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A PRELIMINARY ASSESSMENT OF AGE AND GROWTH OF ANTARCTIC SILVERFISH (*PLEURAGRAMMA ANTARCTICUM*) IN THE ROSS SEA, ANTARCTICA

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Abstract

Antarctic silverfish (*Pleuragramma antarcticum*) were sampled during a trawl survey in the Ross Sea, Antarctica. Biological data, including fish length, weight, sex, gonad maturity, liver weight and diet analysis were collected from 311 specimens. Standard length and weight were well correlated ($r^2 = 0.99$).

Counts of growth zones in 304 thin-sectioned otoliths were used to estimate ages and von Bertalanffy growth parameters. The species is relatively slow-growing with a moderate longevity; the maximum estimated age was 14.3 years. Von Bertalanffy parameters derived for both sexes combined are: L_∞ 22.1 cm SL; K 0.167 y^{-1}; t_0 –0.4 years. Parameter estimates were also derived for the sexes separately. Female Antarctic silverfish appear to reach a larger size than males, but none of the estimated von Bertalanffy parameters were statistically significantly different between sexes. All parameter estimates are preliminary as the ageing method is unvalidated and about two-thirds of the sampled fish could not be sexed.

Precision estimates and age bias plots indicated that there was good within-reader and between-reader agreement, so the otolith sections appear able to be consistently interpreted.

The standard lengths of the sampled Antarctic silverfish ranged from 4.6 to 22.9 cm. Pronounced modes in the length-frequency distribution occurred at 7.1–7.5, 10.6–11.0 and 15.1–15.5 cm. Mean lengths of 4.9 and 7.3 cm (at ages 1.3 and 2.3 years respectively) are consistent with those presented in the literature. The age-frequency distribution exhibited a mode from age 6 to 9 years.

Keywords: Antarctic silverfish, otolith, *Pleuragramma antarcticum*, Ross Sea, CCAMLR

Introduction

Antarctic silverfish (*Pleuragramma antarcticum* Boulenger 1902) is a relatively small planktivorous pelagic nototheniid (Figure 1) that is widely distributed in Antarctic waters between 61°S and 76°S (Andriashev, 1965; Fischer and Hureau, 1985; White and Piatkowski, 1993). It is abundant, accounting for about 98% by number of the total ichthyoplankton on the Weddell Sea continental shelf (Keller, 1983) and more than 90% of the pelagic fish biomass and 98% of the fish larvae by number in the Ross Sea (DeWitt, 1970; Guglielmo et al., 1998). Consequently, it is a key organism in the fish food web and a significant component in the diets of marine mammals and birds (Takahashi and Nemoto, 1984; Eastman, 1985; Smith et al., 2007; Pinkerton et al., 2010).

An understanding of the life history and productivity of a species is not complete without knowledge of its age and growth. Some information is available on the early growth of Antarctic silverfish, primarily derived from clear modes in length-frequency distributions. DeWitt and Tyler (1960) found consecutive modes at 8–9, 30–40 and 50–70 mm in December, and assumed they represented the 0+, 1+ and 2+ year classes. Hubold (1985) examined silverfish occurring in the eastern and southern Weddell Sea and found that 0+ fish ranged in length from 8 to 16 mm and 1+ fish were 25–47 mm in January. Kellerman (1986) studied length-frequency distributions of silverfish from off the Antarctic Peninsula in February 1976, 1978 and 1982, and estimated length modes at 11–22, 33–53 and 65–82 mm. These three size groups were considered to represent 0+, 1+ and 2+ year classes. Guglielmo et al. (1998) found length modes at 8–20 and 36–53 mm in Terra Nova Bay, Ross Sea, and assumed that these represented 0+ and 1+ fish. The pattern of apparent slow growth of young Antarctic silverfish was also found for older fish in a study using otolith zone counts (Hubold and Tomo, 1989). They estimated a maximum age of 14 years, and found a maximum length of 245 mm for fish from the Weddell Sea and Antarctic Peninsula.

Hubold and Tomo (1989) suggested that growth of Antarctic silverfish could be quite variable between different regions of the Southern Ocean; their results were indicative of some differences between the Weddell Sea and Antarctic Peninsula. In the current work, otoliths from Antarctic silverfish from the Ross Sea region were examined to develop growth parameters for the species in this area.

Methods

Data collection

Antarctic silverfish were sampled during a survey conducted by the RV *Tangaroa* in the Ross Sea, Antarctica, during February 2008 (O'Driscoll et al., 2011). Figure 2 shows the sample area. The specimens used in this study were mainly collected using a bottom trawl, or midwater trawl net. A single specimen was also captured in a beam trawl. Trawl gear was fished in depths ranging from 50–926 m, but much of the trawling was focused between about 350 and 500 m.

Biological data (including standard length (SL), total length (TL), weight, sex, gonad maturity and liver weight) were recorded for a subset of 311 specimens. Sagittal otoliths were successfully extracted from 304 of these fish, cleaned and stored dry in Eppendorf™ tubes for later analysis.

About two-thirds of the sample could not be sexed. This was because about 20% of the sample was from small fish (≤10 cm SL) with poorly developed gonads. The remaining unsexed larger fish had gonads that had deteriorated beyond recognition due to being stored frozen for almost two years.

SL has been used for all analyses as caudal fins were frequently damaged. Consequently, it was often not possible to obtain accurate TL measurements. However, the relationship between TL and SL was calculated.

Length–weight relationship

A sample of 311 Antarctic silverfish was used to estimate the length–weight relationship for both sexes combined. The length–weight relationship was calculated using the equation

$$W = \alpha L^{\beta} \qquad (1)$$

where W = weight (g) and L = standard length (cm).

Freezing sometimes causes shrinkage in length and a loss in weight. This has been shown to occur in Antarctic silverfish after about 20 months of freezing (M. Pinkerton, NIWA, pers. comm.), so corrections were made here. Relationships between pre- and post-freeze fish length and weight indicated that the necessary corrections were 7.6% for length (n = 55, r^2 = 0.96) and 4.1% for weight (n = 20, r^2 = 0.98).

Age and growth

Otolith preparation

Otoliths were collected from 35 male, 69 female and 200 unsexed Antarctic silverfish. Otolith extraction was difficult due to the small size of these structures. For example, sagittal otoliths from a 20 cm specimen measured about 2–3 mm in diameter. It was therefore necessary to use a microscope when extracting otoliths from fish ≤10 cm SL.

All otoliths were thin-sectioned following a modified methodology of Stevens and Kalish (1998). They were transversely aligned before being embedded in clear epoxy resin (Araldite K142) and left to cure at 50°C for 24 hours. Once cured, the blocks were transversely cut along the nuclear plane using a diamond-edged saw. One half of the sectioned block was mounted (otolith section down) onto a microscope slide using clear epoxy resin. Preparations were left to cure at 50°C for 24 hours. A 1 200 µm diamond-coated disc was used to grind the upper surface of each mounted sectioned block to a thickness of about 300 µm.

Prepared sections were examined under a stereo microscope (×50–80) illuminated by transmitted light. A pattern of translucent and opaque zones was evident with the number of complete opaque zones interpreted as annuli.

Age interpretation

To convert otolith zone counts to age estimates it is necessary to know when sampling was conducted, when spawning occurred, and when formation of the opaque zone in the otolith was completed.

These specimens were collected during February 2008. Hubold and Tomo (1989) assigned a hypothetical 'birthday' of 1 November for Antarctic silverfish sampled from the Weddell Sea and Antarctic Peninsula, based on first observing yolk-sac larvae in plankton catches in November (Hubold, 1988). The same birthday was adopted for the current work. Hubold and Tomo (1989) concluded that the opaque zone had formed by the end of summer. Consequently, the first opaque zone formed about 0.3 years after the birthday, had a radius of only about 0.1 mm, and was often indistinct. The first distinct opaque zone formed when the fish was about 1.3 years old; its radius was about 0.6 mm. Because the fish for the current work were sampled at the end of summer, otolith sections would be expected to have a margin that was opaque or with only a minute amount of translucent material. A count of the opaque zones (including the margin if it was opaque) could be converted to age in years by adding 0.3.

Interpretation of 'annuli' was very difficult for the first 2–3 zones. It was therefore necessary to rely on length measurements (used by Hubold and Tomo, 1989) for the first three annuli. These researchers analysed otoliths from post-larvae and juveniles to establish otolith measurements for small fish sizes. The radial measurements they calculated for the first three year classes were: 0.5 mm (age group 1+); 0.8 mm (age group 2+); 1 mm (age group 3+). They then related these measurements to length-frequency distributions presented in the literature (Keller, 1983; Hubold, 1984, 1985; Kellermann, 1986) and to the age groups (1+, 2+ and 3+).

Growth parameters

The unweighted length-at-age data were fitted to the von Bertalanffy growth model:

$$L_t = L_\infty\,(1 - \exp(-K^*(t - t_0)))$$

where L_t is the expected length at age t years, L_∞ is the asymptotic maximum length, K is the von Bertalanffy growth constant, and t_0 is the theoretical age at zero length. Growth curves were fitted using the non-linear least squares procedure in the R statistical package (R Development Core Team, 2008), and assuming a lognormal error structure of age-at-length. The fitted data were those from the first reading by reader 1 (CS). Three fits were produced: (i) to all data combined, (ii) to all male fish plus all unsexed fish up to age 5.3 years, and (iii) to all female fish plus all unsexed fish up to age 5.3 years. The incorporation of unsexed age data in the 'by sex' age curves was done to ensure that the juvenile sections of the growth curves are adequately described.

Ageing error

A random subsample of 99 otoliths was re-read by the primary reader (CS) six weeks after the initial reading to determine within-reader variation. A second experienced otolith reader (PH) read a random subsample of 98 otoliths. Precision was assessed by calculating the index of average percent error (APE; Beamish and Fournier, 1981). Age bias plots were used to determine if there were systematic differences within or between readers.

Results

Length and weight parameters

The relationship between standard and total lengths is:

SL = 0.8985 TL (n = 92, range 6.3–21.2 cm SL, r^2 = 0.99).

Table 1: Mean lengths-at-age (standard length in cm, with range, standard deviation (SD) and sample size) for fish sampled from the Ross Sea.

Age (years)	Mean	Range	SD	*n*
1.3	4.9	4.6–5.3	0.19	11
2.3	7.3	6.7–7.8	0.32	10
3.3	9.6	7.9–11.8	1.12	21
4.3	11.0	9.9–13.8	1.18	18
5.3	12.2	10.1–15.6	1.52	27
6.3	14.3	11.0–17.4	1.37	43
7.3	15.4	13.4–18.5	1.15	33
8.3	16.1	13.5–19.6	1.27	43
9.3	16.4	13.4–20.3	1.45	37
10.3	16.7	14.6–19.9	1.41	25
11.3	18.0	13.2–21.0	2.07	15
12.3	18.4	15.5–21.9	2.23	10
13.3	19.9	17.6–22.9	1.63	8
14.3	19.2	17.5–21.2	1.71	4

The relationship between length (SL, cm) and weight (W, g) is:

$W = 0.0011 * SL^{3.674}$ ($n = 160$, range 4.9–23.6 cm SL, $r^2 = 0.99$).

Age and growth

Otolith interpretation

Figures 3 and 4 show transverse thin sections of sagittal otoliths from age group 3+ (3.3 years old) and 8+ (8.3 years old) Antarctic silverfish respectively.

Otoliths showed relatively constant growth, but changed in appearance as the fish grew. Fish up to 150 mm SL generally had circular sagittae, whereas those from larger specimens were more oval. From about 200 mm SL, the dorsal margin of the sagittae grew disproportionately and became dome shaped.

Growth parameters

The mean lengths-at-age (with standard deviation, range and sample size) for all fish aged are shown in Table 1. Calculated von Bertalanffy parameters for the current and previous studies are listed in Table 2. Parameters from this study (as well as the raw data) and from Hubold and Tomo (1989) are fitted in Figure 5. Female Antarctic silverfish appear to reach a larger size than males, but none of the estimated von Bertalanffy parameters are statistically significantly different between sexes.

The graphs show that silverfish demonstrate quite consistent initial growth for about eight years, after which the growth rate declines. The maximum recorded age was 14.3 years.

Precision estimates and the age bias plots (Figure 6) indicated that there was good within-reader agreement. Overall, 73% of readings were identical and 96% were within ±1 year. The within-reader APE was 2%. Between-reader precision was also good. Of reader 2's readings, 84% were within ±1 year of reader 1's first readings, and none differed by more than 3 years. The between-reader APE was 5.5%.

An unscaled length-frequency histogram (Figure 7) shows that SL of Antarctic silverfish ranged between 4.6 and 22.9 cm. Pronounced modes in the length-frequency distribution occurred at 7.1–7.5, 10.6–11.0 and 15.1–15.5 cm SL. Data have not been scaled to size of catch, as silverfish length data was not collected for many of the tows comprising significant quantities of this species. An unscaled age-frequency histogram (Figure 8) shows that fish ranged in age from 0+ to 14+ years with age classes 6–9 years being the most abundant.

Table 2: Von Bertalanffy growth curve parameters (with 95% confidence intervals) for Antarctic silverfish from the Ross Sea (current study), and from the Weddell Sea, Antarctic Peninsula (Hubold and Tomo, 1989[1]); Cosmonaut Sea, Mawson Sea, Prydz Bay (Gerasimchuk, 1992[2]) ; Weddell Sea (Radtke et al., 1993[3]). Sex: M – males; F – females; U – unsexed fish aged up to 5.3 years; All – all available data. - – not available. L_∞ refers to standard length.

Area	Sex	*N*	Ages	L_∞ (cm)	95% CI	K (y^{-1})	95% CI	t_0 (y)	95% CI
Ross Sea	M+U	119	1–14	21.2	19.5–23.1	0.185	0.149–0.221	–0.3	–0.5 to –0.0
	F+U	153	1–14	23.3	21.8–25.0	0.158	0.132–0.184	–0.4	–0.6 to –0.1
	All	304	1–14	22.1	21.0–23.4	0.167	0.143–0.191	–0.4	–0.6 to –0.2
Weddell Sea[1]	All	535	0–14	38.9	-	0.052	-	–1.4	-
Antarctic Peninsula[1]	All	1251	0–12	30.3	-	0.064	-	–1.5	-
Combined[1]	All	1786	0–14	30.8	-	0.073	-	–1.2	-
Cosmonaut Sea[2]	All	-	3–7	33.8	-	0.10	-	0.07	-
	M	-	-	22.5	-	0.26	-	1.20	-
	F	-	-	26.0	-	0.20	-	1.16	-
Mawson Sea[2]	All	-	2–10	26.5	-	0.16	-	0.46	-
	M	-	-	20.4	-	0.32	-	1.29	-
	F	-	-	25.1	-	0.21	-	1.02	-
Prydz Bay[2]	All	-	1–12	31.8	-	0.11	-	0.16	-
	M	-	-	26.6	-	0.14	-	–0.33	-
	F	-	-	23.0	-	0.21	-	0.52	-
Weddell Sea[3]	All	-	1–33	21.1	-	0.07	-	–1.49	-

Discussion

The need to analyse Antarctic silverfish using SL, rather than TL, because of frequent caudal fin damage in the trawl, is consistent with the findings of Hubold and Tomo (1989). Similarly, the inability to determine the sex of fish shorter than about 10 cm SL was also reported by Hubold and Tomo (1989), necessitating that most analyses combine data from both sexes.

A correction was applied to account for shrinkage in length and weight loss as a consequence of long-term freezing. This contrasts with Hubold and Tomo (1989) who found that silverfish from the Weddell Sea measured fresh on board and again after one year stored frozen at –20°C did not differ in length.

Von Bertalanffy growth parameters have been produced for Antarctic silverfish in the Ross Sea region, Antarctica. These estimates are preliminary for two main reasons. First, no attempt has been made to validate the ageing method used. Second, the sample does not comprehensively represent the sex distribution of the population. This was because about two-thirds of the sample could not be sexed due either to poor gonad development in small fish, or to gonad deterioration due to long-term freezing.

It was assumed in this study that the first opaque zone formed at about 3 months of age, but was not clearly visible or not counted because it was so close to the nucleus. If this is an incorrect interpretation, then the ages reported here may be overestimated by one year. However, the estimated mean lengths at ages 1.3 and 2.3 years from the current study (4.9 and 7.3 cm respectively) are similar to those estimated from length-frequency distributions for fish of the same ages from a number of surveys. For example, Hubold (1985) studied the early life-history of Antarctic silverfish occurring in the eastern and southern Weddell Sea and found that in January age group 0 fish ranged in length from 0.8 to 1.6 cm SL and age group 1 fish were 2.5–4.7 cm SL. Similarly, Kellerman (1986) studied length-frequency distributions of Antarctic silverfish near the Antarctic Peninsula and estimated length modes at 1.1–2.2, 3.3–5.3 and 6.5–8.2 cm SL. These three size groups were considered to represent 0+, 1+ and 2+ year classes. These findings are further supported by Guglielmo et al. (1998) who studied the distribution and abundance of juvenile Antarctic silverfish off Terra Nova Bay (Ross Sea) during the summer of 1987/88. They also defined age groups according to length-frequency data analyses undertaken by Hubold (1984) and found that age group 0 fish ranged from 0.8 to 2.0 cm SL and age group 1 fish were 3.6–5.3 cm SL. La Mesa et al. (2010) undertook a survey of early life stages of Antarctic silverfish distribution and abundance in the western Ross Sea during the summer (December–February) of 1998, 2000 and 2004. Based on Hubold (1984), the age groups are defined according to length-frequency data analysis. During the 1997/98 survey they found that 0+ fish ranged from 0.7 to 0.8 cm SL; 1+ fish ranged from 1.9 to 5.0 cm SL; 2+ fish ranged from 5.3 to 6.4 cm SL. In 1999/2000, 0+ fish ranged from 0.9 to 1.8 cm SL; 1+ fish ranged from 3.1 to 5.7 cm SL; 2+ fish ranged from 6.8 to 8.2 cm SL. The length-frequency distribution of specimens caught during 2003/04 showed that 0+ fish ranged from 0.7 to 1.9 cm SL; 1+ fish ranged from 2.8 to 5.0 cm SL; 2+ fish ranged from 5.3 to 7.4 cm SL. Consequently, the interpretation (based on previous studies) that the opaque zone about 0.6 mm from the nucleus is formed at about 1.3 years of age is probably correct.

The current study showed that the species grows relatively slowly to only a moderate size, and has a moderate longevity, reaching a maximum age of about 14 years. Fish length and age ranges (5–23 cm SL, 1–14 years) were similar to those of Hubold and Tomo (1989) (3–25 cm SL, 1–14 years). However, there were differences in the calculated von Bertalanffy growth parameters between the two studies. For example, in the present work the L_∞ value for both sexes combined was 22.1 cm. In comparison, Hubold and Tomo (1989) calculated values of 38.9 cm for 535 fish sampled from the Weddell Sea and 30.3 cm for 1 251 fish sampled from the Antarctic Peninsula. The plotted growth curves from the two studies are not markedly different over the age range of available fish (see Figure 5). However, Hubold and Tomo's (1989) conclusion that L_∞ is markedly higher than the length of the largest fish found is unusual in studies of fish growth; L_∞ is usually less than L_{max}. Possible reasons for L_∞ being greater than L_{max} are that:

- the larger and older fish were not sampled
- individuals of the species seldom reach their asymptotic length, and are still growing when they die of old age

- the otoliths have been misinterpreted, and incorrect growth parameters produced.

Additional von Bertalanffy growth parameters from various studies on Antarctic silverfish age and growth are presented in La Mesa and Vacchi (2001) and are shown in Table 2. They include Gerasimchuk (1992) and Radtke et al. (1993). Gerasimchuk (1992) studied fish from the Cosmonaut Sea, Mawson Sea and Prydz Bay and calculated higher L_∞ values and similar k and t_0 values to the present study. This may be a result of differences in growth between the areas sampled. Radtke et al. (1993) examined specimens from the Weddell Sea and looked at daily increments in sagittal otoliths of 38 fishes. Ages ranged from 1.3 years for small juveniles, to 33 years for the largest individual (20.5 cm SL). The L_∞ value for both sexes combined of 21.1 cm was very similar to the current study, however, the k and t_0 values more closely approximate those of Hubold and Tomo (1989). This may also result from areal differences in growth.

Despite the higher L_∞ values in Hubold and Tomo (1989) and Gerasimchuk (1992), no length records could be found in the literature for this species greater than 27 cm TL (24.5 cm SL), so it appears unlikely that large old fish have been excluded from this ageing study.

The relatively slow growth and relatively long life for such a small fish may be an adaptation to the low energetic level at which these fishes live (Clarke, 1983). Their food comprises copepods, molluscs and euphausiids, with an emphasis on copepods during the prolonged pre-adult phase (Moreno et al., 1986). Smaller size over a longer lifespan may help to successfully exploit these resources. However, because they are small they will not be able to exploit larger prey.

Conclusions

- Counts of growth zones in thin-sectioned otoliths showed that Antarctic silverfish in the Ross Sea region, Antarctica, is relatively slow growing with a moderate longevity (maximum estimated age was 14.3 years).

- Female fish appeared to reach a larger size than males, but none of the estimated von Bertalanffy parameters were statistically significantly different between sexes.

- The SLs of the sampled Antarctic silverfish ranged from 4.6 to 22.9 cm. Pronounced modes in the length-frequency distribution occurred at 7.1–7.5, 10.6–11.0 and 15.1–15.5 cm. Mean lengths of 4.9 cm and 7.3 cm (at ages 1.3 and 2.3 years respectively) are consistent with those presented in the literature. The age-frequency distribution exhibited a mode from age 6 to 9 years.

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Figure 1: Antarctic silverfish (*Pleuragramma antarcticum*). Source: Peter McMillan (NIWA).

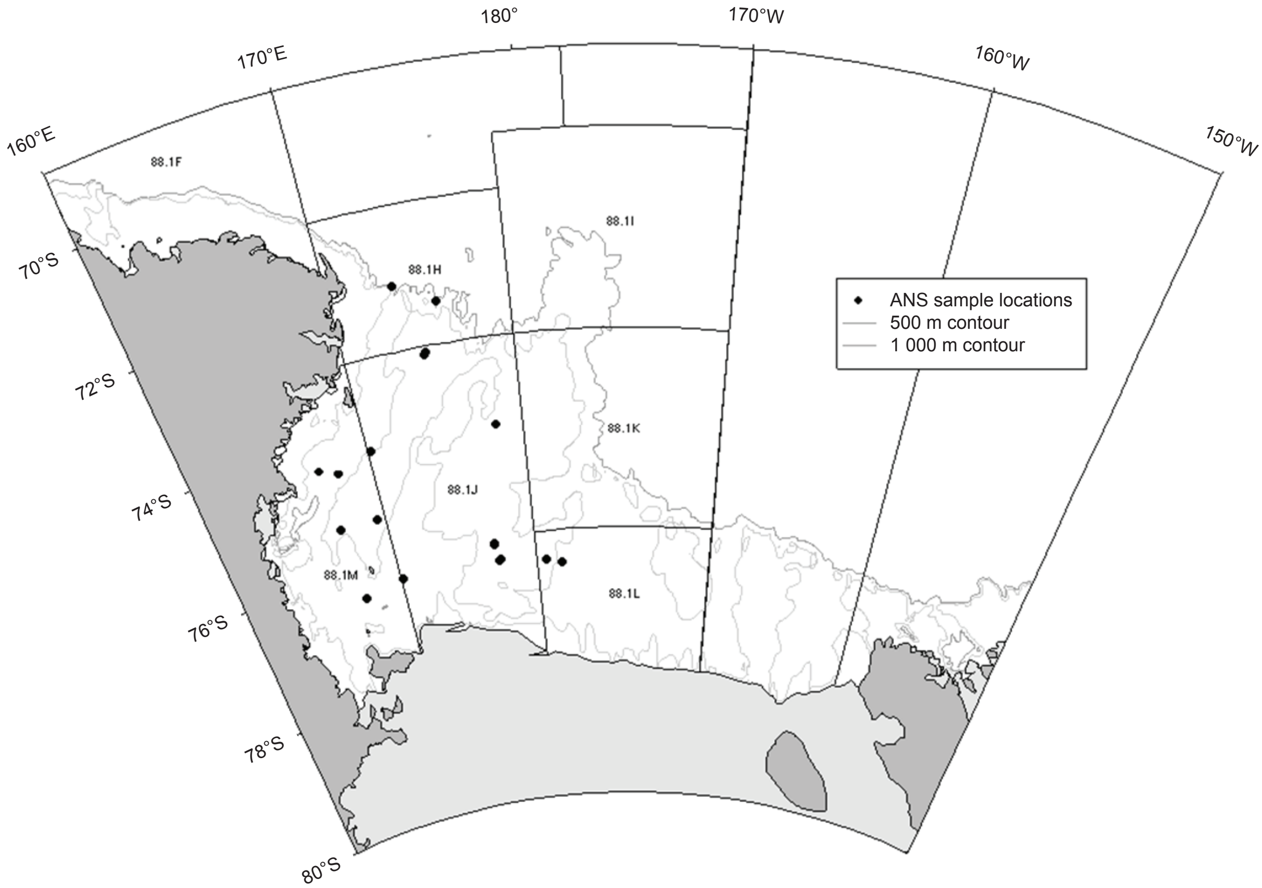

Figure 2: Sample locations of Antarctic silverfish (*Pleuragramma antarcticum*) and small-scale research units (SSRUs) in Subarea 88.1. Depth contours at 500 and 1 000 m are shown.

Figure 3: Transverse thin-sectioned Antarctic silverfish sagittal otolith from a 9.2 cm SL (age group 3+) fish. The white dots indicate zones interpreted as annuli. Scale bar = 1 mm.

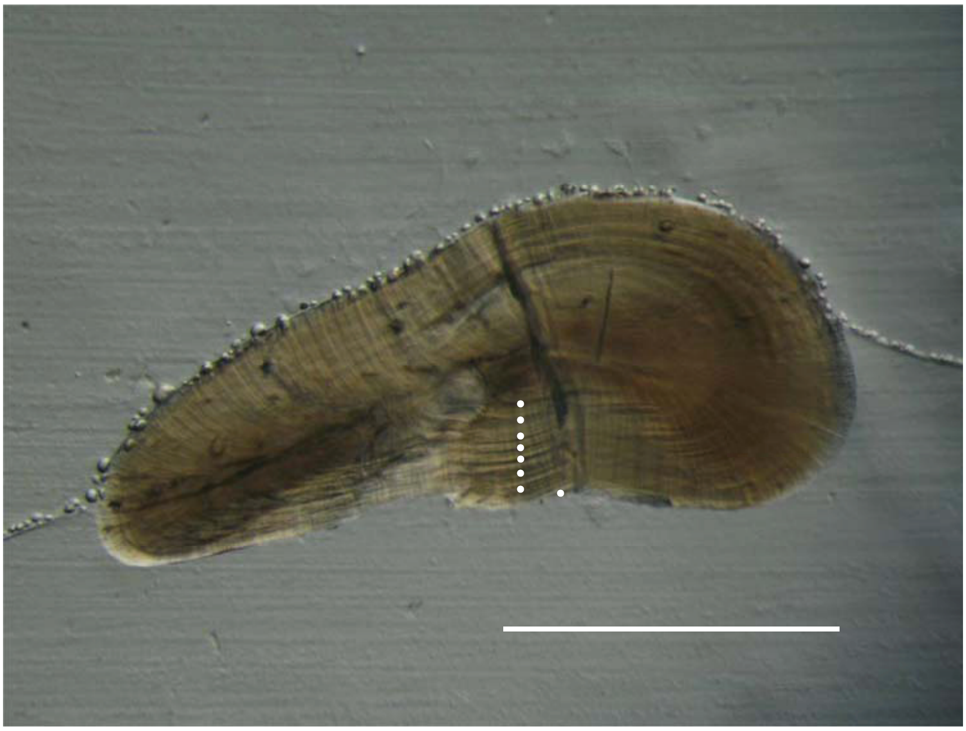

Figure 4: Transverse thin-sectioned Antarctic silverfish sagittal otolith from a 14 cm SL (age group 8+) fish. The white dots indicate zones interpreted as annuli. Scale bar = 1 mm.

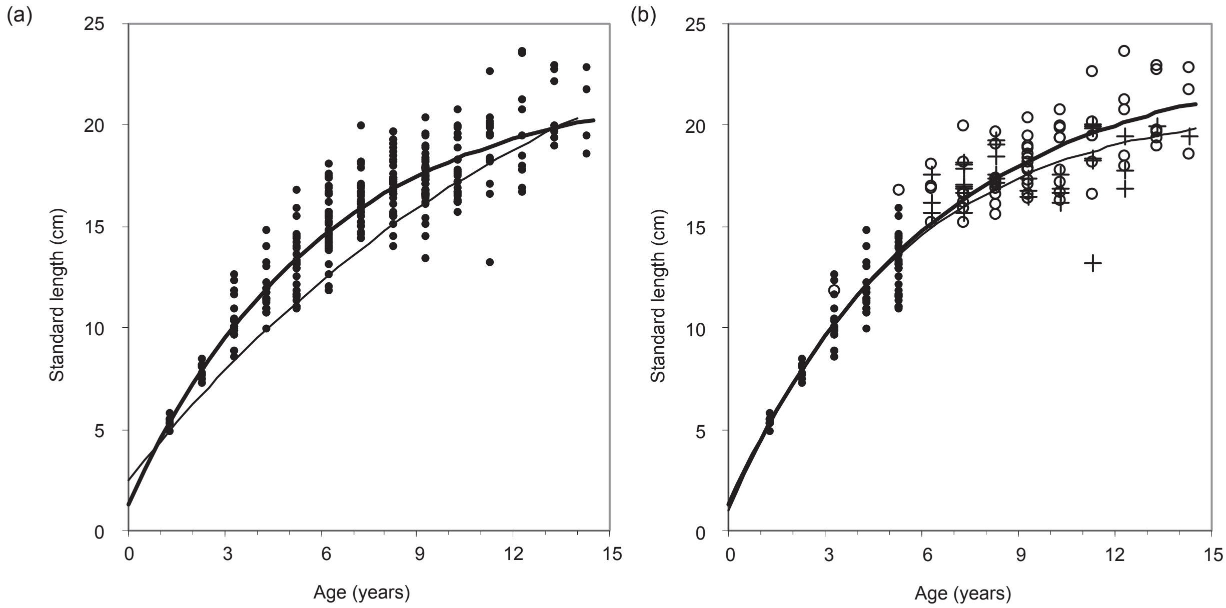

Figure 5: Raw length-at-age data for Antarctic silverfish sampled from the Ross Sea: (a) all data, with fitted von Bertalanffy curve (thick line), and the estimated von Bertalanffy curve from Hubold and Tomo (1989) (thin line) for comparison; (b) data points and fitted von Bertalanffy curves for females (open circles) plus unsexed fish up to 5.3 years (thick line), and males (crosses) plus unsexed fish up to 5.3 years (thin line).

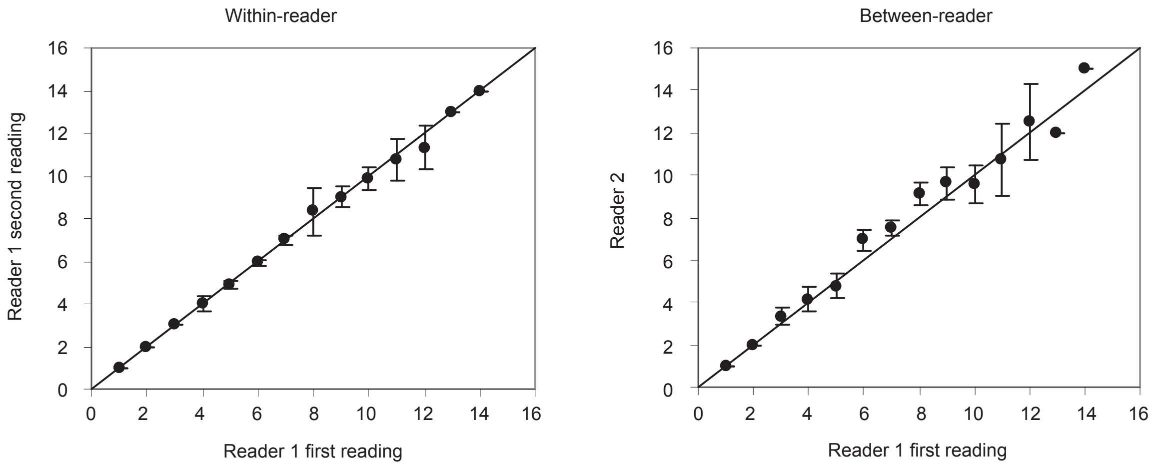

Figure 6: Age bias plots comparing reader 1's second readings and reader 2's readings with reader 1's first readings. Bars indicate 95% confidence intervals.

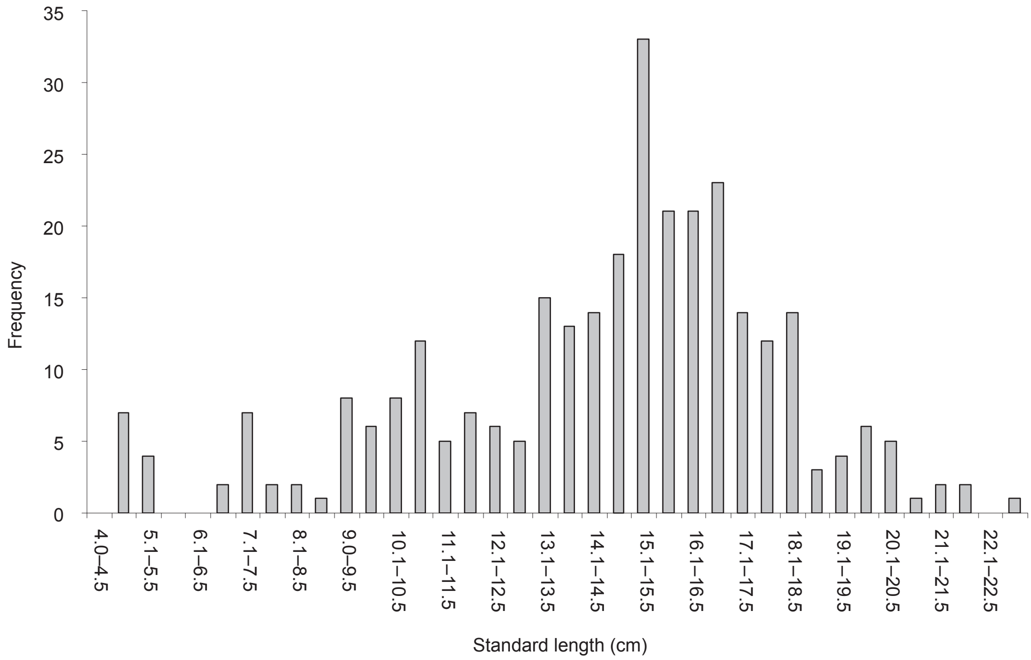

Figure 7: Unscaled length-frequency histogram for 304 aged Antarctic silverfish sampled from the Ross Sea.

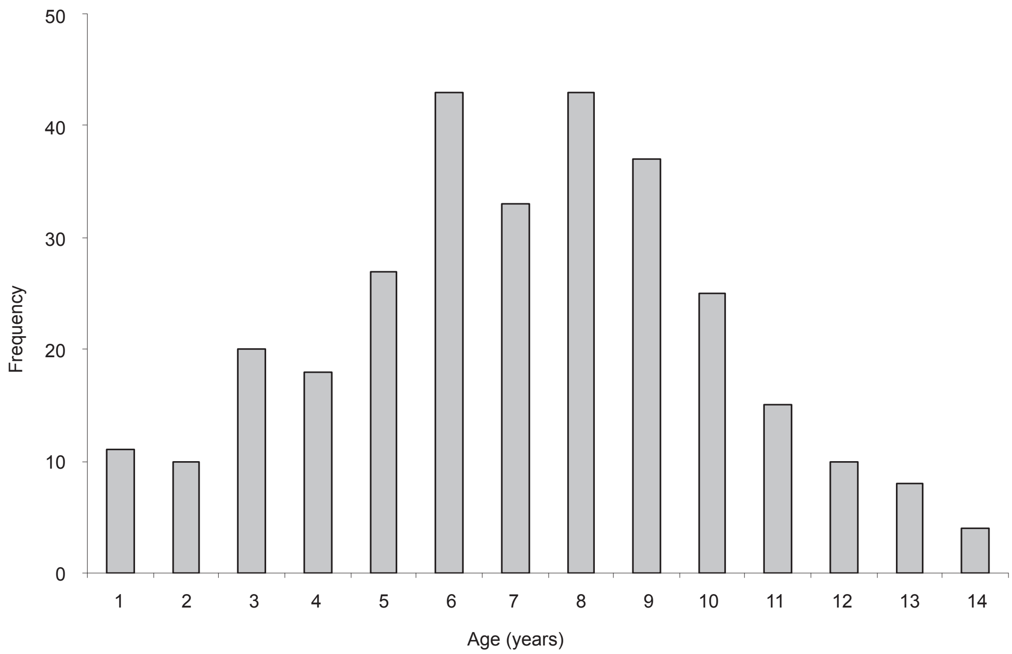

Figure 8: Unscaled age-frequency histogram for 304 Antarctic silverfish sampled from the Ross Sea.