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Approach to ageing and growth back-calculation based on the otolith of the southern boarfish *Pseudopentaceros richardsoni* (Smith, 1844) from the south-west Indian Ocean seamounts

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Abstract. Age and growth of southern boarfish *Pseudopentaceros richardsoni* (Smith 1844) from south-west Indian Ocean seamounts were studied based on whole otolith readings using a non-linear back-calculation method and geometric mean regression to resolve the problem of the lack of young fish in the catches owing to age segregated habitat use by this species. Ages of the fish under study ranged from between 5 and 14 years (45.7–72.5 cm total length). Changes in relative growth of annuli were most probably related to aspects of the life history, such as migration to settle on seamounts. Age distribution was related to depth. The von Bertalanffy growth parameters for all individuals were $L_\infty = 65.1$ cm; $K = 0.27$ year^{-1} and $t_0 = -0.34$ years, obtained by mean length-age from back-calculated lengths. These data are needed to assist in the wise management of this potential fishery and the back-calculation approach shows promise for other species where juvenile fish are difficult to obtain. It is also clear that more information about the southern boarfish biology is needed to establish bases for a responsible fishery development off the seamounts of the Southern Indian Ocean and other deep-sea regions.

Additional keywords: deep-sea fish species biology, southern seamounts.

Introduction

The Pentacerotidae *Pseudopentaceros richardsoni* (Smith 1844), commonly known as boarfish or southern boarfish, is a southern circumglobal, benthopelagic species inhabiting the waters over the outer shelf and slope (100–1000 m) between 0 and 1000 m depth. The species also inhabits seamounts and underwater ridges. Thus, *P. richardsoni* is located in the south-east Atlantic (Tristan de Cunha, Walvis Ridge and South Africa); the Western Indian Ocean (South Africa and seamounts south of Madagascar) and the South Pacific (southern Australia, New Zealand and Cape Horn (Chile)). Studies on this species are very scarce and mainly related to distribution and species description (Borets 1980; Kotlyar 1982; Hardy 1983; Heemstra 1986; Humphreys and Tagami 1986; Parin 1992; Mundy and Moser 1997). Literature is also a little confusing because, initially, only one species (*Pentaceros richardsoni*) was considered, instead of the three current species. Studies on the other two species, distributed in the North Pacific, *Pseudopentaceros pectoralis* and *Pseudopentaceros wheeleri*, have been more frequent (Honma and Mizusawa 1969; Borets 1979, 1980; Hardy 1983; Humphreys and Tagami 1986; Boehlert and Sasaki 1988; Humphreys *et al*. 1989; Martin *et al*. 1992; Somerton and Kikkawa 1992).

Unlike *P. wheeleri*, which is a target species for some fleets in the Pacific Ocean, the boarfish *P. richardsoni* is currently a sporadic target of fishing in the seamounts of the south-east Atlantic Ocean and the south-west Indian Ocean. However, in the seventies the Soviet Union started a series of research expeditions, experimental fishing activities and commercial fishing operations on the deepwater ridges of the Southern Indian Ocean (Romanov 2003) and these activities took place over a period of thirty years (since 1992, the vessels have belonged to the Ukraine). Thus, *P. richardsoni* was part of species caught, as well as, for example, *Beryx* spp., *Hoplostethus atlanticus*, *Hyperoglyphe antartica*, etc., by these fleets and others of different nationalities that conducted experimental fishing activities in the area (e.g. Spain). In the south-east Atlantic Ocean catches of the southern boarfish were a consequence of different experimental fishing activities, sporadic commercial fishing and incidental fishing operations by vessels passing through the area heading for other fishing grounds (e.g. Spain). Catches of southern boarfish mainly occurred in mid-water trawling and bottom longlining, and it represents the second most important species in both areas, after *Helicolenus dactylopterus dactylopterus* in the south-east Atlantic Ocean and *Beryx splendens* in the Southern Indian Ocean.

Two new regional fisheries organisations are being developed in those areas (SEAFO, South East Atlantic Fisheries Organisation; SWIOFC, South West Indian Ocean Commission) and any information on life history characteristics for the most

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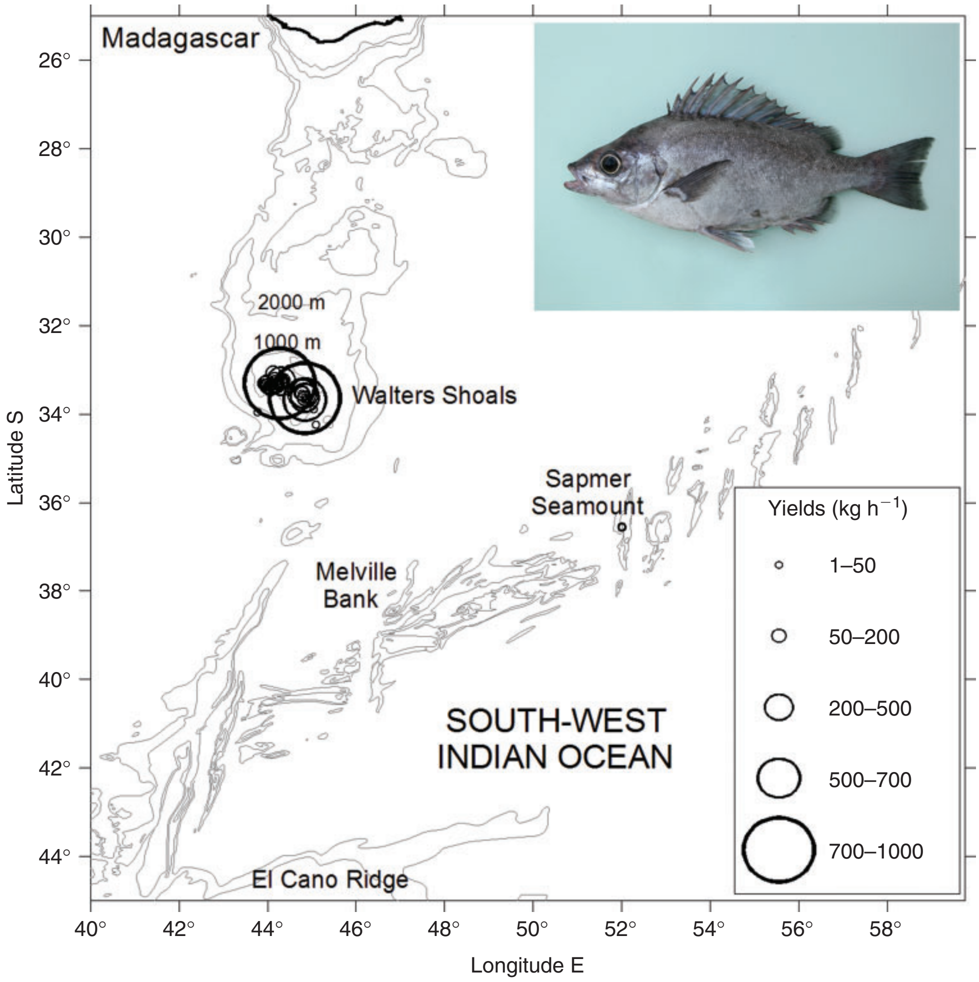

Fig. 1. *Pseudopentaceros richardsoni* (Smith 1844). Area where the specimens were caught in Walters Shoals and Sapmer Seamount (south-west Indian Ocean) and yields (kg h^{-1}) obtained.

important commercial species is essential to the development of precautionary reference points to be applied within those areas.

The species of genus *Pseudopentaceros* seem to lead a pelagic life when they are juveniles, but adults have also been collected from the surface (Humphreys and Tagami 1986). This benthopelagic behaviour causes the formation of large aggregations that may move in a light-darkness cycle, but only adults are completely recruited to the seamounts. Chikuni (1970) and Humphreys *et al*. (1989) suggested that these species shift to a demersal existence over seamounts when the individuals are 4–5 years old. This circumstance seems to be similar to that of our target species and has conditioned the methodology applied in the present study to solve the absence of juveniles in the sampling.

The present study describes, for the first time, an attempt at ageing the boarfish *Pseudopentaceros richardsoni* and at estimating growth parameters starting from individuals harvested in the south-west Indian Ocean, using back-calculation methods to estimate size-at-age of the truncated sample caused by the lack of young fish in the catches. To our knowledge, only studies on ageing *Pseudopentaceros wheeleri* were found in the literature consulted (Vasil'kov and Borets 1978; Uchiyama and Sampaga 1990; Humphreys 2000).

Material and methods

Specimens of *Pseudopentaceros richardsoni* were collected during an experimental trawl fishery carried out in the south-west Indian Ocean by the Spanish vessel *Puente Ladeira* from October to December 2001, in waters ranging between 600 m and 1350 m depth. Catches were taken from the Walters Shoals (Madagascar Plateau) and the Sapmer Seamount (south-west Indian Ridge) (Fig. 1) following normal commercial fishing procedures.

For each fish, the total length (TL) was measured to the nearest millimetre. In all, 90 boarfish were sampled for biological analyses; 63 males ranging in size between 45.7 cm and 65.3 cm TL, and 27 females between 48.3 cm and 72.5 cm TL. Sagittal otoliths were removed from each individual, cleaned with water and stored in small envelopes for later analysis. No fish smaller than 48.3 cm were caught in the whole trawling operation.

Differences in size frequency distributions of *P. richardsoni* by depth were analysed using a two-tailed Kolmogorov–Smirnov

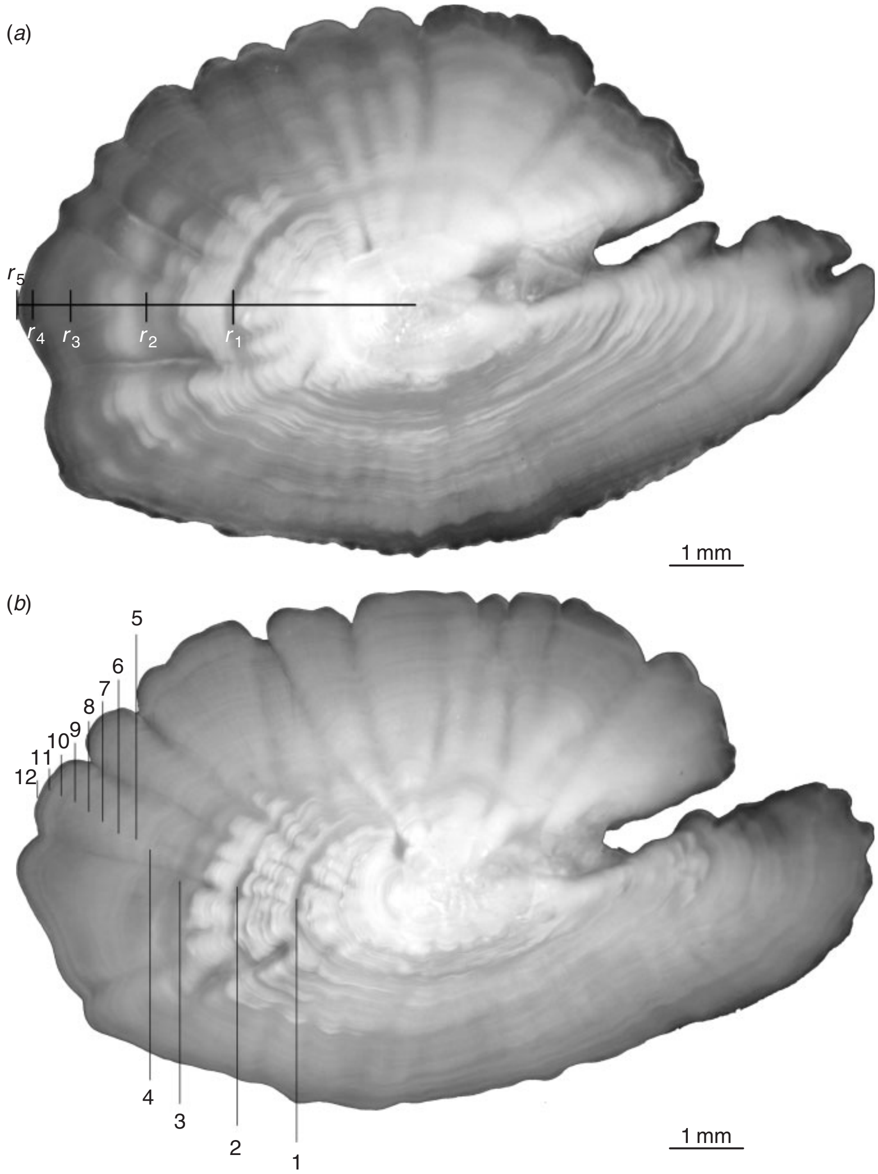

Fig. 2. *Pseudopentaceros richardsoni* otoliths with (*a*) 4 years (50.1 cm total length (TL)) and (*b*) 11 years (61.2 cm TL) assigned. Diagram of sagittal otolith (*a*) showing the measurement method used for the radii (r_n). The reading line shows the most common path used to identify the annuli.

test for large samples, performed for all strata (600–700, 700–800, 800–900 and 900–1000 m) combinations. Critical values were obtained at the 0.05 level of significance using the Siegel and Castellar (1988) method.

Age was determined by interpreting growth rings on the whole otolith (Fig. 2), which were immersed in water and viewed using a stereo microscope with reflected light under 10× magnification. Each otolith was read by two people independently, with no knowledge of the length of the specimen. The readings for a given otolith were accepted if both readers agreed and/or depending on the reliability of the reading. Four levels were established, ranging from reliable to unreliable, for which only the first two readings were accepted. In addition, one otolith from each fish was embedded in black polyester resin and transversal sections (450 μm) were taken through the nucleus of the otolith using a diamond cutting blade. The sections were examined following the same procedure used with the whole otolith but with transmitted light.

The lack of continuity in the monthly samples precluded assessment of the evolution of the marginal rings in the otoliths under study. However, it was considered that rings with one hyaline and one opaque ring are deposited annually (Fig. 2). Uchiyama and Sampaga (1990) followed the same criteria to identify check marks in ageing *P. wheeleri*.

The first day of January was used arbitrarily as the birth date of the fish under study, although the maturation of females caught

(October–December) reinforces this choice as 44% of them were at spawning stage and 48% at post-spawning. Studies on the reproductive cycle of female *Pseudopentaceros wheeleri* indicate that for this species spawning occurs between November and February (Yanagimoto and Humphreys 2005).

The age-length relationship was established for all individuals using 1-cm size intervals (rounding off to the lower centimetre). The mean size and the standard deviation by age class were estimated, taking as a reference the midpoint of the size interval. The age-length key for all individuals was applied to the length distribution to obtain the age composition of the catches.

The lack of young fish in the catches, owing to the fact that they are absent from the seamount, conditioned the growth curve fitting on the left side (truncated sample). Thus, only the use of back-calculation methods could solve the estimation of previous size-at-age. Back-calculated length-at-age values for each individual were then derived with the method proposed by Monastyrsky (1930) (1), which is one of the most common non-linear methods (Francis 1990; Araya and Cubillos 2002; Folkvord and Mosegaard 2002).

$$L_i = \left(\frac{R_i}{R_c}\right)^v L_c \tag{1}$$

where:
L_i = Estimated length at age i;
L_c = Length at capture;
R_i = Otolith radius at age i;
R_c = Otolith radius at capture; and
v = Constant of allometry

Fish size is considered a non-linear function of radius size (power relationship) that can be rearranged to a linear form by the logarithmic transformation of the formula (2), and

$$L = uR^v \tag{2}$$

$$\log L - \log u + v \log R \tag{3}$$

v and u are derived from the linearised equation. The hypothesis to which this approach may be associated depends on how v is calculated, fitting the regression L v. R (body proportional, BPH) or fitting the regression R v. L (calcareous structure proportional, SPH).

Whether the geometric mean regression (GMR) Ricker (1992) is used, both hypotheses are taken into account. This method consists of using a non-linear relationship – Y on X and X on Y:

$$Y = aX^b \tag{4}$$

$$\log(Y) = \log(a) + b\log(X) \tag{5}$$

$$\log(X) = \log(c) + d\log(Y) \tag{6}$$

where Y and X are fish length and otolith radius at capture respectively.

From this, a new non-linear relationship is built that describes the fish length–otolith size relationship and uses a constant of allometry (v) derived from b (5) and r (5 or 6) (correlation coefficient) or b and d (6):

$$v \approx \frac{b}{r} \approx \sqrt{\frac{b}{d}} \tag{7}$$

constant which is used in the *BC Formula* (1).

The central line obtained from the GMR would thus represent a better fit to the data (Folkvord and Mosegaard 2002), mainly when it is difficult to determine which variable should be dependent and which independent in the ordinary regression. The use of the GMR method (Ricker 1992) also reduces the intercept values making this more reliable when sample truncations occur, which is the case in the present study for fish younger than 5 years old, caused by natural age segregation.

For back-calculations of growth only, otoliths showing clear increment patterns were assessed along the actual radius of the otolith, from the focus to the anterior edge of each hyaline zone (r_n; Fig. 2), using a micrometer eyepiece.

To validate the age reading technique used here, the position of each check mark was measured and compared with successive check marks. Mean length-at-age were compared with those provided by other authors for species of the same genus. Back-calculation was validated comparing back-calculated length-at-age with mean length-at-age + 1 from those obtained by direct reading of the otolith and also, standard deviation (s.d.) of back-calculated length-at-age were compared with observed sizes at the same age, as recommended by Folkvord and Mosegaard (2002).

In the current study both sexes have been considered together, taking into account the scarcity of individuals in the samples if we differentiate by sex (27 females–63 males). The growth parameters for all individuals were estimated by means of a non-linear regression, using the Levenberg-Marquardt algorithm (GraphPad Prism version 4.00 for Windows). Length-age pair values were fitted to the von Bertalanffy growth function:

$$L_t = L_\infty[1 - e^{-K(t-t_0)}]$$

where L_t is length (TL) at time t (years), L_∞ the asymptotic length, K the growth coefficient and t_0 the hypothetical time when fish length is zero.

Differences between mean length-at-age obtained by direct reading and those obtained by back-calculation were tested through ANOVA (Zar 1984). Two-way ANOVAs with a Bonferroni post hoc test were performed using GraphPad Prism software. We tested whether the first factor (methods: direct reading; back-calculation) had the same effect at all values of the second factor (age) and how these two methods affect the results or whether the curves were different, once the normality of the data (normality test: Shapiro-Wilk; Kolmogorov–Smirnov; and D'Agostino & Pearson) and the homogeneity of variances (Bartlett's test for equal variances) were verified.

Results and discussion

Age interpretation

Otoliths of *Pseudopentaceros richardsoni* were not easy to read and they generally presented false rings. Shapes were apparently quite similar in the range of age analysed: most of them show a clear nucleus; the presence of a large number of pseudo-rings within the first four rings and a common feature was the presence of wide first three rings (Fig. 2), which is likely a result of physiological changes related to ontogenetic migration during the fourth year of life – changes probably caused by passing from pelagic to demersal life. Despite the problems, only three

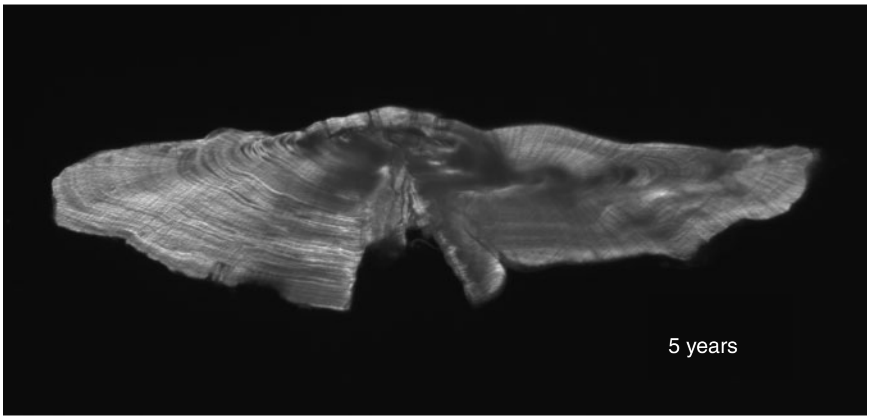

Fig. 3. Transversal section of an otolith with 5 years assigned by direct readings of the whole sagittae.

readings were rejected and 87 were accepted for analysis. The age assignment and the border shape of two boarfish otoliths are also shown in Fig. 2.

Finally, transversal sections were discarded owing to the poor readability of the preparations that shows important differences when compared with whole otolith readings. The interpretation of age was impossible in sections and they only provided the opportunity to count marks (Fig. 3).

Age-length relationship

The age class of the individuals studied ranged between 4 and 13 years. Individuals ranging from age class 0 to 3 were absent from the collection, most likely because of their pelagic behaviour making them unavailable to the bottom trawls.

The age-length key for all the boarfish examined is shown in Table 1. The greatest proportion was at age class 5 (28%), followed by age classes 4, 7 and 6 (18%, 17% and 15%, respectively). Only two specimens older than 11 years were found. The progression of mean length-at-age increments was slightly erratic, mainly as a result of the shortage of individuals of some ages.

The information related to age studies is scarce for the species of this genus. Uchiyama and Sampaga (1990) wrote that two fishes (*Pseudopentaceros wheeleri*) of 48–54 cm FL had five check marks and the largest fish (54.7 cm FL) had eight-plus check marks. Compared with the data in Table 1, those data are of the same range as *P. richardsoni*; four and eight age class respectively. Thus, both species seem to have the same growth pattern at this level. The analysis of radii increments assigned to ages (Fig. 4) that show a reliable structure of radii increments and the above similarities suggest an appropriate reading technique.

Size and age distribution

Length–frequency distributions of catches per depth strata (600–1000 m) are shown in Fig. 5. Individual sizes of fish caught varied between 45.7 cm and 72.5 cm TL. Some discrepancies are found in relation to the maximum length for this species that was established at 56 cm of total length by Heemstra (1986), whereas individuals of 72.5 cm TL were found in the south-west Indian Ocean. Information about maximum length for the other species of the genus *Pseudopentaceros* is also unclear from the literature. Uchiyama and Sampaga (1990) reported 54.7 cm FL as the largest for *P. wheeleri*. Thus, *P. richardsoni* seems to be the largest species of the two.

The two-tailed Kolmogorov–Smirnov test, performed for all possible combinations of 100 m strata, indicates that statistical differences between size structure of strata 800–900 m and 900–1000 m are not significant ($D_{\max} < 0.1386$). However, depth strata 600–700 m, 700–800 m and 800–1000 m are statistically different ($D_{\max} > D_{0.05,(m,n)>25}$). In the shallow strata (600–700 m), there was a unimodal distribution at 53 cm TL. The length distribution of fish in the 700–800 m strata was also unimodal at 55 cm TL. In the deepest strata (800–1000 m), boarfish had a bimodal length distribution: one at 48 cm and the other at 53 cm TL. The mean length of fish inhabiting the deepest strata does not increase with depth in the whole range. Smaller, but adult, fish (45–51 cm) were located at 800–1000 m depth.

This distribution pattern is apparently similar to other species of the same genus, although in this specific case at a different depth range. Thus, Humphreys and Tagami (1986) indicate that Takahashi and Sasaki (1977) reported the tendency of the largest pelagic armorhead (*P. wheeleri*) to occur at 300–390 m depths and the smaller fish at 200–290 and 400–490 m, which is not in contradiction with the transition in size structure by depth found in the south-west Indian Ocean for *P. richarsoni*.

Following these observations, after the pelagic phase, *P. richarsoni* seems to settle over no specific depth (Fig. 6), although younger fish are more frequent at deeper strata and older specimens are more represented between 700 and 800 m depth. At shallower depths all of the ages have similar presence.

Analysing the age composition of catches, it is observed that 78% of boarfish were between 4 and 7 years old and 22% were older than 7 years. Age class 4 seems to be not totally recruited and after age class 7 (23%) the proportion of older fish drops suddenly below 11% (Fig. 7). The pelagic span for *P. wheeleri* differs depending on authors and regions; Uchiyama and Sampaga (1990) establish it at 1–3 years longer (Hawaiian Ridge), Boehlert and Sasaki (1988) consider that this stage takes between 1.5 and 2.5 years longer (the North Pacific). However, Humphreys *et al.* (1989) consider that this species undergoes a longer epipelagic phase and individuals tend to be 4–5 years

Table 1. Age-length key of *Pseudopentaceros richardsoni* for all individuals taken from the south-west Indian Ocean

s.d., standard deviation; TL, total length

Size-class (TL, cm)	Age class (year)									
	4	5	6	7	8	9	10	11	12	13
45		1								
46		2								
47	2	1		1						
48	5	2								
49	2	3	2	1						
50	2	4								
51	2	2	1							
52		2	2		1					
53	1	1	2	1						
54	2	1	1	1		1				
55			2	3						
56		2		3						
57		1		2	1			1		
58		1	1	1	1					
59		1	1		1					
60			1		2				1	
61				1		1		1		
62						1	1	1		
63				1	2					
64										
65						1				
66										1
67										
68										
69										
70										
71										
72								1		
Mean length (cm)	50.2	51.6	54.3	56.0	59.5	61.0	62.5	63.5	60.5	66.5
s.d. (cm)	2.3	3.9	3.5	4.0	3.6	4.7	–	6.4	–	–
n	16	24	13	15	8	4	1	4	1	1

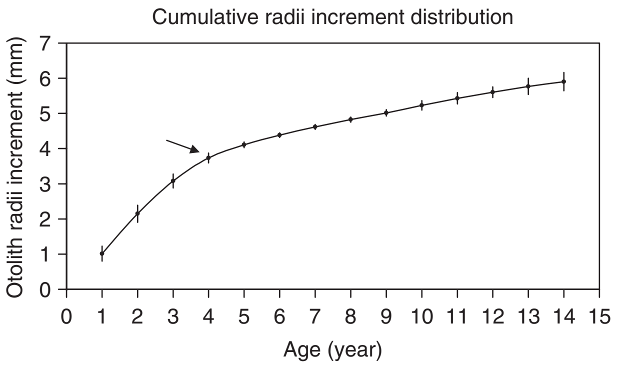

Fig. 4. Cumulative otolith radii increment distribution of *Pseudopentaceros richarsoni* showing the point (aged 4 years) from which the otolith reduces its relative growth.

old when they settle and reproduce, although this phase had been established at 2–3 years old in other locations and changes from one year to the next have been detected (Humphreys 2000). When radius increments in the otolith are analysed (Fig. 4), the cumulative radius increment distribution shows a point at age 4, where the otolith reduces its relative growth, likely connected with some change in the specimen life history that may be related to the starting point of migration to settlement on the seamount.

According to the previous facts, *P. richardsoni* seems to go through similar pelagic and demersal phases in the south-west Indian Ocean to the other species from the Pacific Ocean and this may be reflected in the otolith growth pattern. It has also been suggested that *P. wheeleri* may spawn only a few seasons after settling over the summits and then die (Uchiyama and Sampaga 1990). This fact may explain the drastic reduction of individuals older than 7 years in the current study (Fig. 7).

Growth

The back-calculation procedures allowed us to fill in the lack of information in lengths-at-age 1, 2, 3 and 4, which are absent from catches and also check the lengths-at-age already estimated by direct reading. The results of back-calculation are shown in Table 2, which summarises the annuli identification and measurement phase and the application of the back-calculation formula. Fig. 8 shows the total length at capture and otolith radius

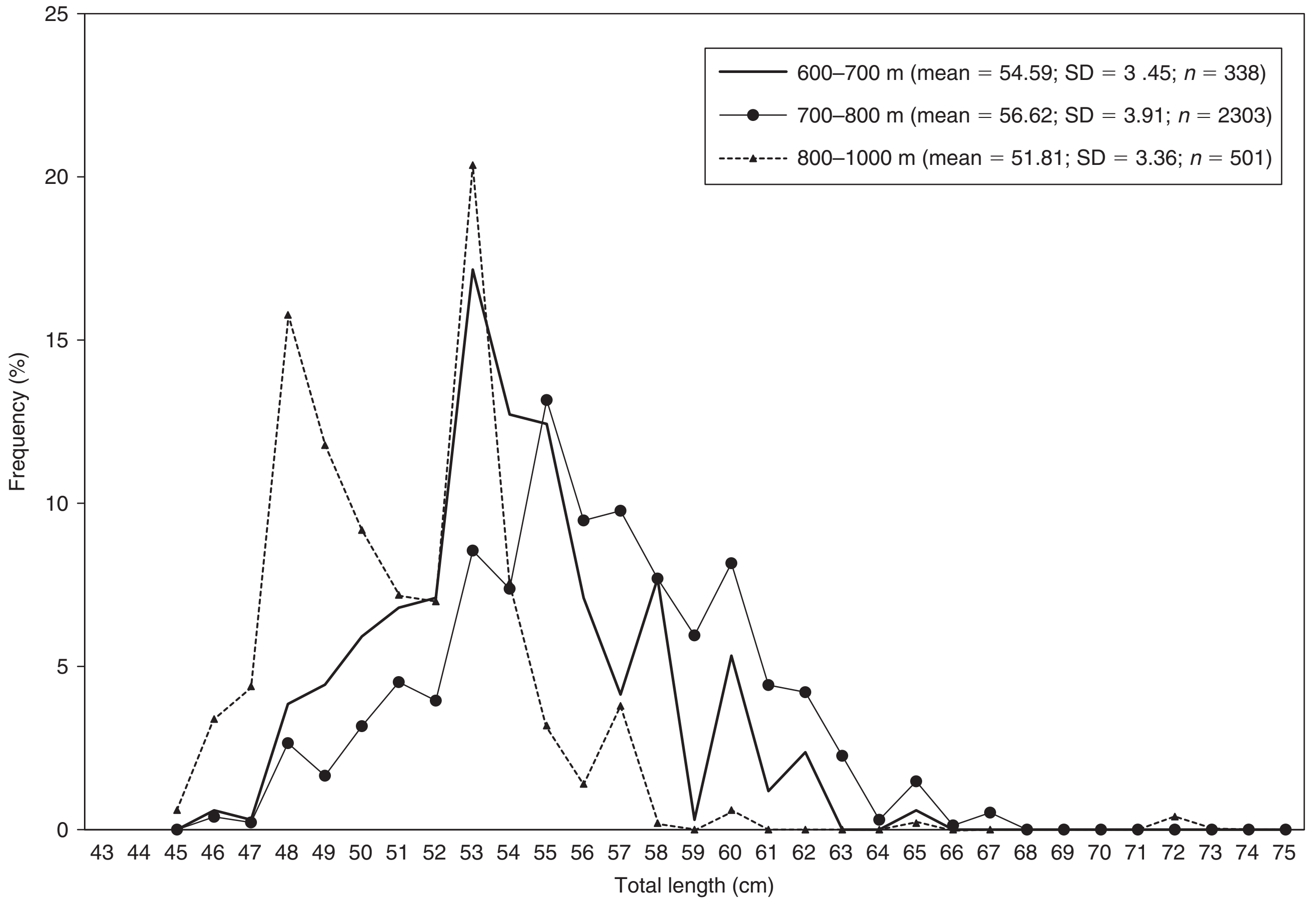

Fig. 5. Length composition of *Pseudopentaceros richardsoni* by depth strata of catches from Walters Shoals and Sapmer Seamount.

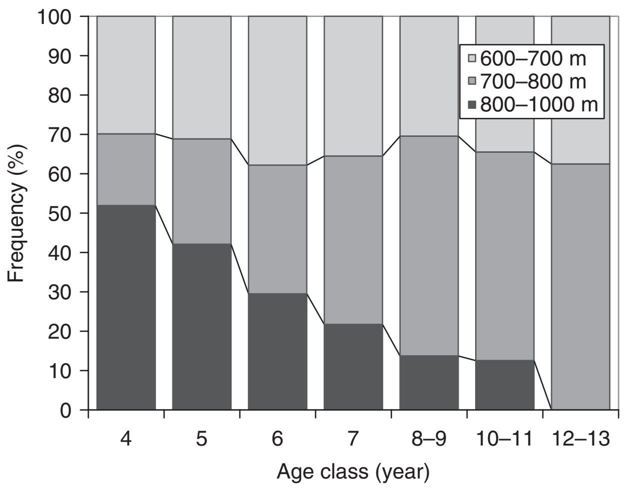

Fig. 6. Age distribution of *Pseudopentaceros richardsoni* by depth strata of catches from Walters Shoals and Sapmer Seamount.

at capture relationship using the GMR (Ricker 1992) ($r^2 = 0.59$; s.e. = 0.03–0.04).

In this approach, the GMR (Ricker 1992) was used because the central line obtained from the GM regression represented a better fit to the data (Folkvord and Mosegaard 2002). This was mainly helpful when it was difficult to determine which variable should be dependent and which should be independent in the ordinary regression. Hence, the GMR allowed us to determine which proportional hypothesis should be used, BPH (body) or SPH (calcareous structure).

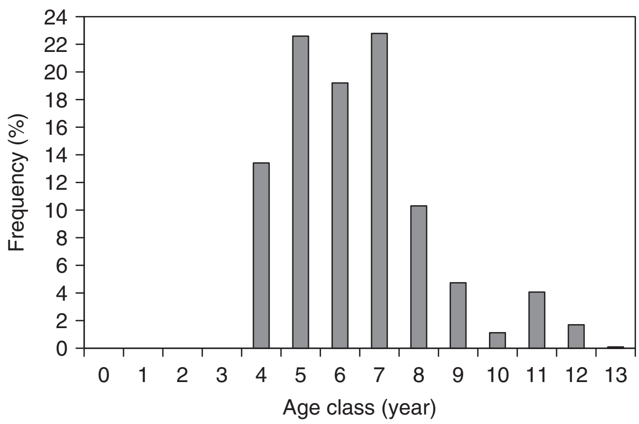

Fig. 7. Proportion of *Pseudopentaceros richardsoni* age classes in the catches from Walters Shoals and Sapmer Seamount.

Table 2. Back-calculation summary: Mean radius-at-age (mm) and mean length-at-age (cm). No. specimens, radius intervals and length intervals from back-calculation technique for all individuals of *Pseudopentaceros richardsoni*

CV, coefficient of variation; s.e., standard error; s.d., standard deviation

Radii (r_n)	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}
Mean radius (mm)	1.013	2.148	3.079	3.735	4.108	4.400	4.665	4.888	5.159	5.400	5.656	5.880	6.533	7.600
s.d. (mm)	0.173	0.212	0.264	0.294	0.315	0.335	0.390	0.442	0.503	0.594	0.739	0.858	1.320	
s.e. (mm)	0.11	0.23	0.33	0.41	0.45	0.53	0.70	0.88	1.22	1.71	2.31	2.63	4.62	
CV (%)	17.1	9.9	8.6	7.9	7.7	7.6	8.4	9.0	9.7	11.0	13.1	14.6	20.2	
n	85	85	85	85	84	70	44	31	18	10	6	5	2	1
Max. radius (mm)	1.600	2.600	3.600	4.467	4.733	5.067	5.400	5.800	6.267	6.667	7.000	7.267	7.467	
Min. radius (mm)	0.800	1.600	2.533	3.133	3.467	3.600	3.733	4.267	4.400	4.800	5.000	5.133	5.600	
Length (r_n)	TL(r_1)	TL(r_2)	TL(r_3)	TL(r_4)	TL(r_5)	TL(r_6)	TL(r_7)	TL(r_8)	TL(r_9)	TL(r_{10})	TL(r_{11})	TL(r_{12})	TL(r_{13})	TL(r_{14})
Mean length (cm)	18.22	31.33	40.58	46.62	49.91	52.25	54.65	56.57	59.16	60.55	61.87	62.99	63.13	66.80
s.d. (cm)	2.60	3.08	3.32	3.40	3.50	3.66	3.69	3.88	3.97	4.65	5.35	5.97	4.00	
s.e. (cm)	0.28	0.33	0.36	0.37	0.38	0.44	0.56	0.70	0.94	1.47	2.18	2.67	2.83	
CV (%)	14.3	9.8	8.2	7.3	7.0	7.0	6.7	6.9	6.7	7.7	8.6	9.5	6.3	
n	85	85	85	85	84	70	44	31	18	10	6	5	2	1
Max. length (cm)	25.89	42.41	49.42	54.41	57.71	60.17	62.59	64.97	67.32	69.64	71.36	72.50	65.95	
Min. length (cm)	13.80	25.46	34.07	37.98	43.42	45.66	46.74	47.80	52.50	54.50	56.22	57.30	60.30	

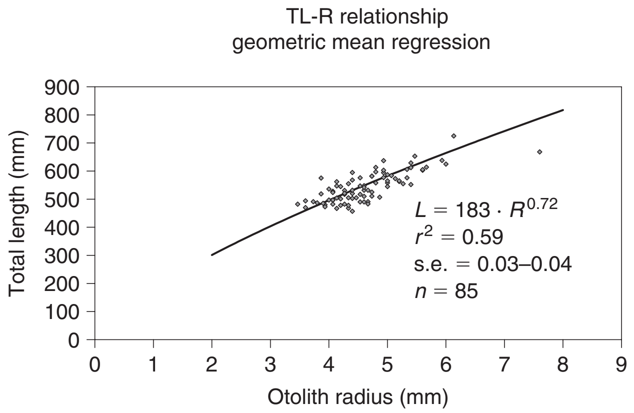

Fig. 8. Total length at capture and otolith radius at capture relationship using the geometric mean regression (GMR) (Ricker 1992).

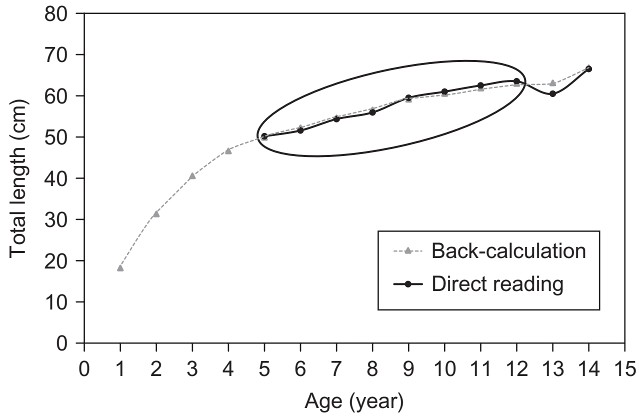

Fig. 9. Total length-at-age estimated by back-calculation and by direct reading. The circle focus on pairs of length-at-age compared statistically (differences not significant).

Fig. 9 is a representation of total length-at-age estimated by back-calculation and by direct reading. Comparisons between mean length-at-age values obtained by both methods show that there are no significant differences between them (two-way ANOVA, $P \sim 0.996$). The results of the test indicated that the difference in effect between methods is the same for all ages analysed and that the mean response is the same for both methods. Also, comparisons between s.d. of back-calculated length-at-age (Table 2) and those of observed sizes (Table 1) at the same age do not show inflated s.d., with values of the same order.

Nevertheless, as Araya and Cubillos (2002) mentioned, one of the problems using back-calculation with truncated samples is that estimates of the regression slope and intersection may be poor and tend to deviate the data distribution of the relationship at both extremes. Ricker (1992) widely analysed the effect of different truncations and possible bias when the line is extrapolated to unsampled ages, which is the case in the present study at the lower extreme of the array. We suggest that the elimination of any artificial truncation, which is not possible at this stage because the youngest fishes were absent in the catches, and

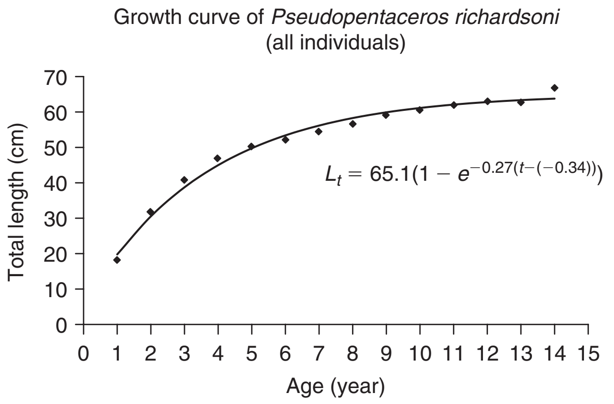

Fig. 10. Growth curve of *Pseudopentaceros richardsoni* from the south-west Indian Ocean for all individuals fitted to the mean length-at-age back-calculated.

the use of GMR as a method that reduces the intercept values, makes these results more reliable. In spite of this, no anomalous data and trend are detected in Figs 8 and 9 supporting any unacceptable bias. After that, it was assumed that the results reasonably validate the back-calculation methodology used and the results obtained, providing the base for the estimation of growth parameters.

In Table 2, a relatively larger value of coefficient of variation (CV) is observed at age 1 (14.3) than at the following ages (≈8). This reflects the uncertainty in identifying the focus in the sagittae as the starting point of measurements – uncertainty that is transferred to the first annuli measurement as greater variability. Nevertheless, this variability would not affect the value of length estimated at age 1.

The growth parameters estimated for *P. richarsoni* in the south-west Indian Ocean for all individuals are: $L_\infty = 65.1$ cm; $K = 0.27$ year^{-1} and; $t_0 = -0.34$ years. The coefficient of determination (r^2) was high at 0.99. Figure 10 shows the growth curve of *Pseudopentaceros richardsoni* from the south-west Indian Ocean for all individuals fitted to the mean length-at-age values back-calculated. These results seem to be accurate; for instance, L_∞ is placed very close to the maximum length of males (65.3 cm), which are more abundant in the samples than females (maximum length 72.5 cm). These early estimations may represent a good starting point in growth studies for this species.

Ageing approaches using various methods including back-calculation from otoliths (Ballagh *et al*. 2006) have proved valuable for assessment of growth rates of long-lived temperate fish (e.g. Ewing *et al*. 2007) and are especially applicable in the current study where limited numbers of juvenile fish were available. However, given the lack of published studies on this species and the mentioned difficulties in the current study, it is clear that more information about the southern boarfish biology is needed to establish bases for a responsible fishery development off the seamounts of the Southern Indian Ocean and other deep-sea regions.

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