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Relationship between somatic growth and otolith growth: a case study of the ornate jobfish *Pristipomoides argyrogrammicus* from the coast of Réunion (SW Indian Ocean)

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Abstract :

The ornate jobfish *Pristipomoides argyrogrammicus* Valenciennes 1832 occurs in the Indo-West Pacific Ocean, where it is harvested by small-scale coastal fisheries. Management of this species is hindered by lack of adequate biological data. We sampled a total of 113 individuals from the landings of local artisanal fishers on the island of Réunion (southwestern Indian Ocean), from March 2014 to March 2015. The relationships between two types of body length (total and standard length, cm) and total weight (g) were shown to be significant ($p < 0.05$). The length–weight relationship was described by a power function, with the scaling factor estimated to be 0.008 and the exponent 3.146. Age was determined using whole otoliths. The von Bertalanffy growth equation was estimated to be TLt = 30.68(1 – e–0.52(t)). Otolith morphometry variables (length, width and area) were significantly correlated with age estimates ($p < 0.05$). No significant difference in age estimates was observed between left and right otoliths used as predictors. Readings from observed age and the estimates from modelled age indicated relatively good agreement, suggesting the potential to use whole otoliths for age estimation.

Keywords : age estimate, general linear model, Lutjanidae, modelled age, morphometric parameters, otolith morphometry, reading precision

Introduction

The ornate jobfish *Pristipomoides argyrogrammicus* Valenciennes, 1832 is a member of the snapper family (Lutjanidae), which is one of the important fisheries resources in the tropical and subtropical waters of the Indo-West Pacific (Allen 1985). This species occurs at depths of 70 m to 350 m (Anderson and Allen 2001) in the Western Indian Ocean from Kenya to Mauritius Island (Smith and Smith 1963; Allen 1985; Fricke et al. 2009; Wickel and Jamon 2010; Fulanda et al. 2011) and in the Western Pacific Ocean from Japan to New Caledonia (Wass 1984; Allen 1985; Fricke et al. 2011). *P. argyrogrammicus* is targeted particularly by artisanal fisheries at Reunion Island. The main deep-water tropical fishes - snappers, groupers (Epinephelidae) and emperors (Lethrinidae) - support locally important artisanal fisheries throughout the Indo-Pacific region, but quantitative assessments of these species have been limited by a lack of adequate biological and fisheries data (Newman et al. 2016). Since the 2000s, the fishery for *P. argyrogrammicus* at Reunion Island has increased significantly with the emergence of a new fishing technique, the 'electric fishing reel', employed by commercial and recreational fishermen. Qualitative assessments of Reunion Island deep-water species showed fishing impacts on this stock. The first results showed that the fishing yield and the mean landing size decreased (Fleury et al. 2011, 2012). Moreover, there were no management measures and regulations in place on these fisheries. However, catches of the predators of *P. argyrogrammicus* (*Etelis coruscans* and *E. carbunculus*) increased, which seemed to bring about positive effects on the prey population (Roos et al. 2015). Data on *P. argyrogrammicus* biology are scarce and growth parameters to date have not been documented, with only one study on reproductive biology off Ishigaki Island, Japan (Nanami 2011). In view of the requirement for data, the aim of this study was to investigate the growth of *P. argyrogrammicus* along the coast of Reunion Island, based on an age determination method from otolith readings. The results of this growth study will be used in regional stock assessments and serve as an addition to global knowledge of this ecologically important species. Development of a low-cost ageing technique is an additional benefit of this study. Reliable techniques for estimating age composition of exploited deep-water snapper populations are limited or costly, making alternative ageing techniques necessary in fisheries management. Consequently, the aim of this study was also to contrast *P. argyrogrammicus* ageing based on otolith readings versus evaluation of otolith shape.

Material and methods

One hundred and thirteen *P. argyrogrammicus* were sampled from Eastern Reunion Island local deep-water handline artisanal fisheries landings. Monthly specimens were collected between March 2014 and March 2015. Specimens were examined in the laboratory for sex, total length (TL, cm), fork length (FL, cm), standard length (SL, cm) and total wet weight (W, g).

Length-weight relationships were estimated separately for males and females. In order to estimate the parameters of the allometric L-W relationship, a least squared linear model was fitted to the base-10 logarithm of the data:

$$W = a\,L^{\,b} \tag{1}$$

$$\log W = \log a + b \log L \tag{2}$$

where *a* is the intercept or initial growth coefficient and *b* is the slope i.e. the growth coefficient (Le Cren 1951; Ricker 1975; Froese 2006). Analysis of covariance (ANCOVA) was used to assess the differences between the fitted length/weight relationships for males and females.

For ageing, sagittal otoliths were removed from the left and right side of the head of each specimen. Since growth of *P. argyrogrammicus* has not been investigated before, ageing calibration was performed. Calibration was based on contrasting results from multiple ageing techniques. Ageing techniques comprised readings performed on whole otoliths, sectioned otoliths, and scales. Whole otoliths were read under both transmitted and reflected light, both before and after burning. After the otoliths were embedded in epoxy resin, transverse sections (TS) through the core (or nucleus) were made using a precision saw with a blade thickness of 0.3 mm. Finally, the TS were ground and polished on both sides until the core was visible (thickness of 0.2 mm). Five scales were extracted from under the pectoral fin to limit the regenerated scales.

Otolith morphometry was also used to develop a faster and cheaper alternative method to obtain fish age. Each otolith was weighed (Ow: otolith weight, mg) and was analysed using TNPC software (Digital Processing of Calcified Structures; www.tnpc.fr) in two steps: (1) the extraction of morphometric parameters of the whole otolith (O_L = otolith length; O_{Wl} = otolith width; O_A = otolith area and O_w = otolith weight).

Each otolith was examined twice by two readers to control for observer bias and estimate reading precision. Coefficient of variation (CV), percent agreement (PA; ±1 y), and absolute percent error (APE) were used to estimate reading precision (Beamish and Fournier 1981; Kimura and Lions 1991). Precision metrics were calculated as:

$$\mathrm{CV}_j(\%) = 100 \times \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{\mathrm{ij}} - X_j)^2}{R-1}}}{x_i}$$

$$\mathrm{PA} = \frac{\sum |n_{\mathrm{diff}} \leq 1|}{n}$$

$$\mathrm{APE}_j(\%) = 100 \times \frac{1}{R} \sum_{i=1}^{R} \frac{|X_{\mathrm{ij}} + X_j|}{X_j}$$

where R is the number of times each fish is aged, X_{ij} is the i(th) ageing of the j(th) fish, Xj is the mean age calculated for the j(th) fish, and n_{diff} is the difference in ageing between the first and second readings.

Age and total length data were used to describe growth using the Von Bertalanffy (1938) model for the lengths:

$$\mathrm{TL}_t = \mathrm{TL}_\infty (1 - e^{-K(t-t_0)})$$

and for the weight: $$W_t = W_\infty (1 - e^{-K(t-t_0)})^3$$

with $$W_\infty = a\ \mathrm{TL}_\infty{}^{b}$$

where TL_t and W_t are the length and the weight at age t, TL_∞ and W_∞ the asymptotic length and weight, K the rate at which the asymptote is reached and t_0 the theoretical age (in years) at zero length (scaling factor). The growth model was performed under the constraint of $t_0 = 0$, because the adjustment of the model with only 2 parameters was better than the initial model without constraint.

Fish growth was estimated using the growth performance index (Pauly and Munro 1984):

$$\varphi' = \log K + 2 \log \mathrm{TL}_\infty$$

where K and TL_∞ are as above. Growth comparison was based on φ' rather than from a comparison of TL_∞ and K individually, since these two parameters are correlated (Sparre et al. 1987). Likelihood ratio tests were used to compare the von Bertalanffy growth curves between sexes (Kimura 1980; Haddon 2001).

The relationship between age estimation from readings, otolith morphometry, and otolith location (left or right side) was investigated using a complete generalised linear model (GLM;

McCullagh and Nelder 1999). Age estimates were the response variable, and otolith shape and location the independent variables. The age estimation model was

$$\text{Age} \sim O_L + O_{\text{WI}} + O_A + O_W + S + O_L \times S + O_{\text{WI}} \times S + O_A \times S + O_W \times S$$

where S is the side

To predict the probability of accurate otolith readings, a binary logistic regression was used. The same independent variables as above were used in the logistic regression. The response variable was constructed from the age groups identified by readers (ages 1–5). Five groups (Group 1–5) were constructed, each used in a separate logistic model. Categories for the response variable were coded as 1 if belonging to an age group and 0 otherwise. As an example, for the Group 1 model, fish read as age 1 were coded as 1, and fish read as ages 2–5 were coded as 0. The logistic model was

$$\text{Age}_{0/1} \sim O_L + O_{\text{WI}} + O_A + O_W + S + O_L \times S + O_{\text{WI}} \times S + O_A \times S + O_W \times S + \varepsilon_{0/1}$$

where $\varepsilon_{0/1}$ assumed the binomial distribution

The above model was used independently for each of the five age groups obtained from readings. The overall best model was chosen from the final logistic models using a stepwise selection based on the Akaike information criterion (AIC; Akaike 1974; Sakamo et al. 1986). The probability of falling into either the 0 or the 1 group was calculated for each otolith for each of the five models as (McCullagh and Nelder 1999:

$$p(\text{Age}_{0/1}) = \frac{\exp(O_L + O_{\text{WI}} + O_A + O_W + S + O_L \times S + O_{\text{WI}} \times S + O_A \times S + O_W \times S + \varepsilon_{0/1})}{1 + \exp(O_L + O_{\text{WI}} + O_A + O_W + S + O_L \times S + O_{\text{WI}} \times S + O_A \times S + O_W \times S + \varepsilon_{0/1})}$$

The precision of the age modeled from morphometric parameters was determined from the age estimated by the experts.

All analyses were done in ‘*R*’ (R Core Team 2016).

Results

Out of 113 *P. argyrogrammicus* collected from February to December 2004, two were juveniles, 52 males and 59 females. Male and female measured length (TL) and weight (W) ranged respectively from 14 cm to 32 cm and from 31 g to 418 g. Significant *L*-*L* and *L*-*W* relationships ($p < 0.05$) were detected:

$$TL = 1.232\ SL + 0.498;\ r^2 = 0.99;\ p < 2.10^{-16}$$

$$TL = 1.150\ FL + 0.265;\ r^2 = 0.99;\ p < 2.10^{-16}$$

$$W = 0.008\ TL^{3.146};\ r^2 = 0.99;\ p < 2.10^{-16}$$

The length–weight relationship showed a significant positive allometric growth (greater than 3), regardless of the sex of individuals **[Figure 1]**. The sex effect was not significant on TL-SL ($p = 0.753$), TL-FL ($p = 0.424$) and TL-W ($p = 0.925$) relationships.

Whole otolith was found to be the best technique, providing very clear visible alternating translucent and opaque bands (Figure 2). The observed ages of *P. argyrogrammicus* ranged from 1 to 5 years (Figure 3). Whole otolith readings indicated good agreement between estimates (agreement = 83.8%, CV = 3.5% and APE = 3.1%). Von Bertalanffy growth parameters for females ($n = 59$) and males ($n = 52$) were $TL_\infty = 30.97$ cm; $W_\infty = 383.91$ g; $K = 0.54\ y^{-1}$ and $TL_\infty = 28.99$ cm; $W_\infty = 323.38$ g; $K = 0.52\ y^{-1}$, respectively. These results translated into similar growth performance indices for females (φ' = 2.71) and males (φ' = 2.68). No significant differences in growth parameters was found between sexes (likelihood ratio test: $\pi^2 = 0.532$, df = 3, $p = 0.465$). The estimated growth parameters for both sexes combined were: $TL_\infty = 30.68$ cm; $W_\infty = 380.75$ g; and $K = 0.52\ y^{-1}$.

Three morphometric parameters of the otolith (O_L, $p = 0.041$; O_A, $p < 0.001$; O_{WI}, $p = 0.009$) were significantly correlated with age estimates from whole-otolith readings, following GLM analysis (Table 1). Logistic regression using GLM significant predictors showed O_L to be significant in all but the Group 5 model. Predictors O_{WI} and O_A were significant in Group 3 models. Predictor O_W was significant in groups 2 and 5 models (Table 2). The precision of the modelled age decreased with age (Table 3). The bias between observed age and modelled age was low (agreement = 77.9%, CV = 5.5% and APE = 6.5%).

Discussion

Ornate jobfish contribute to important fisheries in the tropical and subtropical waters of the Indo-West Pacific, particularly the Reunion Island artisanal fisheries. For this reason, data on the biology of this species are key for effective stock assessment for global and local populations (Froese 2006). The length range observed in this study was similar to that of other studies on this species in the Pacific Ocean (Nanami 2011). This study showed that total, fork, and standard lengths are highly correlated, which makes data based on lengths taken from different methods interchangeable. Sex in this study did not show an effect on morphometric variables, contrary to the data observed in the China Sea (Nanami 2011). This difference could be due to environmental conditions and genetic traits of ornate jobfish stocks from different geographical areas and sampling periods. Fish body measurements may change with reproduction phase (gonad development and spawning period) or feeding activities (food availability and feeding rate; Wootton 1990). The length–weight relationship showed a significant positive allometric growth (b = 3.15), confirming data from other geographical areas, such as the south-west of Japan (b = 3.12; Nanami, 2011), the Vanuatu islands (b = 3.22; Brouard and Grandperrin, 1984; Pakoa, 1998), the Mariana Archipelago (b = 3.14; Ralston, 1988) and the Gulf of Suez (b = 3.02; Mehanna, 2003).

Estimates of age in tropical deep-water fishes, especially snappers, have been obtained from several different calcified structures (scales, fin spines, vertebrae, whole otoliths and sectioned otoliths; Newman et al. 2016). In temperate waters, the formation of translucent zones is generally considered to occur during winter, whereas opaque zones are formed during the rapid growth periods of spring and summer. This pattern is linked to temporal fluctuations in metabolism and water temperature, where seasonal temperature variations exceed 3–4 °C (Høie et al. 2008; Neat et al. 2008). Consequently, the age of tropical deep-water fishes, where seasonal temperature differences are slighter, is more difficult to estimate than those of temperate waters fishes. In this study, ageing based on whole otolith were of similar accuracy than that from sectioned otoliths, contrary to what has been shown in other *Pristipomoides* species (Newman et al. 2016). Ages from this study ranged between 1 and 5 years. The only previous ageing work for ornate jobfish was by Fry et al. (2006), who used four specimens with estimated ages ranging from 4 to 6 years. Our study, therefore, showed a good agreement as to the possible maximum age for our target species.

This is the first study to document the von Bertalanffy growth function for *P. argyrogrammicus* (Figure 4). The lower growth and the growth performance index of this species compared with those from other *Pristipomoides* could be explained by: (1) species-specific differences; (2) variations in environmental conditions (such as temperature and food availability) among sampled areas; (3) different size distributions (probably caused by different types of sampling gear); and (4) sex ratio when there was sexual dimorphism. No significant difference in growth parameters for *P. argyrogrammicus* was observed between sexes, contrary to *P. multidens* (Newman and Dunk 2003). This result may make sex-specific fishery regulations unnecessary. Several growth studies of *Pristipomoides* species have been reported for the Pacific Ocean, but only one for the Indian Ocean, namely for *P. filamentosus* (Pilling et al. 2000). The growth difference between *Pristipomoides* species could also be accounted for by the more favourable environmental conditions of the Pacific

Ocean, where the maximum total length for *P. argyrogrammicus* was 45.7 cm (Anderson and Allen 2001).

Between 800 000 and 1 000 000 otoliths are sampled and analysed per year for stock assessment for an annual cost of approximately CAN$ 8 000 000 (Campana and Thorrold 2001; ICES 2011). The lengthiest step in this process is the preparation and the reading of otoliths. As routine age estimation for deep-water snapper populations from otolith readings is costly, other alternative approaches must be developed, such as age estimation from whole otoliths. Otolith biomineralisation results from interactions of many internal (physiological) and external (environmental) factors (Campana and Nielson 1985; Morales-Nin 2000; Allemand et al. 2007). Age may even be predicted by the otolith morphological features (Ochwada et al. 2008). Three variables describing whole otolith morphometry were significantly correlated in this study with the age of *P. argyrogrammicus.* When considering left or right otoliths, there was no difference in age estimates using their morphometric parameters. This result was expected, based on a study that showed that only the flatfishes had otolith shape differences between head sides (Mille et al. 2015). Among the morphometric parameters of whole otoliths, several authors have shown that a significant relationship between the otolith weight (Ow) and fish age exists (Boehlert 1985; Cardinale et al. 2000; Labropoulou and Papaconstantinou 2000; Arayaa et al. 2001; Cardinale and Arrhenius 2004; McDougall 2004; Ochwada et al. 2008; Steward et al. 2009; Beyer and Szedlmayer 2010; Williams et al. 2015; Mahé et al. 2016a). The species in these studies were long-lived , whereas *P. argyrogrammicus* is short-lived, with maximum observed age of five years, according to our observations. Otolith weight was the only parameter in this study taking into account growth in three dimensions. In similar studies, a significant relationship between otolith radius and fish age was observed in *Hippoglossoides platessoides* (Fossen et al. 2003) and *Trematomus newnesi* (Mahé et al. 2016b), attributed to the low thickness of the otolith. The relationship between age and the different morphometric parameters of otolith could change with time. Radtke et al. (1985) showed that age could be predicted by O_L and O_{Wl} with ~~a~~ good precision at the early life stages. For older fish, O_W was shown to be a better variable. For young *P. argyrogrammicus,* O_w had no significant effect on age estimation. For older individuals (Age 3 and Age 5), however, O_W was significant in age growth models. During the life of *P. argyrogrammicus,* the length and the width of the otolith increase with the fish length and after a certain age is reached, the otolith only continues to increase in thickness.

Our study shows the effectiveness in age estimation precision using several morphometric parameters of whole otoliths (Troynikov and Robertson 2005; Ochwada et al. 2008). The precision of 5.5% CV observed in this study was superior than the common level of precision in the ageing studies using conventional methods (CV = 7.6% from a review of 117 ageing papers, Campana 2001). The approach used in this study is less costly and faster when predicting age and it can be applied for many species. However, to estimate precision, our method must be calibrated with age-length keys derived from samples of the same region and-time.

Conclusion

Among snapper species, *P. argyrogrammicus* showed slower growth. Age estimation using morphological parameters of whole otoliths showed a good precision (CV = 5.5%), similar to that shown for other snappers, namely *Lutjanus campechanus* (Beyer and Szedlmayer 2010) and *Pristipomoides filamentosus* (Williams et al. 2015). However, using this technique requires calibration based on age readings using traditional techniques. We recommend age estimation using whole otoliths as an alternative method of ageing adult fish, especially short-lived fish from regions with data-poor fisheries.

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Figure legends

Figure 1: Total length-total weight relationship of *Pristipomoides argyrogrammicus* from Reunion Island; female: (black line, +), and male: (grey dashed line, x) (n=113).

Figure 2: Whole otolith of *Pristipomoides argyrogrammicus* (TL= 27 cm; catch date: July 2014) using reflected light. Growth increments are indicated by red crosses

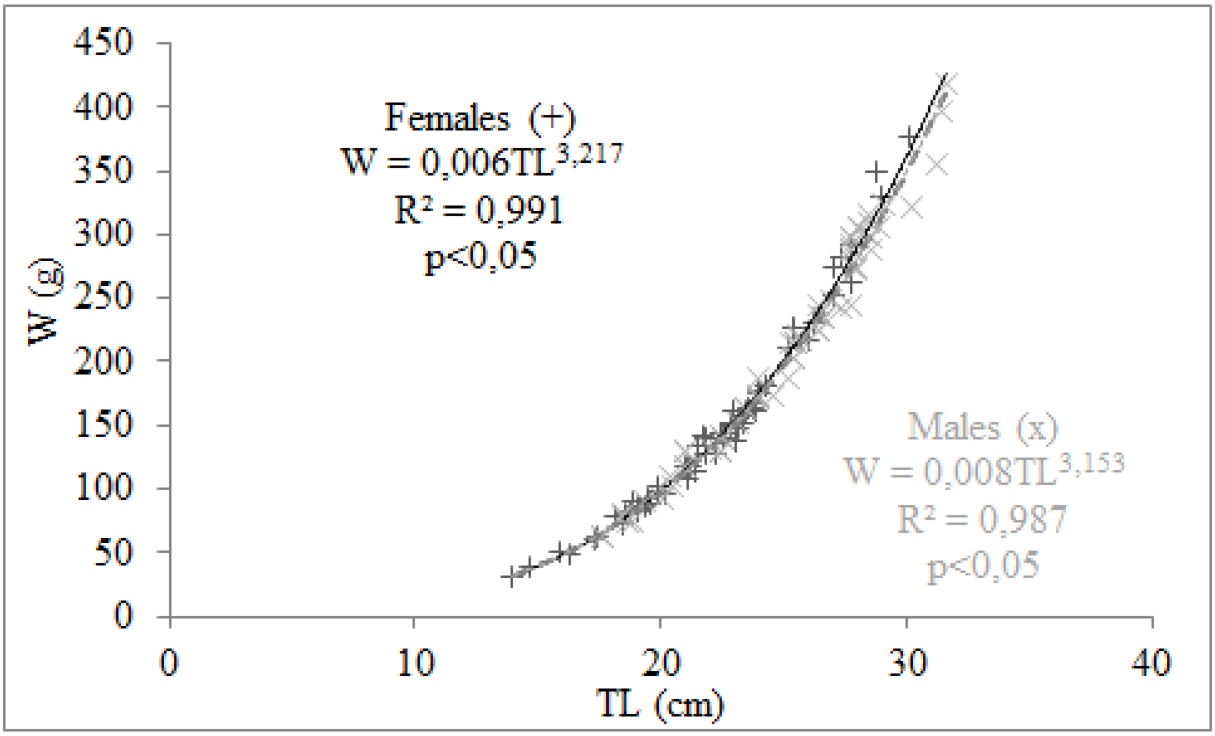

Figure 3: The von Bertalanffy growth curves of *Pristipomoides argyrogrammicus* from Reunion Island

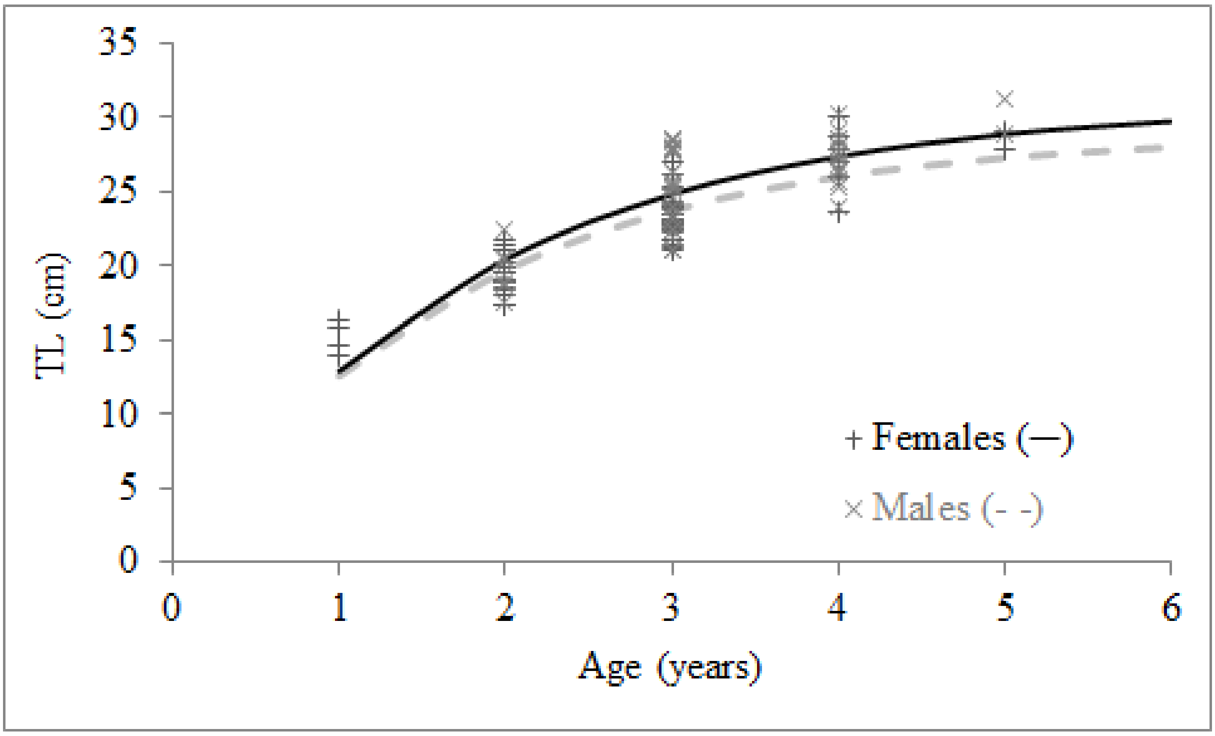

Figure 4: Growth comparison of different *Pristipomoides* species in the southern hemisphere (a) Ralston and Williams 1988; (b) Pilling et al. 2000; (c) Fry et al. 2006; (d) Manooch 1987). The value of growth performance index (φ') is expressed in the brackets.

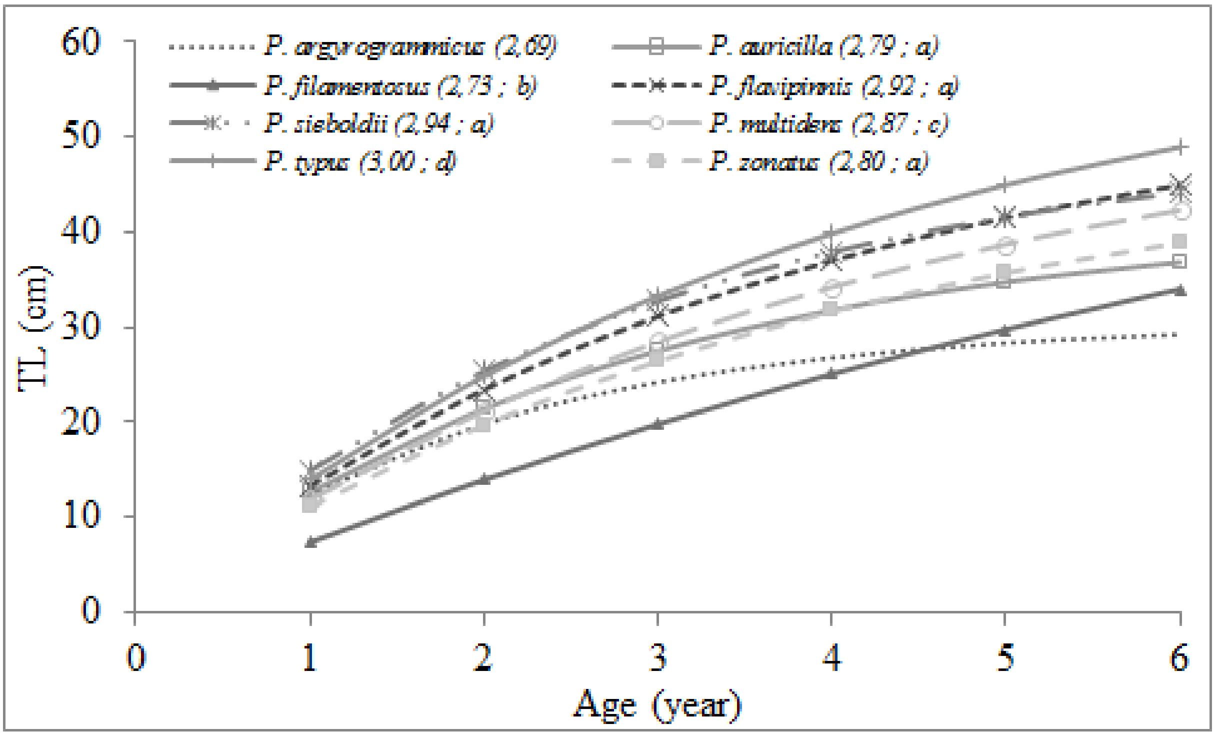

Table 1: General linear model age estimation summary statistics for *Pristipomoides argyrogrammicus* from Reunion Island. The factors are defined in the text

Factors	F	p
O_L	0.718	0.041
O_{WI}	7.091	0.009
O_A	14.616	$2\ 10^{-4}$
O_W	1.663	0.199
$O_L \times S$	0.389	0.534
$O_{WI} \times S$	0.065	0.799
$O_A \times S$	0.123	0.727
$O_W \times S$	1.292	0.258

Table 2: Summary statistics for the logistic model for age estimation of *Pristipomoides argyrogrammicus* from Reunion Island

Age group	Morphometric parameters			
	O_L	O_{WI}	O_A	O_W
G1	0.0020			
G2	0.0073			0.0046
G3	0.0264	0.0000	0.002	
G4	0.0008			
G5				0.0130

Table 3: Age error matrix of modelled versus estimated pairwise comparisons obtained from morphometric parameters of whole otoliths (n = 113). Numbers in tables are number of observations. Grey cells are 1:1 ratios

		Observed age (year)				
		G1	G2	G3	G4	G5
Modelled age (year)	G1	9				
	G2		21			
	G3		3	47	12	1
	G4		1	4	8	2
	G5				2	3