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Age and growth of ocellated icefish, *Chionodraco rastrospinosus* DeWitt and Hureau, 1979, from the South Shetland Islands

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Abstract Age and growth of ocellated icefish, *Chionodraco rastrospinosus*, were investigated using counts of annual growth increments from sagittal otoliths. Samples were collected during research surveys by benthic trawl carried out around Elephant and South Shetland Islands in January–February 2002 and December 2006–January 2007. A total of 290 specimens were selected for the study, consisting of 120 females and 170 males. The age of fish was estimated by counting annuli on transverse sections obtained by grinding and polishing whole otoliths embedded in epoxy resin. The precision-of-age estimates within and between readers were tested applying both the average percent error (APE) and the coefficient of variation (CV). The estimated age-range was 1–12 for both sexes of *C. rastrospinosus*. Applying the von Bertalanffy growth function to the age–length data, a growth curve was obtained for each sex. The estimated values of VB growth parameters L_∞ and k were, respectively, 47.9 cm and 0.28 for females and 42.9 cm and 0.36 for males. Compared to other congeneric species, the growth performance of *C. rastrospinosus* was relatively high, being 2.82 and 2.81 in males and females, respectively. Age at sexual maturity was estimated to be about 4 years in both sexes. *C. rastrospinosus* captured in the studied area consisted mainly of adult specimens between 3 and 8 years, with few older fish.

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Introduction

The composition of the coastal fish fauna around the South Shetland Islands is of particular interest, as it consists of species typical of both low-Antarctic and high-Antarctic zones, which generally exhibit a different depth-range of distribution (Kock and Stransky 2000). Species composition is largely dominated by few abundant low-Antarctic species, such as mackerel icefish (*Champsocephalus gunnari*), marbled notothenia (*Notothenia rossii*), green notothenia (*Gobionotothen gibberifrons*) and Scotia Sea icefish (*Chaenocephalus aceratus*), distributed between 100 and 400-m depth. Below 400–500-m depth they are replaced by high-Antarctic species, such as ocellated icefish (*Chionodraco rastrospinosus*), Antarctic toothfish (*Dissostichus mawsoni*) and several *Trematomus* spp. (Kock and Stransky 2000).

Fish stocks in the vicinity of the South Shetland Islands and off the tip of the Antarctic Peninsula (Statistical Sub-area 48.1) were exploited commercially by trawling from 1978/1979 to 1988/1989, accounting for about 87,000 tons of finfish, before the area was closed to any harvesting in 1989/1990 (Kock 1991, 1992). Since 1996, research surveys using benthic trawls have been conducted around the South Shetland Islands by RV *Yuzhmorgeologiya* (U.S. AMLR Surveys 1998, 2001, 2003 and 2006) and RV *Polarstern* (Cruises ANT XIV/2, ANT XIX/3 and ANTXXIII/8, respectively, 1996, 2002 and 2007), to acquire biological data for monitoring the status of the local fish stocks (Kock 1998; Kock et al. 2000; Jones et al. 1998a, b, 2001, 2003). In particular, the acquisition of new data on age and growth

rate of species exploited in the past, and potentially targeted by exploratory fishing in the future, are urgently required (Kock and Everson 1998; Kock et al. 2000).

In the Statistical Subarea 48.1, the few data available so far on age and growth of fish concerned almost exclusively low-Antarctic species that have been heavily exploited in the past, i.e., *C. gunnari* and *N. rossii* (Freytag 1980; Tomo and Barrera-Oro 1986; Kock 1990; Barrera-Oro and Casaux 1992), as well as several by-catch species occasionally taken by the fishery, such as *G. gibberifrons* and *C. aceratus* (Barrera-Oro 1988; La Mesa et al. 2004). In contrast, age and growth of high-Antarctic species inhabiting this area are still poorly known.

The ocellated icefish, *Chionodraco rastrospinosus*, sometimes taken as by-catch, is the most abundant high-Antarctic fish in the South Shetland Islands. It is distributed on the continental shelf of the southern Scotia Arc region from the South Orkney islands to the tip of the Antarctic Peninsula, mainly in waters of more than 200-m depth (Tiedtke and Kock 1989; Iwami and Kock 1990; Kock and Stransky 2000). Within 500-m depth, the biomass of this species on the shelf of Elephant Island was estimated to be approximately between 200 and 480 tons (Kock 1998; Kock et al. 2002). The only published data on age and growth of this species are from a few specimens collected around the South Orkneys and King George Island (Gubsch 1982).

In this paper we report new data on age and growth rate of *C. rastrospinosus* collected off Elephant and King George Islands during the benthic trawl surveys conducted in 2002 and 2006.

Materials and methods

Otolith samples of *C. rastrospinosus* were collected during the ANTXIX/3 cruise of the RV *Polarstern* in January–February 2002. The study area was located on the continental shelf off the South Shetland Islands (Elephant and King George). Sampling was by an area-swept method carried out by a commercial benthic trawl with a cod-end mesh size of 40 mm, fishing down to 500-m depth, using a stratified simple random-sampling design (Jones et al. 1998a, 2001). For each sampling event, the net was towed at about 3 knots for generally 30 min during daylight hours. Except for five hauls carried out off King George, all the specimens of *C. rastrospinosus* caught during the survey were selected for the study. In addition, a small sample consisting of juveniles *C. rastrospinosus* was collected during the ANTXXIII/8 cruise of the RV *Polarstern* in December 2006-January 2007.

Each specimen was sorted from the catch, measured to the nearest-lower cm (TL), weighed (*W*, g) and sexed.

Sexual maturity was assessed macroscopically, according to the five-point scale proposed by Everson (1977) and revised by Kock and Kellermann (1991). Sagittal otolith pairs were extracted from each fish, cleaned and stored dry in vials.

To test for difference in otolith pairs of each specimen (Neilson 1992), the weight of both left and right otoliths were recorded with an accuracy of 0.1 mg and compared using a *t* test for paired comparisons (Sokal and Rohlf 1995). As *t* test gave no difference between left and right otoliths ($df = 273$, $t = 1.35$, $P > 0.1$), we selected right otoliths to measure their maximum length under a stereomicroscope coupled to a CCD videocamera using image analysis software (OPTIMAS 6.5). The relationship between fish length (TL) and maximum otolith length (OL) was estimated by linear regression analysis.

As commonly reported in Antarctic fish (Everson 1980; White 1991), sagittal otoliths of *C. rastrospinosus* were opaque with a dense calcareous matrix, thus requiring sectioning or grinding to read the annulation pattern. For each specimen, one otolith was randomly selected and embedded in epoxy resin (IMPLEX) in moulds. The small blocks were first ground using decreasing grit abrasive paper and then polished on lapping films (0.05 μ alumina powder) by a grinding wheel (REMET LS2) to obtain a surface without scratches. Grinding was performed to obtain transverse sections, because these gave the clearest images for age estimation. Care was taken to reach the otolith core in order to obtain the annulation pattern from the core to the otolith margin. Otolith sections were fully immersed in water to improve the contrast and read under reflected light using a stereomicroscope at 25–40× magnification.

Under reflected light, the nucleus and the opaque zones appeared as light rings and the translucent or hyaline zones as dark rings (Fig. 1). The combination of each opaque and subsequent translucent zone was considered to form an annulus, as observed in other notothenioids (Everson 1980; North 1988). The count-path was generally from the core towards the proximal-ventral margin of the otolith section (Fig. 1). Within the nucleus, the core is clearly visible and is delimited by an evident check, surrounded by a clear, regular incremental pattern. The nucleus in turn is surrounded by a region consisting of three/four large annuli, followed by a region consisting of a series of narrower and more regular annuli. The large annuli were sometimes split in two or more checks, making annuli difficult to identify. In any case, the annuli were formed by large opaque zones and very thin translucent zones. The annuli that did not persist far on either side of the count-path were considered as false checks.

As in the Antarctic Peninsula region the larval hatch of *C. rastrospinosus* was estimated to occur in late winter/
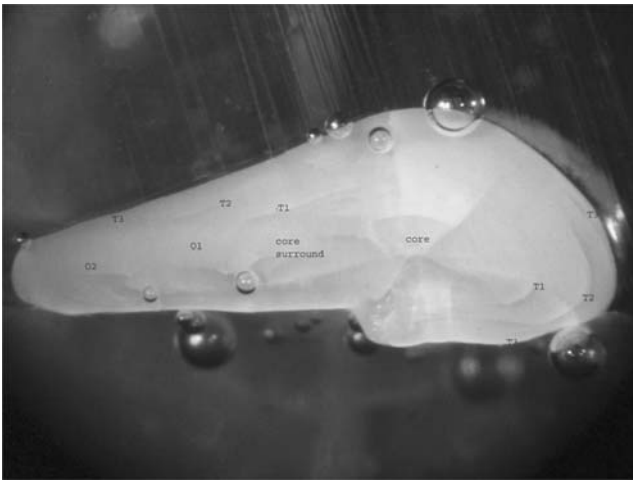
Fig. 1 Transverse section of sagittal otolith of *Chionodraco rastrospinosus*, showing the pattern of translucent (*T*) and opaque (*O*) zones surrounding the opaque core

early spring, i.e., from mid-September to mid-October (Kellermann 1986), we assumed that the opaque nucleus is laid down in the first summer season after hatching, followed by the first translucent zone laid down on the otolith during the following winter just before the birthday. Hence, the birth-date of all fish was assumed to be first October. Considering that most samples were collected in January–February, the age of each specimen was estimated by counting all the translucent zones plus one (represented by the last incomplete annulus constituted of only the opaque zone) (see Gubsch 1982). Instead of following the conventional terminology by adding "+" to the number of translucent zones considering first October as birth-date, we preferred to follow the criterion of Gubsch (1982), who aged *C. rastrospinosus* by adding one to the number of translucent zones. As a general trend in channichthyids (Kock 2005), Gubsch (1982) supposed for this species a pelagic phase as long as 2 years, during which no translucent zone is laid down.

After several readings beforehand to familiarize ourselves with the annulation pattern, each otolith was read twice by two different readers without any ancillary data on the fish, in order to estimate the reproducibility of age readings (i.e., aging precision). The index of average percent error (APE) (Beamish and Fournier 1981) and the mean coefficient of variation (CV) (Chang 1982) were calculated from the whole data set of estimated ages, in order to estimate the relative precision both within and between readers (Campana 2001). Since the annual periodicity of annulus formation has been validated in the congeneric species *Chionodraco myersi* (Morales-Nin et al. 2000), we assumed that the annuli were laid down yearly also in *C. rastrospinosus*. Furthermore, to estimate population features such as age at sexual maturity, growth and

age structure we have to assume that samples derived from one spatially-discrete population which is stable over time.

The age at which 50% of the population reaches sexual maturity (A_{50}) was estimated on the basis of age–gonad maturity data pairs. For each sex, age against proportion (*P*) of fish in maturity stages 2–5 (Everson 1977) was fitted to the following logistic equation (Ni and Sandeman 1984):

$$P = 1 \left/ \left[1 + e^{-(\alpha + \beta A)} \right] \right.$$

where *A* is the estimated age in years and α and β are coefficients. Applying a ln-transformation to both terms of the above function, the coefficients values are obtained by the following linearized equation:

$$\ln(P/1 - P) = \alpha + \beta A$$

where α is the intercept and β the slope. Finally, A_{50} is estimated as the negative ratio of coefficients ($-\alpha/\beta$), by setting $P = 0.5$ in the equation.

The von Bertalanffy growth function was fitted to the age–length data using the program FISHPARM of the statistical package FSAS (Saila et al. 1988), which implements the Marquardt algorithm for non-linear least squares parameter estimation. The von Bertalanffy growth parameters (L_∞, k and t_0) were calculated for each sex, using the modal value of age estimates. When readings between readers differed more than 2 years, the otolith was discarded. Growth curve parameters were compared between sexes applying the likelihood ratio test (Kimura 1980). Following Haddon (2001), full data rather than mean length-at-age was used in this analysis. The growth performance index ($\Phi' = 2 \log L_\infty + \log k$) (Munro and Pauly 1983), was calculated to compare growth of this species with other channichthyids.

Finally, the length–weight relationship of fish was calculated both for the whole population and for each sex. The exponential equation $W = a \times \text{TL}^b$, where W is total weight (g), TL is total length of fish (cm) and a and b are regression parameters, was fitted to the data. Applying the $\log_{10}$-transformation to both terms, the equation was linearized to determine the regression parameters. An F test was applied to test for difference between males and females in allometric indices (b) (Sokal and Rohlf 1995).

Results

Length–frequency distribution and length–weight relationship of fish

Overall, 290 specimens were selected for the study, consisting of 120 females and 170 males. Thus, on the basis of

the chi-square test for goodness of fit, the sex ratio differed significantly from 1:1 ($\chi^2 = 8.62$, df = 1, $P < 0.005$). The length–frequency distribution of both sexes is shown in Fig. 2. It was largely dominated by a strong peak at 36 cm, while other well-defined modes appeared at 30, 40 and 42 cm TL. An additional mode at 15 cm TL was also present, consisting of juveniles collected in December 2006–January 2007. Females were slightly larger than males, ranging from 14 to 49-cm TL and from 17 to 1182 g. Males ranged from 15 to 45-cm TL and from 16 to 932 g.

The relationship between TL (cm) and total weight (g) of fish was calculated for each sex and the whole sample and is summarized in the following equations:

$$W = 0.00101 \ TL^{3.60} \quad n = 120 \quad r^2 = 0.97 \qquad \text{females}$$
$$W = 0.00086 \ TL^{3.65} \quad n = 170 \quad r^2 = 0.96 \qquad \text{males}$$
$$W = 0.00095 \ TL^{3.62} \quad n = 290 \quad r^2 = 0.97 \quad \text{whole sample}$$

Length–weight data and the fitted-exponential curves are shown in Fig. 3. No significant difference of the allometric coefficient (b) was observed between sexes (F test, $F_{1,286} = 0.34$, $P > 0.5$), and both exhibited a positive allometric growth (i.e., $b > 3$).

Otolith size and morphology

The main diagnostic features of otoliths of *C. rastrospinosus* are the greater height than length and the resultant near rectangular shape, as well as the well-developed colliculi (Fig. 4). During ontogeny, the size of the dorsal half of the otolith increases and becomes squared-off (Hecht 1987).
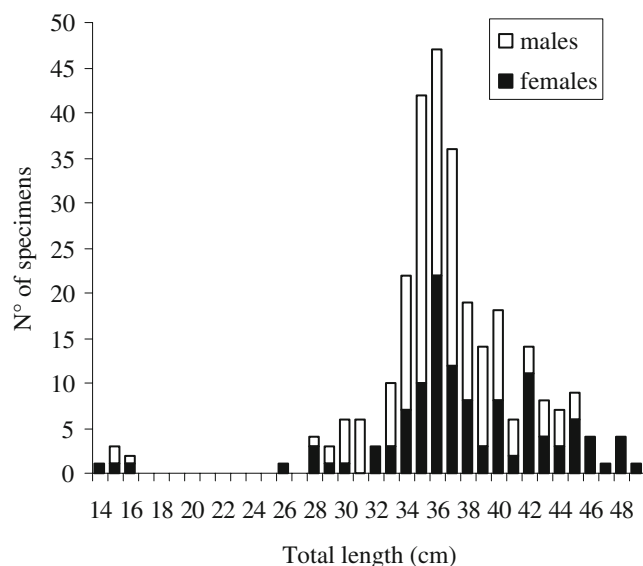
Fig. 2 Length–frequency distribution of *Chionodraco rastrospinosus* collected off South Shetlands
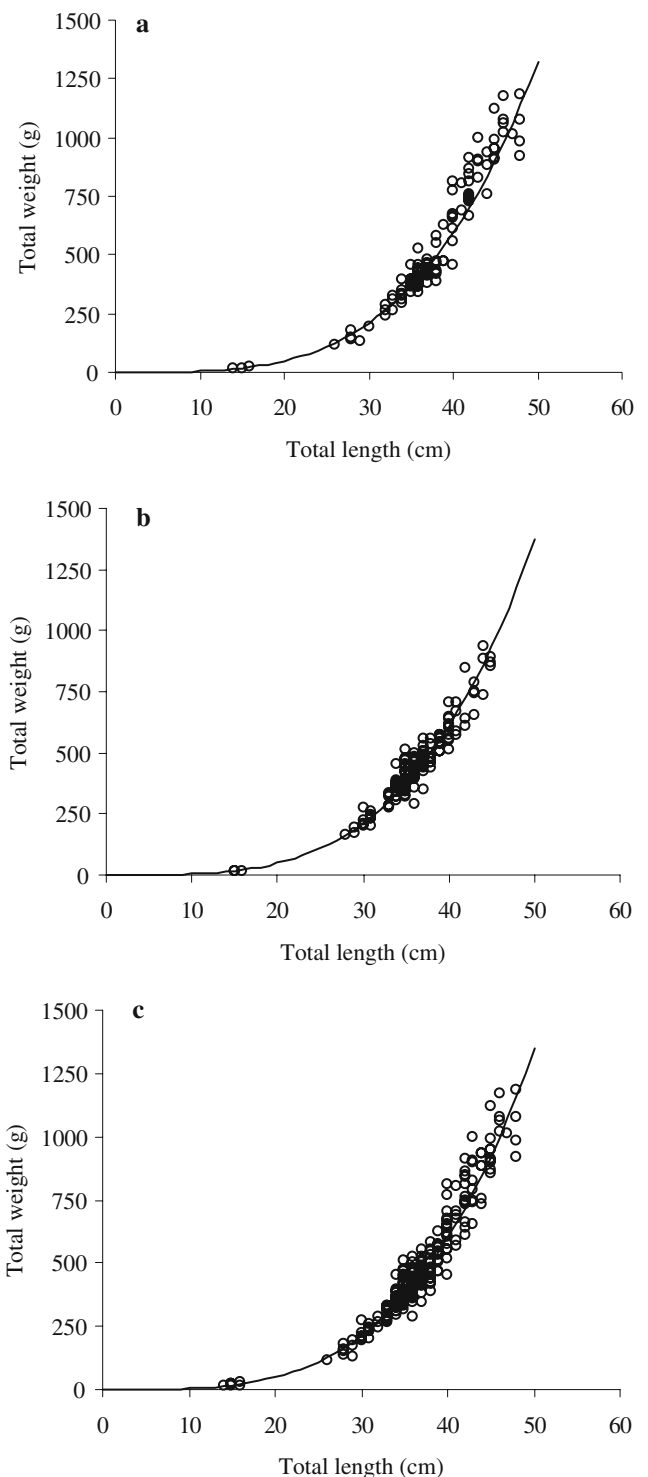
Fig. 3 Length–weight relationships for *Chionodraco rastrospinosus*. **a** females; **b** males; **c** whole population

The maximum otolith length (OL) and weight (OW) ranged between 1.48–4.98 mm and 1.2–39.1 mg, respectively. The linear relationship between OL and TL was rather poor, because of the large variability of otolith length in fishes of
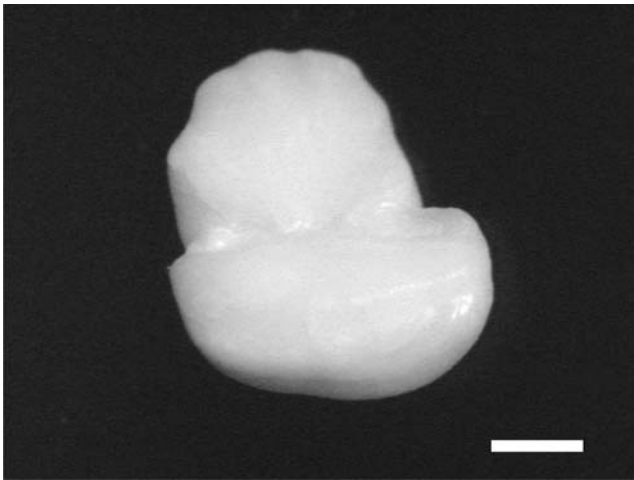
Fig. 4 Micrograph showing the proximal side of sagittal otolith from *Chionodraco rastrospinosus* (38 cm TL). *Scale bar* = 1 mm

the same size. However, the best fitting of data is described by the following equation:

$$TL = 11.53 \, OL^{0.94} \quad n = 286 \quad r^2 = 0.72$$

Age and growth

Out of 290 otoliths examined, approximately 27% (79) were discarded because they were either unreadable (65) or provided age estimates that differed by more than two annuli (14). Overall, 87 females between 14 and 49 cm TL and 124 males between 15 and 45 cm TL were aged. To summarize the age composition of the sample of *C. rastrospinosus*, age–length keys for each sex are shown in Tables 1 and 2. Age estimates ranged between 1 and 12 years for both males and females. However, most samples were composed of 3–8 years-old fish, representing nearly 90% of the sample aged.

The age-precision analysis, performed on readings of the same reader and between different readers, allowed testing of the agreement between them. To make a comparison, all the age readings within and between readers were plotted with a diagonal line representing the perfect agreement between them (Fig. 5). Counting-variability indices APE and CV were both quite low (Table 3), indicating the goodness of the aging procedure adopted and a rather good consistency (or reproducibility) between readings or readers. Anyway, on the basis of the relatively high number of otoliths discarded, it is worth noting that *C. rastrospinosus* was a difficult species to age, similar to other species of channichthyids (Kock 2005).

The von Bertalanffy growth function was fitted to the age–length data pairs for each sex (Fig. 6). The estimated von Bertalanffy growth parameters and the derived growth performance index Φ' are shown in Table 4. The likelihood-ratio test indicated that the estimated growth curves

Table 1 Age–length key of *C. rastrospinosus* females from the South Shetland Islands

TL (cm)	Age (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
14	1											
15	1											
16	1											
17												
18												
19												
20												
21												
22												
23												
24												
25												
26		1										
27												
28		3										
29		1										
30												
31												
32		1	1									
33		1			1							
34			4	1								
35				6	1							
36		1	4	9								
37			3	6	1							
38			1	5								
39				1	1							
40				2	1	2						
41				1								
42					1	2	2			1		
43						1		2		1		
44						1						
45							1	1	2			
46							1	1		2		
47					1							
48									1		2	1
49												1
n	3	8	13	31	7	7	4	4	4	4		2

of males and females differed significantly, as males reached a lower asymptotic length (L_∞) ($\chi^2 = 12.02$; df = 1; $P < 0.001$) at a faster rate (k) ($\chi^2 = 3.82$; df = 1; $P < 0.05$) than females. To follow the growth rate over the observed age range, the length-at-age data were calculated from the von Bertalanffy growth curves for each sex (Table 5). The annual growth rate ranged between 0.5 and 7.8 cm for females and between 0.2 and 8.0 cm for males, at least in the estimated age range (1–12 years).

Table 2 Age–length key of *C. rastrospinosus* males from the South Shetland Islands

TL (cm)	Age (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
15	2											
16	1											
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28			1									
29			2									
30			3	1								
31			6									
32												
33				5	1							
34			2	3	8							
35				15	11							
36				4	11	3						
37				3	8	1						
38					4	2	2					
39					4	5						
40						2	2	2				
41						2		1				
42										1		
43								1			1	
44								1	1	1		
45												1
n	3		14	31	47	15	4	5	1	2	1	1

The proportion of maturing males and females (stage 2–5) in relation to age is described by the logistic equation shown in Fig. 7. The age at sexual maturity (A_{50}) was approximately 4 years for both sexes, namely at 30% of maximum age sampled.

Discussion

On the basis of present study and earlier data from the literature (Jones et al. 1998b, 2000, 2001, 2003; Kock 1998; Kock et al. 2000, 2002), the size composition of *C. rastrospinosus* population inhabiting the fishing grounds
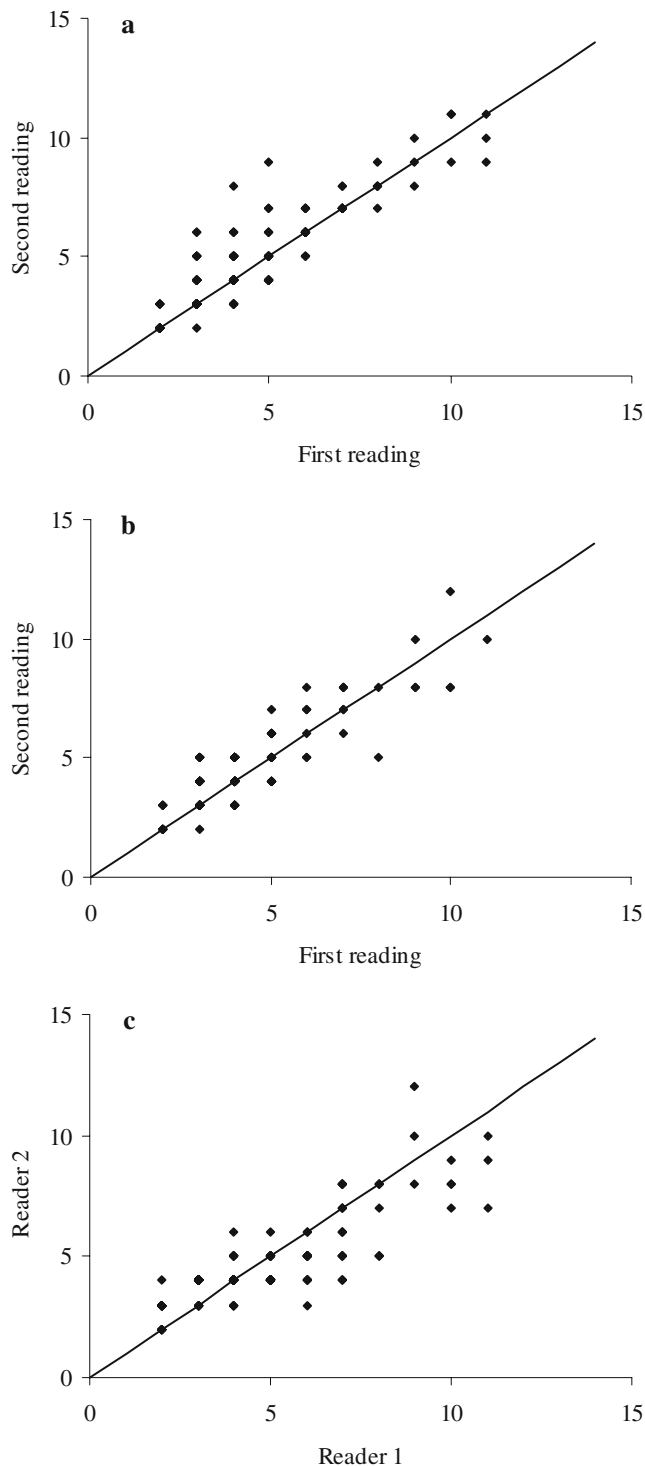
Fig. 5 Pair-wise age estimates within readers (**a** and **b**) and between readers (**c**). *Diagonal lines* indicate the full agreement between readings/readers

off Elephant and South Shetland Islands consisted almost exclusively of adult fish larger than 25-cm TL, i.e., when they are 3-years-old. Juveniles smaller than 25-cm TL are rarely caught by bottom trawling, indicating that probably

Table 3 Mean coefficient of variation (CV) and index of average percent error (APE) within and between readers

	Within reader 1	Within reader 2	Between readers
CV	7.8	7.7	13.2
APE	5.5	5.5	9.3
n	193	201	201

n is the number of pair-wise age estimates
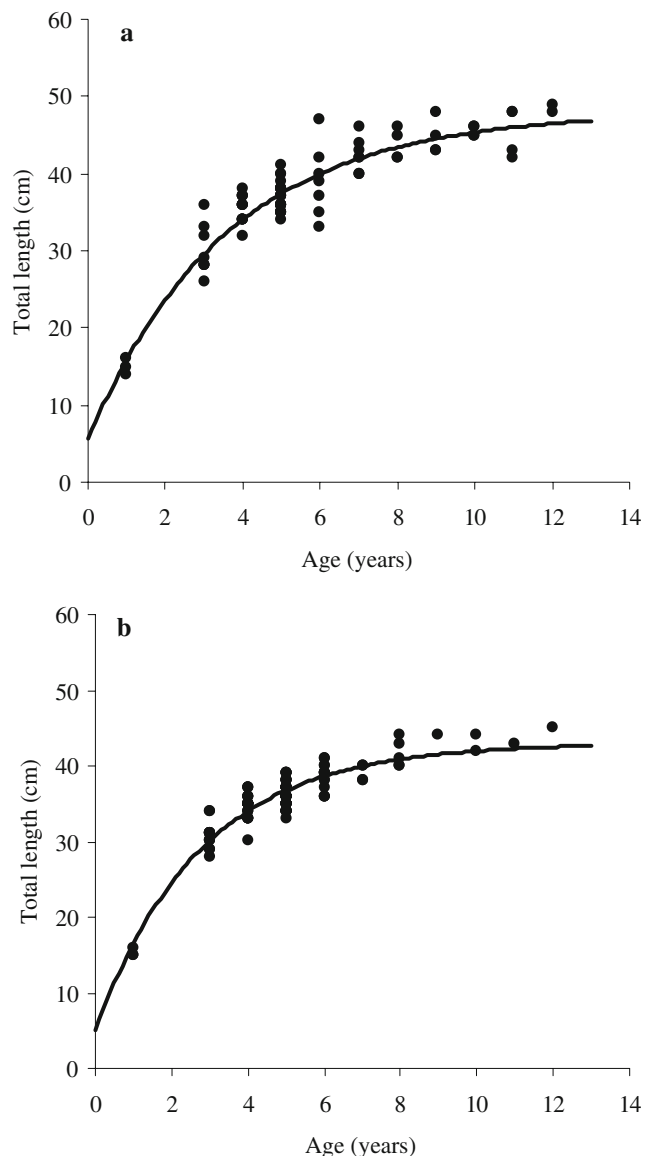
Fig. 6 Von Bertalanffy growth curves fitted to age–length data pairs from *Chionodraco rastrospinosus* females (**a**) and males (**b**)

Table 4 Von Bertalanffy growth parameters estimated for *C. rastrospinosus* collected off the South Shetland Islands

	Females			Males		
	Value	Ase	CV	Value	Ase	CV
L_∞	47.96	1.10	0.02	42.96	0.72	0.02
k	0.28	0.03	0.09	0.36	0.03	0.08
t_0	−0.45	0.23	−0.51	−0.35	0.16	−0.46
Φ'	2.81			2.82		

Φ' Growth performance index, *Ase* symptotic standard error, *CV* coefficient of variation

**Table 5** Fish length-at-age derived from the von Bertalanffy equations

Estimated age (years)	Females		Males	
	TL (cm)	Annual growth (cm)	TL (cm)	Annual growth (cm)
1	15.9		16.6	
2	23.7	7.8	24.6	8.0
3	29.6	5.9	30.1	5.5
4	34.1	4.5	34.0	3.9
5	37.5	3.4	36.7	2.7
6	40.0	2.5	38.6	1.9
7	42.0	2.0	40.0	1.4
8	43.4	1.4	40.9	0.9
9	44.5	1.1	41.5	0.6
10	45.4	0.9	42.0	0.5
11	46.0	0.6	42.3	0.3
12	46.5	0.5	42.5	0.2

Annual growth rates are calculated by difference of fish length (TL) between two subsequent years

25 cm, forming a distinct modal size group (Jones et al. 2000; Kock et al. 2000). Postlarvae and juveniles of icefish commonly prefer subsurface waters and inhabit in the upper 100 m of the water column (Loeb et al. 1993; Kellermann 1996), becoming a regular by-catch in krill fisheries at the southern Scotia Arc (Slosarczyk 1986; Slosarczyk and Rembiszewski 1982; Slosarczyk and Cielniaszek 1985; Skora 1988).

The estimate of aging precision using standard indices of counting variability gave a good consistency or reproducibility between age-readings within the same reader, although the level of precision decreased when comparing age-readings between different readers, probably as a consequence of differences in counting the first annuli outside the opaque nucleus.

The von Bertalanffy growth curves fitted to modal age estimates differed significantly between sexes, indicating that females attain bigger size (L_∞) at a lower rate (k) than
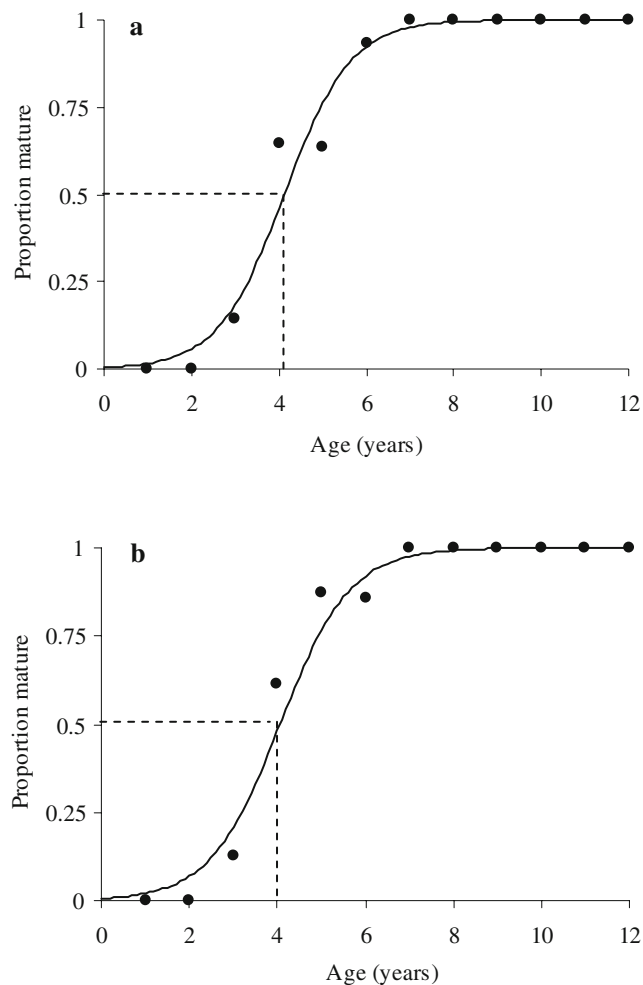
Fig. 7 Logistic curves fitted to the proportion of mature fish at age for males (**a**) and females (**b**) of *Chionodraco rastrospinosus*. *Dashed line* defines the age at sexual maturity (A_{50})

males. Nevertheless, annual growth rates of fish derived from the length at age data were consistently lower in males than in females. Juveniles collected in 2006 provided younger age-class (1+), enabling us to obtain a meaningful estimate of the VB parameter "t_0". In addition, the presence in the sample of several specimens attaining a TL close to the maximum size of *C. rastrospinosus* reported in

literature (i.e., 52-cm TL, Iwami and Kock 1990) provided a reliable estimate of the other VB parameter L_∞ and k. Although both parameters differed significantly between sexes, the growth performance (Φ') was very similar in males and females.

Based on logistic curve fitted to age and gonad maturity, both sexes of *C. rastrospinosus* would attain the sexual maturity at about 4-years-old, i.e., at 30% of their maximum estimated age. Derived from the length at age data, the length at sexual maturity (L_{50}) of *C. rastrospinosus* was estimated to be 34.0 and 34.1 cm for males and females, respectively, in good agreement with results reported for this species in the same area (Kock 1989; Kock et al. 1985, 2000; Kock and Jones 2005). Similar to other icefish, such as *Pseudochaenichthys georgianus*, *Chaenocephalus aceratus*, *Chionodraco hamatus* and *C. myersi* (Chojnacki and Palczewski 1981; Kompowski 1990; Vacchi et al. 1992; Morales-Nin et al. 2000; La Mesa et al. 2004), body growth of *C. rastrospinosus* decreased to less than 2–3 cm/year once they have attained sexual maturity (Gubsch 1982; present study).

Comparing our results on age of *C. rastrospinosus* with previous studies from the Antarctic Peninsula (Rowedder 1984), the Von Bertalanffy growth parameters and the growth performance index estimated for the whole population are quite different ($L_\infty = 51$ cm, $k = 0.19$ and $P = 2.52$; Rowedder 1984), indicating low consistency in the age estimates. On the other hand, the lengths at age estimated in the present study are comparable to those reported from King George Island by Gubsch (1982), who found an age range of 4–8 years for specimens between 35 and 40 cm TL.

In order to draw a complete picture of growth strategies adopted within the genus *Chionodraco*, present results can be compared with those reported in literature for *Chionodraco hamatus* and *C. myersi* (Vacchi et al. 1992; Morales-Nin et al. 2000; La Mesa and Vacchi 2001). As summarized in Table 6, *C. hamatus* and *C. rastrospinosus* would attain a bigger size (i.e., L_∞) than *C. myersi*. On the other hand, *C. hamatus* and *C. myersi* evidenced an instantaneous growth rate (k) and a growth performance (Φ') very similar to each

Table 6 Age and growth parameters estimated in *Chionodraco* species

Species	Site	Sex	Size (cm)	L_∞ (cm)	K (/years)	Φ'	Max age (years)	Source
Chionodraco hamatus	Ross Sea	Pop*	30−42	52.5	0.12	2.17	10	1
Chionodraco myersi	Weddell Sea	Male	10–35	43.4	0.09	2.24	16	2
		Female	10–39	43.3	0.12	2.35	17	
Chionodraco rastrospinosus	South Shetlands	Male	15–45	42.9	0.36	2.82	12	3
		Female	14–49	47.9	0.28	2.81	12	

Source: 1 La Mesa and Vacchi 2001, 2 Morales-Nin et al. 2000, 3 present study

* Available data only for the whole population

other, both being considerably lower than those observed in *C. rastrospinosus*. Thus, the growth rate, and possibly metabolic rate, show apparently an interesting latitudinal trend, being lower in species living at higher latitudes (*C. hamatus* and *C. myersi*) than in species inhabiting northerly (*C. rastrospinosus*). Conversely, if we consider that the maximum age reported for *C. hamatus* (Table 6) was estimated in fish considerably smaller than the maximum size reported in literature (i.e., 49 cm, Iwami and Kock 1990), fish longevity increases toward higher latitudes.

Finally, looking at the stock structure of *C. rastrospinosus* off the South Shetland Islands, it consisted mainly of adults of 3–8 years of age, with few older specimens. At present, we cannot say how much it closely resembled the structure of the pristine stock of *C. rastrospinosus* in this area; however, they should be quite similar to each other, as the species was little affected by fishing in the past, if at all (Kock 1998).

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