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Size related changes in *sagitta* otoliths of *Australoheros facetus* (Pisces; Cichlidae) from South America

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Summary

The *Australoheros facetus*, locally known as 'chanchita', is the southernmost (38º44′S) distributed cichlid species in South America where it is eurytopic and abundant in the pampasic 'laguna', and an important dietary component of numerous piscivorous fishes and birds. The objective of the present study was to extend and correct the description of *sagitta* otoliths of *Australoheros facetus* and evaluate the occurrence of morphological and morphometric changes at different development stages. The *sagittae* were described morphologically and the morphometric analyses performed using the regression equation of allometric growth and discriminant analysis. The results of this analysis indicate that the *sagitta* of *A. facetus* acquires its definitive shape at 60 mm maturity, laboratory standard length (LS), which is near the lower limit of the size range achieved in laboratory conditions. The main difference compared to individuals below 60 mm LS can be seen in the general shape, type of dorsal and ventral rims, type of cauda ending, and presence of a groove at the posterior end. The presented results on ontogenetic changes in otolith morphology can be used in studies of trophic ecology to avoid overestimating the number of prey species found in the diet of freshwater piscivorous fishes and birds.

Introduction

The Cichlidae is one of the largest families of the order Perciformes, comprising about 1300 species found in Africa, India, the Middle East, Madagascar and America. Almost 400 species are in South America, representing 10% of their freshwater ichthyofauna. The southern end of the 'del Plata' basin is the northern distribution limit of many neotropical fishes, including most cichlids. In Argentina, the family is represented by 45 formally described species (López et al., 2003) but new species are being continuously described (Gómez et al., 2009).

The cichlids are in the biological type of placement inhabiting quiet and vegetated waters, which were subdivided by Menni (2004) into the orbicular type (e.g. *Australoheros facetus, Gymnogeophagus* sp.) and predator type (elongated fishes, e.g. *Crenicichla* sp.).

Australoheros facetus (Jenyns, 1842), locally known as 'chanchita', is found in southern Brazil, Argentina and Uruguay and is the most southerly distributed cichlid species (38º 44′S) and an eurytopic fish abundant in pampasic 'laguna' (Gómez, 1996). As are many cichlids, this species is important in aquaculture and for ornamental purposes, and also used in bioassays because it is easy to handle and well adapted to captivity. *A. facetus* is an important dietary item for piscivorous fishes (Grosman et al., 2001) and birds, such as the biguá *Phalacrocorax olivaceus* (Gómez, pers. comm.). The study of the trophic ecology of piscivorous fishes is mainly based on the identification of prey by recognizing specific structures, e.g. bones and otoliths (Hecht, 1987; Gosztonyi and Kuba, 1996; Volpedo and Echeverría, 2000). Information on otoliths can be used to construct food webs in different aquatic ecosystems. There are few reports of otoliths from freshwater fish species of Argentina (Martínez and Monasterio de Gonzo, 1991; Fuchs, 2008), and only one involving a cichlid species: *Australoheros facetus* (Mollo, 1981). Mollo's description is based on a few specimens of small size from only one laguna (n and size not indicated), and there are no meristic or morphometric references.

Although the morphology and morphometry of the *sagittae* are species-specific, they may show intraspecific differences, not only during ontogenetic development as reported for other eurytopic species like *Odontesthes bonariensis* Valenciennes and *Micropogonias furnieri* Demarest (Volpedo and Echeverría, 1999; Brown and Fuentes, 2001; Tombari et al., 2005) but also among individuals from different geographic regions (Volpedo and Echeverría, 1999; Volpedo, 2001; Tombari et al., 2005). Such variations are especially observed in the size, shape and topography of the inner face of the otolith, and have been related to different exogenous and endogenous factors (Paxton, 2000; Volpedo and Echeverría, 2003; Lombarte and Cruz, 2007; Volpedo et al., 2008).

The objective of the present study was to describe the *sagitta* otolith of *Australoheros facetus,* including a detailed characterization of the morphology and morphometry, and to evaluate possible changes in relation to the size of the fish.

Materials and methods

Specimens of *Australoheros facetus* were collected using trawl nets without selectivity from ten locations, the Adela 'laguna' (35°41′S; 57°59′W), Chis-Chis, Vitel, Salada de Monasterio and others which belong to the laguna system ''Encadenadas del Este'' in the Buenos Aires province, Argentina. Species identification was based on the key proposed by Casciotta et al., 2006. The standard length (LS) of each fish was recorded to the nearest mm. The *sagittae* were removed from the otic capsules for examination and measurement; they were drawn

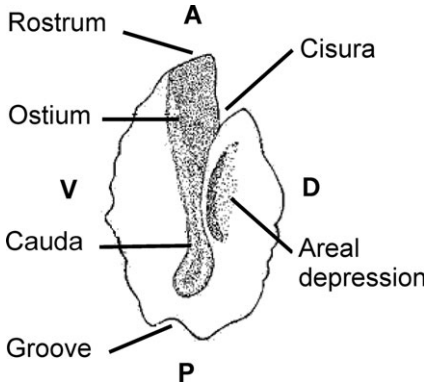

Fig. 1. Definition of morphological features of *sagitta* otolith, *Australoheros facetus*. A, anterior region; P, posterior region; D, dorsal margin; V, ventral margin

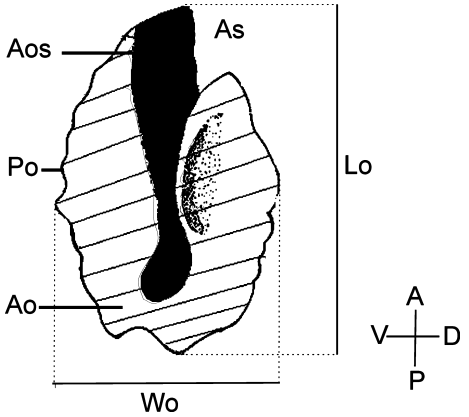

Fig. 2. Measured variables of *sagitta* otolith, *Australoheros facetus*. W_O, maximum width; L_O, maximum length; P_O, perimeter of otolith; A_O, otolith area; A_{OS}, *ostium* area; A_S, *sulcus* area. The scheme represents a left otolith; A, anterior region; P, posterior region; D, dorsal margin; V, ventral margin

and photographed from the inner and outer faces and in lateral view with a digital camera attached to a stereoscopic microscope.

A total of 71 otolith pairs of *Australoheros facetus* were analyzed. The morphological characters considered were: otolith general shape, types of rim, presence of rostrum and cisure, presence of a groove at the posterior end; topography of the inner face, type of *ostium*, position of *pseudocolliculum*, type of cauda ending and presence of dorsal areal depression (Fig. 1). The nomenclature proposed by Volpedo and Echeverría (2000) was used for the morphological analysis. The morphometric characters considered were: maximum length of the otolith (L_O), maximum width of the otolith (W_O), perimeter of otolith (P_O) in mm, and area of otolith (A_O), area of *sulcus* (A_S) and area of *ostium* (A_{OS}), in mm^2 (Fig. 2). The image analysis software Image-Pro Plus version 4.5.0.29 (Media Cybernetics, Inc.) was used for surface calculations. Some morphometric variables were analyzed using the regression equation of allometric growth (Huxley and Tessier, 1936) calculated according to Sokal and Rohlf (1995). In addition, the morphometric characters of the *sagittae* were compared using discriminant analysis. The collection of *sagittae* is deposited in the Laboratory of Experimental Biology, Division of Ichthyology, Museo Argentino de Ciencias Naturales ''Bernardino Rivadavia'' (MACN), Buenos Aires, Argentina.

Results

The *sagitta* otoliths of *A. facetus* analyzed in this study showed the morphological characteristics: subcircular to oblong shape, dorsal and ventral rims of variable shape, conspicuous cisure and *rostrum*, convex inner face, *sulcus* divided into *ostium* and *cauda*, funnel-shaped *ostium*, and presence of an *anterocaudal pseudocolliculum*. The *cauda* is wide, its distal end is curved towards the ventral rim, and it has a dorsal areal depression. The outer face is slightly concave and has folds and radial striae. The otolith width is approximately 59% of the total otolith length.

Based on the observed morphological characters of the otoliths, the studied specimens could be separated into three groups: (i) Size range 11.5–49.1 mm LS: *Sagitta* with cauda has a closed distal end and with no groove. (ii) Size range 53.7–60.7 mm LS: *Sagitta* with or without open cauda and an incipient groove at the level of the *cauda*. (iii) Size range 61.8–100 mm LS: The *cauda* has an open distal end with groove.

Regression equations were obtained for these three groups (Table 1). The dependence of Lo on LS is best described by a power function showing a statistically significant positive relationship ($P < 0.05$). When all individuals are included

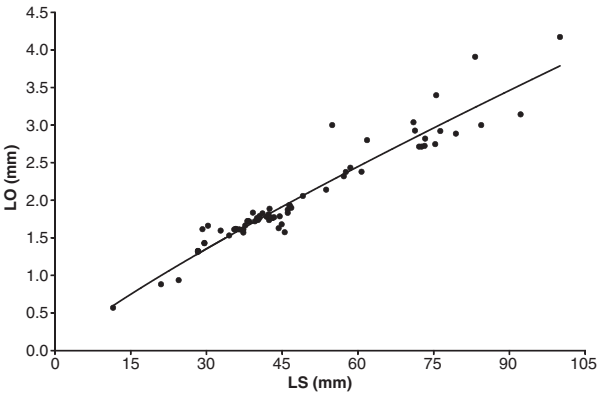

Fig. 3. Dispersion diagram and regression (power function) of maximum length of *sagitta* (L_O) in standard length (LS), *Australoheros facetus*

Groups	Morphological characters	Size range, mm	Regression equation	R^2	Statistical significance
a	CC + AG	11.5 to 49.1 (n = 50)	$L_o = 0.079LS^{0.83}$	0.88	$P < 0.01$
b	CC or OC + IG	53.7 to 60.7 (n = 6)	–	0.01	$P > 0.05$
c	OC + PG	61.8 to 100 (n = 15)	$L_o = 0.099LS^{0.79}$	0.48	$P < 0.05$

CC, cauda closed, AG, absent groove, IG, incipient groove, OC, open cauda; PG, present groove, n, total number of individuals in the corresponding size group.

Table 1
Relation of otolith size to fish size for three size groups of *Australoheros facetus,* separated according to morphological differences of the otoliths

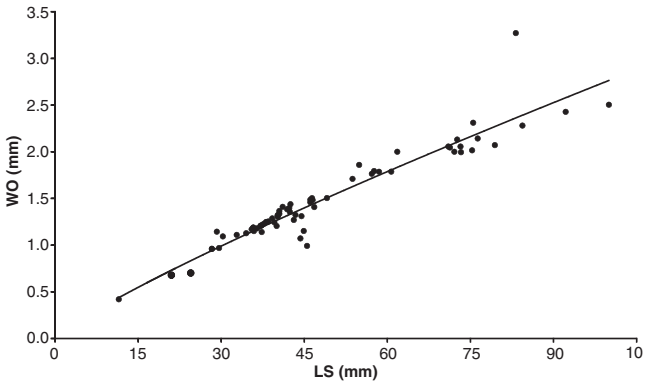

Fig. 4. Dispersion diagram and regression (power function) of maximum width of *sagitta* (W_O) on standard length (LS), *Australoheros facetus*

(n = 71), the regression analysis leads to the equation: $L_O = 0.0739.\ LS^{0.8548}$ ($R^2 = 0.937$), indicating a negative allometry (Fig. 3). Likewise, a significant and positive relationship ($P < 0.05$) was found between maximum width of the otolith (W_O) and LS, with $W_O = 0.0545.\ LS^{0.8526}$ ($R^2 = 0.929$) (Fig. 4).

Discriminant analysis (DA) of the morphometric characters separated fish into two categories of standard length: shorter than 60 mm and higher than 60 mm (Table 2). The first component explains 100% of this variation and is principally defined by the area of the otolith (A_O), with an eigenvector of 0.85. The cross-classification table indicates a small error in the assignment of fish to each LS category (Table 3).

Table 2
Results of morphometric analysis for two size groups of *Australoheros facetus* defined by discriminant analysis

	Category 1	Category 2
LS (mm)	< 60	> 60
n	55	17
	Mean ± SD	Mean ± SD
LS (mm)	39.69 ± 8.73	80.25 ± 18.62
L_o (mm)	1.72 ± 0.35	3.26 ± 1.08
W_o (mm)	1.26 ± 0.26	2.30 ± 0.56
A_o (mm^2)	1.58 ± 0.55	6.35 ± 4.26
P_o (mm)	5.06 ± 0.94	10.56 ± 3.36
A_s (mm^2)	0.42 ± 0.16	1.78 ± 1.33
A_{os} (mm^2)	0.19 ± 0.08	0.87 ± 0.71

LS, standard length; n, number of fish measured; SD, standard deviations of measured variable; W_o, maximum width of the *sagitta*; L_o, maximum length of the *sagitta*; P_o, perimeter of otolith; A_o, otolith area; A_{os}, *ostium* area; A_s, *sulcus* area.

Table 3
Results of discriminant analysis: eigenvalue, eigenvectors and cross-classification table for two separate size groups, *Australoheros facetus* (abbreviations see Table 2)

Eigenvalue		
Lambda	Value	Proportion
1	2.48	100
Eigenvectors		
Variables		e1
L_o		0.45
W_o		0.25
A_o		0.85
P_o		−0.47
A_s		−0.45
A_{os}		0.46
Cross-classification table		
Categories	1	2	Total	Error (%)
1	54	1	55	1.82
2	1	15	16	6.25
Total	55	16	71	2.82

It is notable that discriminate analysis provides a value of dividing the two categories within the size 'group b' with LS 53.7 to 60.7 (Table 1).

Specimens of less than 60 mm standard length (LS) had *sagitta* of subcircular shape, with the posterior end rounded and an incipient groove at the level of the *cauda,* which is wide and has a closed distal end, pointing towards the ventral rim (Fig. 5). In specimens over 60 mm LS the *sagitta* is oblong, with a slightly dentated dorsal rim and a smooth ventral rim; the posterior end of the otolith is irregular, with a groove at the level of the distal end of the *cauda*, which is wide, sinuous and with an open distal end (Fig. 6).

Discussion

The morphological pattern of the *sagittae* of *A. facetus* characterized in the present paper coincides with the description given by Gaemers (1984) for the family of Cichlidae, showing the particular type of anterocaudal pseudocolliculum of the synapomorphic character, which strongly indicates the monophyly of the family.

The general shape of the *sagitta* changed in relation to size, with the cauda developing from a closed to an open distal end

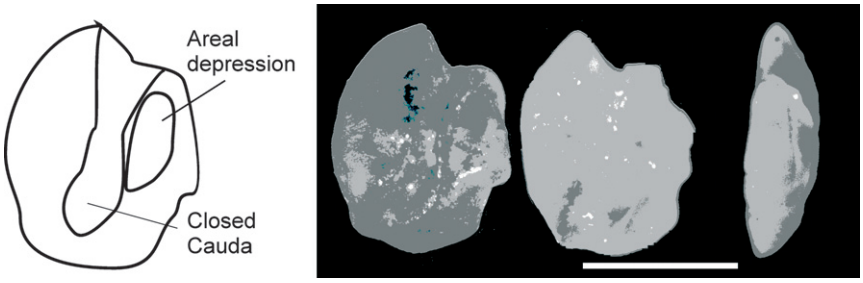

Fig. 5. Morphology from *sagitta* otolith of *A. facetus*. Category I LS < 60 mm (44.1 mm). Scale bar: 1mm. Left to right: Drawing and photograph of internal face of right otolith, external face and dorsal side view of left otolith

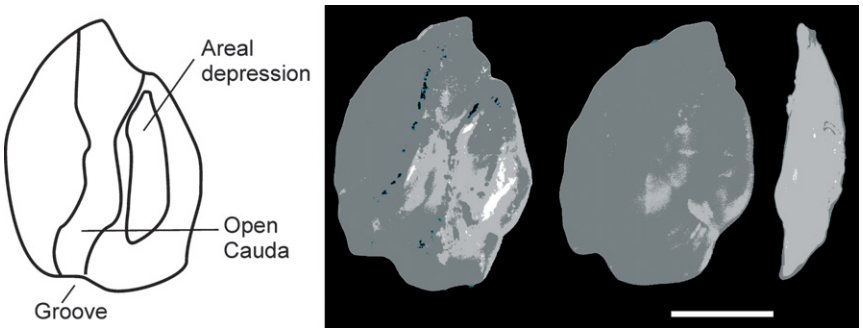

Fig. 6. Morphology from otolith *sagittal*, *Australoheros facetus*. Category II LS > 60 mm (76.3 mm). Scale bar: 1 mm. Left to right: Drawing and photograph, internal face of right otolith; external face and dorsal side view, left otolith

and a groove developing at the posterior end of the otolith. The definitive morphology is attained at 60 mm LS, which is near the lower size limit of sexual maturity under laboratory conditions.

The presented results on ontogenetic changes in otolith morphology can be used in studies of trophic ecology to avoid overestimation of the number of prey species found in the diet of freshwater piscivorous fishes and birds.

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