Sea scaled the length frequency of the observed catch (in tonnes) in each observed set to the total set catch (in tonnes), then to the stratum catch (in tonnes), and then to the total annual catch (in tonnes). Here, the rescaling is done using the length-weight relationship (see Hanchet et al. 2005). If this approach was to be applied for estimating the length frequency of the commercial catch, then it may be better to utilise the area-specific length weight relationships described above. Alternatively, as numbers of fish caught have also been recorded, then rescaling could be carried out using the numbers of fish in each set, stratum, and for the annual catch. Here, any area-specific length-weight relationships would be incorporated automatically into the calculations.

3.4 Stock-recruitment relationship and recruitment parameters

The estimation of stock recruitment parameters for Antarctic toothfish from the information provided by Myers et al. (1995) and Myers et al. (1999) could be rather tenuous. The classification used to select the data summarised in Table 7 was essentially “marine teleost”. Most of these are short-lived species from temperate to sub-Arctic waters in the northern hemisphere. Very few were long-lived, high order predators, like the toothfish. However, the values presented probably provide a reasonable starting estimate for the Antarctic toothfish stock recruitment relationship parameters.

Estimates of h are available from Punt et al. (2005); the value of 0.76 recommended for “other species” is probably the most applicable for Antarctic toothfish, and we note that the median estimate from Myers et al. (1999) was very similar ($h = 0.73$). We propose that the current value of $h = 0.75$ be retained for Antarctic toothfish. The median or default σ_R values of both Punt et al. (2005) and Myers et al. (1995) are very similar (~ 0.60). We recommend the adoption of $\sigma_R = 0.6$ for future assessments of Antarctic toothfish.

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