DOI: 10.3856/vol39-issue2-fulltext-11

Research Article

Age determination, validation, and growth of Brazilian flathead (*Percophis brasiliensis*) from the southwest Atlantic coastal waters (34º-41ºS)

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ABSTRACT. The age and growth parameters of Brazilian flathead, *Percophis brasiliensis*, from the southwest Atlantic coastal waters (34º-41ºS) were determined for samples collected in spring (n = 853; years 1998 and 2000) and winter (n = 596; year 2004), whereas age was validated through the edge analysis of otoliths collected in 2007 (n = 1367 otoliths). The indices of precision APE, V, and D were used to test the reproducibility, between agers, of the ages determined from 845 otoliths. Maximum determined ages were 19 years for males and 15 years for females. One opaque and one translucent band are laid down per year, in the sagittal otolith. According to the APE (0.668%), V (1.121%), and D (0.647%) indices, the age determination was consistent. Von Bertalanffy's growth parameters [males: spring (L_∞ = 58.1 cm, k = 0.26 year^{-1}, t_0 = -2.02 years), winter (L_∞ = 58.7 cm, k = 0.21 year^{-1}, t_0 = -2.90 years); females: spring (L_∞ = 65.2 cm, k = 0.29 year^{-1}, t_0 = -1.15 years), winter (L_∞ = 63.5 cm, k = 0.26 year^{-1}, t_0 = -2.01 years)] were significantly different between sexes and seasons. From the first year of life, females grow faster and reach greater lengths than males of the same age due, probably, to an asynchronism in the sexual maturity.

Keywords: Brazilian flathead, *Percophis brasiliensis*, age determination, otolith, validation, growth, southwest Atlantic.

Determinación de edad, validación y crecimiento del pez palo (*Percophis brasiliensis*) de aguas costeras del Atlántico sudoccidental (34º-41ºS)

RESUMEN. Se determinó la edad y los parámetros de crecimiento del pez palo, *Percophis brasiliensis*, de aguas costeras del Atlántico sudoccidental (34º-41ºS) en muestras obtenidas durante primavera (n = 853; años 1998 y 2000) e invierno (n = 596; año 2004), mientras que la edad fue validada mediante análisis del tipo de borde de otolitos colectados durante 2007 (n = 1367 otoliths). Los índices de precisión APE, V, y D fueron usados para probar la reproducibilidad, entre lectores, de las edades determinadas a partir de 845 otolitos. Las edades máximas determinadas fueron 19 años para machos y 15 años para hembras. Una banda opaca y una translúcida se depositan anualmente en el otolito sagitta. Los índices APE (0,668%), V (1,121%) y D (0,647%) indican que la determinación de la edad fue consistente. Los parámetros de crecimiento de Von Bertalanffy [machos: primavera (L_∞ = 58,1 cm, k = 0,26 año^{-1}, t_0 = -2,02 años); invierno (L_∞ = 58,7 cm, k = 0,21 año^{-1}, t_0 = -2,90 años). hembras: primavera (L_∞ = 65,2 cm, k = 0,29 año^{-1}, t_0 = -1,15 años); invierno (L_∞ = 63,5 cm, k = 0,26 año^{-1}, t_0 = -2,01 años)] fueron significativamente diferentes entre sexos y estaciones. A partir del primer año de vida, las hembras crecen más rápido y alcanzan mayores longitudes que los machos de la misma edad debido, probablemente, a un asincronismo en la madurez sexual.

Palabras clave: pez palo, *Percophis brasiliensis*, determinación de edad, otolito, validación, crecimiento, Atlántico sudoccidental.

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INTRODUCTION

The Brazilian flathead *Percophis brasiliensis* (Quoy & Gaimard) is a demersal fish species (Olivier *et al.*, 1968) that inhabits southwest Atlantic coastal waters. Its distribution extends from 23°S (Rio de Janeiro, Brazil) to 47°S (north of Santa Cruz Province, Argentina) (Gosztonyi, 1981; Cousseau & Perrotta, 2004). In the southern area of its distribution (34º-41ºS), it is one of the most important species caught by the coastal commercial fishery (Lasta *et al.*, 1999; Carozza *et al.*, 2001; Fernández-Aráoz *et al.*, 2004). Despite the importance of this species and the increasing captures that have been detected during the last years (Rico & Perrotta, 2009), few studies have been focused to obtain relevant biological information for its fisheries management. There are information about feeding (San Román, 1972; Bergonzi, 1997), growth (Tomo, 1969; San Román, 1974; Perrotta & Fernández-Giménez, 1996), distribution (Fernández-Giménez, 1995; Rico & Perrotta, 2006) and reproduction (Macchi & Acha, 1998; Militelli, 1999; Militelli & Macchi, 2001; Rodrígues *et al*., 2007). For successful fisheries management is very important to evaluate the fish population state. Studies on age determination and growth parameters estimation, amongst others, are fundamental to knowledge of population dynamics (Sparre & Venema, 1995; Cotter *et al.*, 2004; Dulvy *et al.*, 2004; Begg *et al.*, 2005).

The age and growth parameters of Brazilian flathead have been determined through the counting of the otolith rings (Tomo, 1969; San Román, 1974; Perrotta & Fernández-Giménez, 1996). However, none of these authors reported the growth parameters of each sex nor validated the determined ages. In marine teleost fishes it is assumed that growth increments are laid down annually on hard parts, such as scales or otoliths, and the age is determined by counting the rings that are present in these hard structures (Jones, 1992; Campana & Thorrold, 2001). Errors in the assignment of age may contribute to overexploitation of a stock or species, often through underestimating true age and producing optimistic estimates of growth and mortality rates. Consequently, validation of age readings is a requirement for manage stocks, particularly for those being assessed by means of age-structured models (Campana, 2001; Begg *et al.*, 2005).

Therefore, the aims of this study were determine the age of males and females of Brazilian flathead, validate it, obtain the growth parameters of each sex (in spring and winter) and compare it statistically (between sexes, in each season; and between season, for each sex). The seasonal migration of Brazilian flathead, associated to its reproduction activity in the salinity front located within the southwest Atlantic coastal water (34º-41ºS) (Macchi & Acha, 1998; Militelli & Macchi, 2001), could allow differences in the estimated growth parameters. Detect, therefore, these differences is important at the time of using age-length keys for transforming length data in age data. This study represents the first attempt to validate Brazilian flathead's age determination and to estimate the growth parameter of each sex by season.

MATERIALS AND METHODS

Age determination

Samples were collected from southwest Atlantic costal waters (34-41ºS) by bottom trawling in waters from 7 to 50 m depth (Fig. 1), during INIDEP cruises carried out in spring (1998, 2000) and winter (2004). Age was determined to 1449 specimens, 853 in spring (439 males, 414 females) and 596 in winter (251 males, 345 females). Of each specimen total length (TL) and sex (by macroscopic examination of the gonads) were recorded, while sagittal otoliths were removed from the fish and stored dry in paper envelopes for age determination. Randomly, one sagittal otolith from the pair was embedded in opaque epoxy resin and sectioned transversely through the core with a micro-cutter (Maruto MC-201) obtaining thus thin transverse sections of 0.5 mm in thickness. The opaque bands of these sections were counted by two independent readers under incident and transmitted light using a stereomicroscope at 40X magnification. Age was determined to the nearest lower without knowledge of the length and sex of the specimen. If the two independent readings differed, then the otolith was considered unreadable. We used the average percent error (APE), the coefficient of variation (V) and the index of precision (D) (Beamish & Fournier, 1981; Chang 1982) to test the reproducibility between agers of the ageing process, from 845 otoliths (620 spring, 225 winter).

Age validation

The validation of the annual formation of opaque bands was established by examining the monthly proportions of opaque or translucent edges (Dannevig, 1933) throughout a year. Monthly samples (1367 otoliths) from commercial fisheries in the same area, from January to December 2007, were use to validate the age.

Growth

The Von Bertalanffy growth model (1938) was fitted, in each season, to observed length-at-age data of

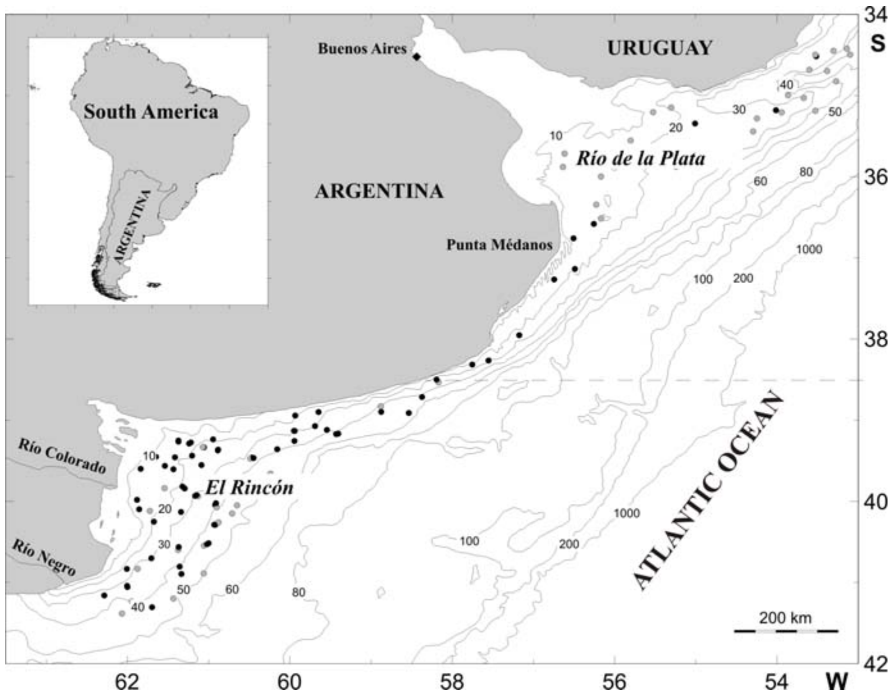

Figure 1. Study area showing their bathymetry (m) and the location of the sampling stations during spring (●) and winter (●).

Figura 1. Área de estudio indicando la batimetría y localización de las estaciones de muestreo durante primavera (●) e invierno (●).

males and females by nonlinear regression $TL = L_\infty (1 - e^{-k(t - t_0)})$; where "*TL*" is the total length (cm) at age *t* (years), "L_∞" the mean maximum total length (cm), "*k*" a growth rate parameter (year^{-1}) and "t_0" the theoretical age (years) at zero length. The likelihood ratio test (LRT) was used to estimate the growth parameters (L_∞, *k*, t_0) and to compare the growth curves (Aubone & Whöler, 2000). The approximate growth parameter values required by LRT were obtained following Gulland & Holt's methodology (1959) for L_∞ [male (spring = 57.6 cm, winter 63.5 cm), female (spring = 63.3 cm, winter 62.1 cm)] and von Bertalanffy's methodology (1934) for *k* [males (spring = 0.28 year^{-1}, winter = 0.21 year^{-1}), female (spring = 0.43 year^{-1}; winter = 0.29 year^{-1})] and t_0 [males (spring = -1.93 years; winter = -1.54 years), female (spring = -0.04 years, winter = 1.79 years)] (Sparre & Venema, 1995). These approximate values were also used to evaluate the goodness of fit of different growth models through the Quasi-Newton Method (QNM) of the Statistica® 6 Program. QNM was also used to estimate the goodness of fit of the selected growth model to the observed length-at-age data. All statistical inferences were based considering an alpha error level of 5% ($\alpha = 0.05$).

RESULTS

Age determination

Of the 1467 otoliths that were examined, 1449 were considered readable (98.8% of coincidence between readers). The average percent error (APE = 0.668%), the coefficient of variation (V = 1.121%) and the index of precision (D = 0.647) indicate that the determination of age was consistent. All the spring otoliths sections showed opaque bands at the edge, whereas the 99.2% of the winter otoliths showed a translucent one. The first band next to the core was not as well defined as the others and in the 95.4% of the otoliths it was opaque. In some cases this band was very much thicker (or very much thinner) than the second opaque band, in other cases was composed of 1 to 3 opaque bands separated by much thinner translucent bands, or was less visible than the other opaque bands, or was present on one side of the sulcus. This band was only considered if it was present inside the sulcus.

The age and length ranges of each considered group of Brazilian flathead specimens were: males [spring (0-14 years), (24-61 cm); winter (0-19 years), (26-63 cm)], females [spring (0-14 years), (20-67 cm); winter (0-15 years), (23-73 cm)]. Both sexes showed, in each season, unimodal age frequency distributions: males showed a modal value of 2 years in both seasons, whereas spring modal value of females (2 years) was smaller than the one of winter (4 years) (Fig. 2).

Age validation

The monthly proportions of the sagittal otoliths' edge types showed that the opaque-band formation begins in September and it remains present at the otolith edge until February; from this month on, the translucent band begins to lay down and it is present at the otolith's edge until September, when the opaque-band formation begins (Fig. 3). This beginning of the opaque band formation is earlier in males than in females. These results show that, annually, one opaque and one translucent band are deposited at the edge of the sagittal otoliths and, therefore, one opaque plus one translucent band represents 1 year of the fish's life.

Growth

The von Bertalanffy growth model showed a good fit to the observed length-at-age data (Table 1): females are larger than males of the same age from the first year of life (Figs. 4a y 4b). At this age, both sexes attain 50% of its maximum total length. Comparison of growth parameters for both seasons showed significant differences between sexes (LRT, $P < 0.01$).

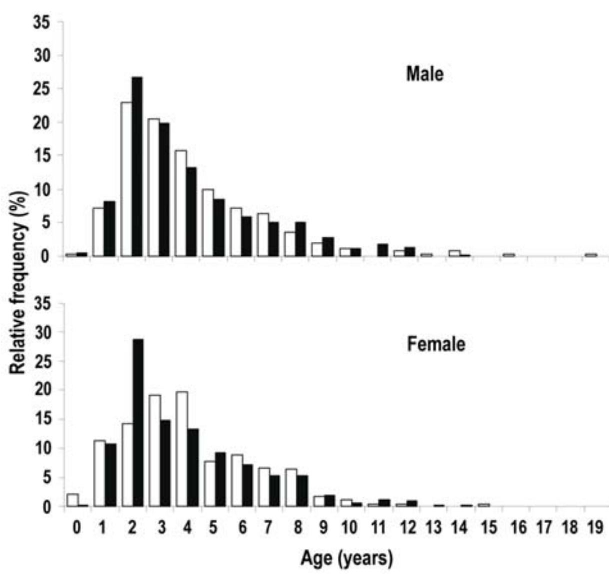

Figure 2. Age frequency distributions of males (a) and females (b) during spring (■) and winter (□).

Figura 2. Distribuciones de frecuencia de edades de machos (a) y hembras (b) durante primavera (■) e invierno (□).

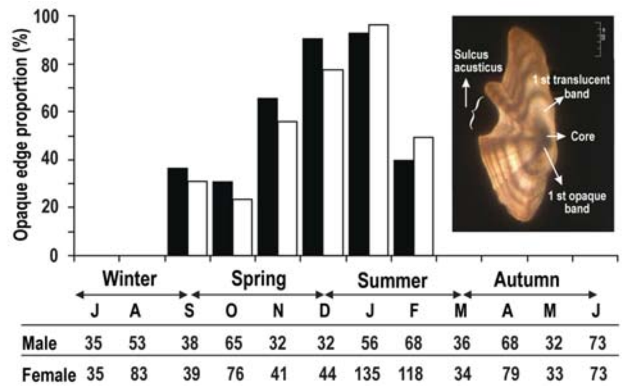

Figure 3. Monthly frequency of the opaque and translucent edges in the sagitta otolith of *Percophis brasiliensis* males (■) and females (□) during 2007 and the monthly sample size by sex. Transverse section of a sagitta, at core level, of a 5 years old specimen collected in winter.

Figura 3. Frecuencia mensual de bordes opacos y translucidos en otolitos sagitta de *Percophis brasiliensis* por sexo: machos (■) y hembras (□) durante el año 2007 y tamaños muéstrales mensuales por sexo. Sección transversal de un sagitta, a nivel del núcleo, de un espécimen de 5 años de edad colectado en invierno.

Females grow faster and attain larger sizes than the males [L_∞ ($P < 0.01$), k ($P < 0.1$), t_0 ($P < 0.01$), in spring; and L_∞ ($P < 0.01$), k ($P < 0.05$), t_0 ($P < 0.1$), in winter] (Figs. 4a-4b; Table 1). The difference between k's of both sexes was marginally significant in spring ($P = 0.06$).

Furthermore, significant differences in the estimated growth parameters of each sex were detected between seasons (LRT, $P < 0.05$ for males and $P < 0.01$ for females) (Figs. 4c-4d). The males showed marginally significant differences in k ($P = 0.077$) and t_0 ($P = 0.056$), but did not differ in L_∞ ($P > 0.5$); whereas the females showed significant differences in L_∞ ($P < 0.01$) and t_0 ($P < 0.01$), but did not differ in k ($P > 0.05$).

DISCUSSION

The high coincidence percentage among the two independent readers as well as the values of the precision indices indicate that the sagitta otolith of Brazilian flathead is easy to read, as happens with most of sagitta otoliths of template waters marine fishes (Panella, 1974; Ricker, 1979; Sparre & Venema, 1995). In spite of this, there were doubts about considering or not the first opaque band next to the core because it was not as well defined as the others. Peres & Haimovici (2004), studying chernia's *Polyprion americanus* (Bloch & Schneider) otoliths,

Table 1. Von Bertalanffy's growth parameters (L_∞, k, t_0) of *Percophis brasiliensis,* determination coefficient (r^2) estimated through LRT and QNM respectively, and sample size (n).

Tabla 1. Parámetros de crecimiento de von Bertalanffy (L_∞, k, t_0) de *Percophis brasiliensis,* coeficiente de determinación (r^2) estimado mediante de LRT y QNM respectivamente, y tamaño muestral (n).

Parameter	Males		Females	
	Spring	Winter	Spring	Winter
L_∞ (cm)	58.1	58.7	65.2	63.5
k (year^{-1})	0.26	0.21	0.29	0.26
t_0 (years)	-2.02	-2.90	-1.15	-2.01
n	439	251	414	345
r^2	0.82	0.66	0.84	0.67

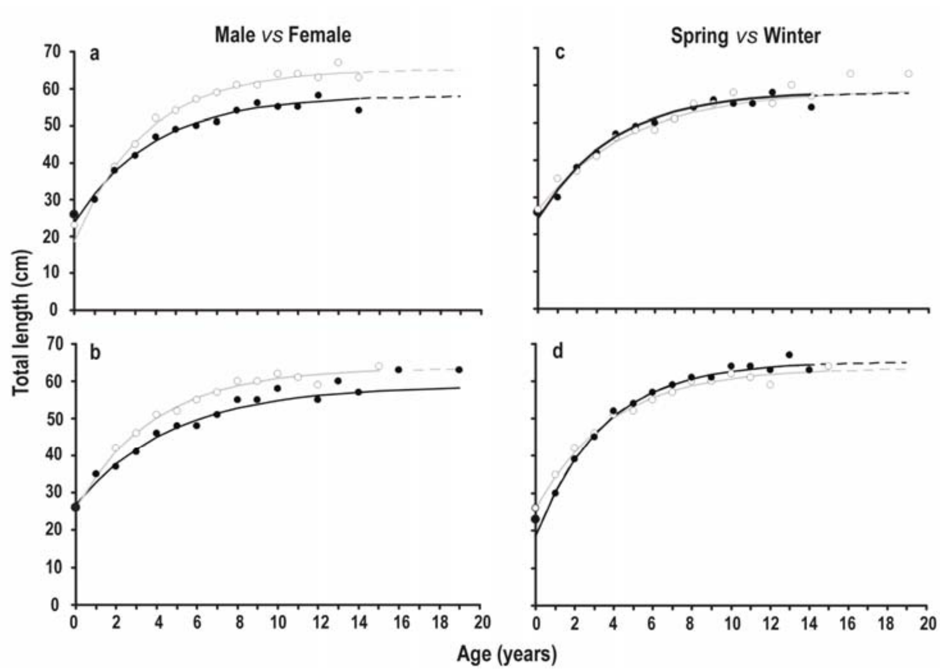

Figure 4. Growth curves of both sexes (● males and ○ females) of *Percophis brasiliensis* in a same season, a) spring and b) winter, and of each sex c) males and d) females by season (● spring and ○ winter). Observed mean total length-at-age and fitted von Bertalanffy growth model (dash line, predicted total length values for ages out of observed range). Sample sizes (n) of each comparison were: a) (● 439 and ○ 414), b) (● 251 and ○ 345), c) (● 439 and ○ 251) and d) (● 414 and ○ 345).

Figura 4. Curvas de crecimiento de ambos sexos (● machos y ○ hembras) de *Percophis brasiliensis* en una misma estación, a) primavera y b) invierno), de cada sexo c) machos y d) hembras por estación (● primavera y ○ invierno). Longitud total media por edad observada y modelo de crecimiento de von Bertalanffy ajustado (línea discontinua, valores de longitud totales predichos para edades fuera del rango observado). Tamaños muestrales (n) para cada comparación: a) (● 439 y ○ 414), b) (● 251 y ○ 345), c) (● 439 y ○ 251) y d) (● 414 y ○ 345).

considered it as a false band, and named it central area. However, the age determinations made to the nearest inferior age are not modified by considering or not this band. Future studies must be done to verify if this first opaque band is true or not. The maximum ages observed in this study (19 years for males and 15 for females) were higher than maximum ages registered for the species [6 years, Tomo (1969); 7 years, San Román (1974); 12 years, Perrotta & Fernández-Giménez (1996)].

It was verified that only one opaque and one translucent band are laid down annually in the sagittal otoliths of Brazilian flathead, which appear between September-February and during the rest of the year, respectively. This result is consistent with previous studies for other coastal species at the region e.g.

Micropogonias furnieri (Desmarest) (Cotrina, 1998), *Cynoscion guatucupa* (Cuvier) (Castelli-Vieira & Haimovici, 1993; López-Cazorla, 2000) and *Pogonias cromis* (Linnaeus) (Urteaga & Perrotta, 2001). The opaque-band (fast growth) formation period coincides, partially, with Brazilian flathead's reproductive period. Males' reproductive period (August-April) is wider than the females' (October-April) (Rodrígues, 2009). This difference could be responsible of the earlier onset of males' opaque-band formation.

The Von Bertalanffy growth model acceptably described ($r^2 \approx 0.7$) Brazilian flathead's growth, as generally occurs when this model is fitted to length-at-age data of adult specimens (Jones, 1992; Sparre & Venema, 1995). The estimated L_∞ (♂`s: 58.1 and 58.7 cm; ♀'s: 65.2 and 63.5 cm) values were lower than the values estimated previously by Tomo (1969) [L_∞ = 86.94 cm (pooled sexes); L_∞ = 84.70 cm (females)], by San Román (1974) [L_∞ = 86.2 cm (pooled sexes)], and by Perrotta & Fernández Giménez (1996) [L_∞ = 68.39 cm (pooled sexes; northern study area); L_∞ = 70.78 cm (pooled sexes; southern study area)] (Tables 1 and 2). On the other hand, the estimated k values (♂`s: 0.26 and 0.21 year^{-1}; ♀'s: 0.29 and 0.26 year^{-1}) were higher than those estimated by San Román (1974) [k = 0.170 year^{-1} (pooled sexes)] and by Perrotta & Fernández-Giménez (1996) [k = 0.186 year^{-1} (pooled sexes; northern study area); k = 0.145 year^{-1} (pooled sexes; southern study area)]; were also higher than those estimated by Tomo (1969) [k = 0.210 year^{-1} (pooled sexes); k = 0.220 year^{-1} (females)], with the exception of the males' k value of winter (k = 0.210 year^{-1}) which was similar to those values estimated by the latter author (Tables 1 and 2).

The lower L_∞ values estimated in this study could be a consequence of the greater number of > 9 years old specimens (age from which maximum total length seems to be reached) and of the greater longevity of them. In the case of k, differences could be consequence of the greater number of < 3 years old specimens and of its younger ages. The age and growth determinations done indicate that Brazilian flathead is a relatively long-lived, low-growing species; as most of the demersal species of the South Atlantic coastal water (34-41ºS) (Lasta *et al.*, 2000), like *M. furnieri* (*Age*max = 39 years; *k*max ≈ 0.20 year^{-1}; Carozza *et al.*, 2004), *C. guatucupa* (*Age*max = 23 years; *k*max ≈ 0.40 year^{-1}; Ruarte *et al.*, 2004), *Pagrus pagrus* (Linnaeus) (*Age*max = 16 years; *k*max ≈ 0.15 year^{-1}; Cotrina & Carozza, 2000) and *P. cromis* (*Age*max = 41 years; *k*max ≈ 0.18 year^{-1}; Urteaga & Perrotta, 2001).

Brazilian flathead showed differential growth from the first year of life (Figs. 4a-4b); in coincidence with San Román (1974) females are larger than males of the same age. Considering the age determinations done in this study and the length-at-maturity reported by Militelli (1999), males' first sexual maturity occurs when they are 1 years old (*TL*50% = 29.24 cm), while in females this happens when they are 2 years old (*TL*50% = 38.71 cm). This asynchronism in the sexual maturity could explain the differential growth developed for each sex because, from this event, the growth rate decreases markedly (Brett, 1979). The earlier onset of males' sexual maturity could be responsible for both the earlier decrease of their growth rate and, consequently, the lower total length reached because, after this event, they ought to channel surplus energy not only into growth, like females do up to 2 years old, but also into reproduction. This sexual dimorphism in growth, with females larger than males of the same age, is common in some

Table 2. *Percophis brasiliensis's* growth parameters (L_∞, k, and t_0) obtained, from von Bertalanffy's model, by previous studies in the southwest Atlantic coastal water (34º-41ºS).

Tabla 2. Parámetros de crecimiento de *Percophis brasiliensis* obtenidos (L_∞, k, and t_0), a partir del modelo de von Bertalanffy, por estudios previos en aguas costeras del Atlántico sudoccidental (34º-41ºS).

Reference	Sample			Sex	L_∞ (cm)	k (year^{-1})	t_0 (years)
	Area	Season	Type				
Perrotta & Fernández-Gimenéz (1996)	Northern SACS	Winter	Research	♂+♀	68.39	0.186	-1.956
Perrotta & Fernández-Giménez (1996)	Southern SACS	Winter	Research	♂+♀	70.78	0.145	-2.858
San Román (1974)	Inside SACS	All year round	Commercial	♂+♀	86.20	0.170	0.270
Tomo (1969)	Inside SACS	Not available	Commercial	♂+♀	86.94	0.210	0.160
Tomo (1969)	Inside SACS	Not available	Commercial	♀	84.70	0.220	0.035

coastal species that inhabit the South Atlantic coastal water (34º-41ºS), like *M. furnieri* (Carozza *et al.*, 2004) and *C. guatucupa* (Ruarte *et al.*, 2004).

Finally, differences in the growth parameters of each sex were detected between seasons. The seasonal differences in females' growth parameters (L_∞ and t_0) would be associated to their age-structure seasonal changes whereas the seasonal similarity in males' age-structure would explain the non-significant seasonal differences of their parameters (L_∞, k, t_0) [Figs. 2 and 4c-4d]. These seasonal changes in the female structure could be related to spring reproductive immigration of older female to the spawning area. Within the South Atlantic coastal water (34º-41ºS) the reproductive activity is associated to outer salinity front of the Rio de la Plata and El Rincon (Macchi & Acha, 1998; Militelli & Macchi, 2001; Rodrígues *et al.*, 2007). Consequently, these results indicate that an adequate age-length key is necessary for the estimation of Brazilian flathead age from length data; that is, a key that corresponds in sex and season with the sample of lengths that will be transformed. Dissimilar growth parameters between seasons have been detected in species which have seasonal migratory-age-dependent habits (Sparre & Venema, 1995). So, these results could be indicating that Brazilian flathead of the South Atlantic coastal water (34º-41ºS) is a species which have this kind of migratory habits, although studies with a greater temporal cover are necessary to confirm this hypothesis.

ACKNOWLEDGEMENTS

This study was partially published as part of a Licenciatura thesis by the Biodiversity and Experimental Biology Department, Universidad de Buenos Aires (UBA),Argentina, and was carried out at Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP-Mar del Plata), Argentina. Contribution INIDEP Nº 1663. We thank INIDEP Coastal Project for providing biological material and information, and Alicia Matthews for improving the language.

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Received: 27 May 2010; Accepted: 22 May 2011

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