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Short communication

Assessing the use of two southwestern Atlantic estuaries by different life cycle stages of the anadromous catfish *Genidens barbus* (Lacépède, 1803) as revealed by Sr : Ca and Ba : Ca ratios in otoliths

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Introduction

The marine catfish *Genidens barbus* (Lacépède, 1803) (Siluriformes, Ariidae) is an anadromous species inhabiting estuaries and the marine continental shelf from Brazil to Argentina (17°00′S–40°32′S), and is considered to be one of the most important fish resources in Uruguay, Brazil and Argentina (Velasco et al., 2007; MINAGRI, 2013). Reis (1986) suggested that the adults migrate to the Lagoa dos Patos estuary (31°54′S–52°05′W, Brazil) from an age of 8–9 years to breed. After females spawn in freshwater, males return to the estuarine waters of the lagoon system with the eggs inside their oropharyngeal cavity (Reis, 1986; Velasco and Reis, 2004). Juveniles are released into the lower estuary waters, after which the adult males migrate to the continental shelf. Velasco et al. (2007) have suggested that juveniles live in the estuary until the age of 3–4 years, when they migrate to the ocean. However, little is known about the displacements and environments frequented by marine catfish throughout ontogeny in the remaining estuaries of the southwestern Atlantic Ocean.

In the last decade, the strontium : calcium (Sr : Ca) and barium : calcium (Ba : Ca) ratios of fish otoliths (complex polycrystalline apposition structures located in the inner ear and composed mainly of calcium carbonate) has been used to study fish movements between estuarine environments with great spatial variations in salinity, because those ratios are closely related to this water parameter (e.g. Brown and Severin, 2009). In particular, the otolith Sr : Ca ratio is positively correlated with water Sr : Ca ratio and salinity (e.g. Brown and Severin, 2009), while the otolith Ba : Ca ratio is negatively correlated with water salinity (e.g. Miller, 2011). These layers of material are deposited in the otoliths continuously, thus the quality of such material reflects the different water masses the fishes live in during each period.

The objective of this study was to assess the long-term patterns of estuarine and estuarine-to-continental shelf use by *G. barbus* in two estuaries in the southwestern Atlantic Ocean, using Sr : Ca and Ba : Ca ratios in otoliths.

Materials and methods

A total of five adult fish (total length: 54.0–78.1 cm) were caught with gillnets in the Lagoa dos Patos estuary in Brazil, and six adult fish (total length: 64.0–79.2 cm) were collected with longlines in the De la Plata River estuary in Argentina-Uruguay during October 2012 (Fig. 1). The pair of *lapilli* otoliths were removed from each fish, washed with Mili-Q water, dried and embedded in epoxy resin, ground in the sagittal plane to expose the core, then polished with diamond paper. The number of rings in each section was counted by two independent observers under a stereomicroscope (Leica® EZ4-HD, Leica Microsystems, Singapore) at 40× magnification (there was 100% of agreement between the two readers). Age determination by counting the ring number in *lapilli* otoliths of *G. barbus* was validated by Reis (1986). Subsequently, the otoliths were rinsed with Milli-Q water and dried prior to the laser ablation ICP-MS analysis. A New Wave UP193FX (193 nm excimer laser) LA system was coupled to an Agilent 7500ce Quadrupole ICP-MS in order to determine the chronological variation of ^{88}Sr, ^{138}Ba and ^{43}Ca throughout ontogeny. The otolith sections were cleaned according to standard protocols and then placed in the LA chamber. A linear raster scan ablation (width: 35 μm) was taken along the longest radius of the otolith. The laser was set at a pulse rate of 10 Hz with and traveled at 5 $\mu m\ s^{-1}$. External calibration was performed using the USGS carbonate reference material MACS-3 (synthetic calcium carbonate with marine carbonate-like minor element component). The NIST610 and NIST612 silicate glass reference materials were run as a secondary reference, quality check material and drift monitor. Drift was <5% for all analyses throughout each session. Finally, the element : Ca ratios were calculated and the profiles constructed for each fish.

Results

The obtained profiles were highly variable (Fig. 2). All fish (except the *f*) showed an increase in the otolith Sr : Ca ratio and a decrease in the otolith Ba : Ca ratio during the first

Fig. 1. Sampling sites of marine catfish *Genidens barbus*. 1) De la Plata River estuary (Argentina-Uruguay); 2) Lagoa dos Patos (Brazil)

year of life, indicating their displacement from relatively low salinity waters to higher salinity waters.

In the specimens *b–e* from De la Plata River estuary the otolith Sr : Ca ratio increased until the age of 1 or 2 years (2.5×10^{-3}–$4.9.5 \times 10^{-3}$), then decreased markedly between the ages of 3 and 5 years and the ages of 6 and 8 years ($<1.9 \times 10^{-3}$), when peaks in the otolith Ba : Ca ratio were evident ($>0.01 \times 10^{-3}$). The latter pattern indicates the movement of fish into low salinity waters (fresh or brackish waters). A peak in the otolith Sr : Ca ratio was observed for the specimens *c–e* at the age of 5 years (5.2×10^{-3}–6.5×10^{-3}) and the specimen *b* at the age of 8 years (6.2×10^{-3}). This indicates that they migrated to the more saline waters of the continental shelf. The fish *a* showed fluctuations in the level of Sr : Ca at about 2×10^{-3} to 10 years, indicating the permanence in brackish water. After 10 years of age they will have migrated to waters with lower salinity (low Sr : Ca ratio). The specimen *f* showed levels of Sr : Ca and Ba : Ca low and constant up to 7 years (low salinity waters), and high and variable from age 7 years onwards (brackish water or continental shelf).

On the other hand, all specimens from Lagoa dos Patos (*g–i*) showed relatively low levels of Sr : Ca ($<2.3 \times 10^{-3}$) and high values of Ba : Ca (0.01–0.14×10^{-3}) in their life time, indicating a dependence on low salinity waters. The specimens *j* and *k* showed an increase in the otolith Sr : Ca ratio until the age of 4 and 1 year, respectively; these fish showed a decrease in the Sr : Ca ratio from the age of 4 or 5 years onwards.

Discussion

Our results show that the migratory behavior of the marine catfish *G. barbus* is very complex and highly variable among individuals. The estuarine dependence of specimens *f–i* was evident. Some specimens such as *a* possibly spent much of their lives in slightly higher saline waters. This might be a reflection of the oceanographic characteristic of the De La Plata estuary: a wide and variable estuary, largely influenced by the off-shore dynamics of the subtropical convergence and the strong continental runoff (Piola et al., 2000).

Estuarine dependencies were reported by other authors for a euryhaline species such as *Microponias furnieri* (Albuquerque et al., 2012) in the same study area, mullets in different estuaries of the Gulf of Mexico (Ibáñez et al., 2012), and for some diadromous fish such as *Salvelinus alpinus*, *Salmo trutta* (Arai et al., 2002) and *Lycengraulis grossidens* (Mai et al., 2014). Mai et al. (2014) suggested that the decision to migrate or remain resident is an adaptive response to temporal fluctuations in resource availability or predation pressure, and any individual fish will attempt to maximize its evolutionary fitness. However, studies evaluating the costs and benefits of migratory or resident behaviors are scarce (Mai et al., 2014). Gomes and Araújo, 2004 indicated that the catfish of the Ariidae family are by far the dominant species in the estuaries of South America. According to these authors, the estuaries are well known as one of the most productive of all aquatic ecosystems, and *G. barbus* could take advantage of such an environment because they are very well adapted to such systems due to their freshwater origins (Gomes and Araújo, 2004).

On the other hand, several specimens (*b–e* and *j*) moved into estuarine waters during the first year of life and lived in high salinity waters from age 5 years onwards (estuary or marine continental shelf). These patterns found in both study sites are consistent with those reported by Reis (1986) and Velasco et al. (2007).

In conclusion, *G. barbus* showed high plasticity in its displacement patterns in the southwestern Atlantic Ocean. Present results suggest the occurrence of different fish groups in that area, each with a particular migratory behavior: some specimens may undertake large migrations between the estuaries and the platform while others may have a higher degree of estuarine dependence. Such plasticity may be influenced by the environmental conditions and food availability in the

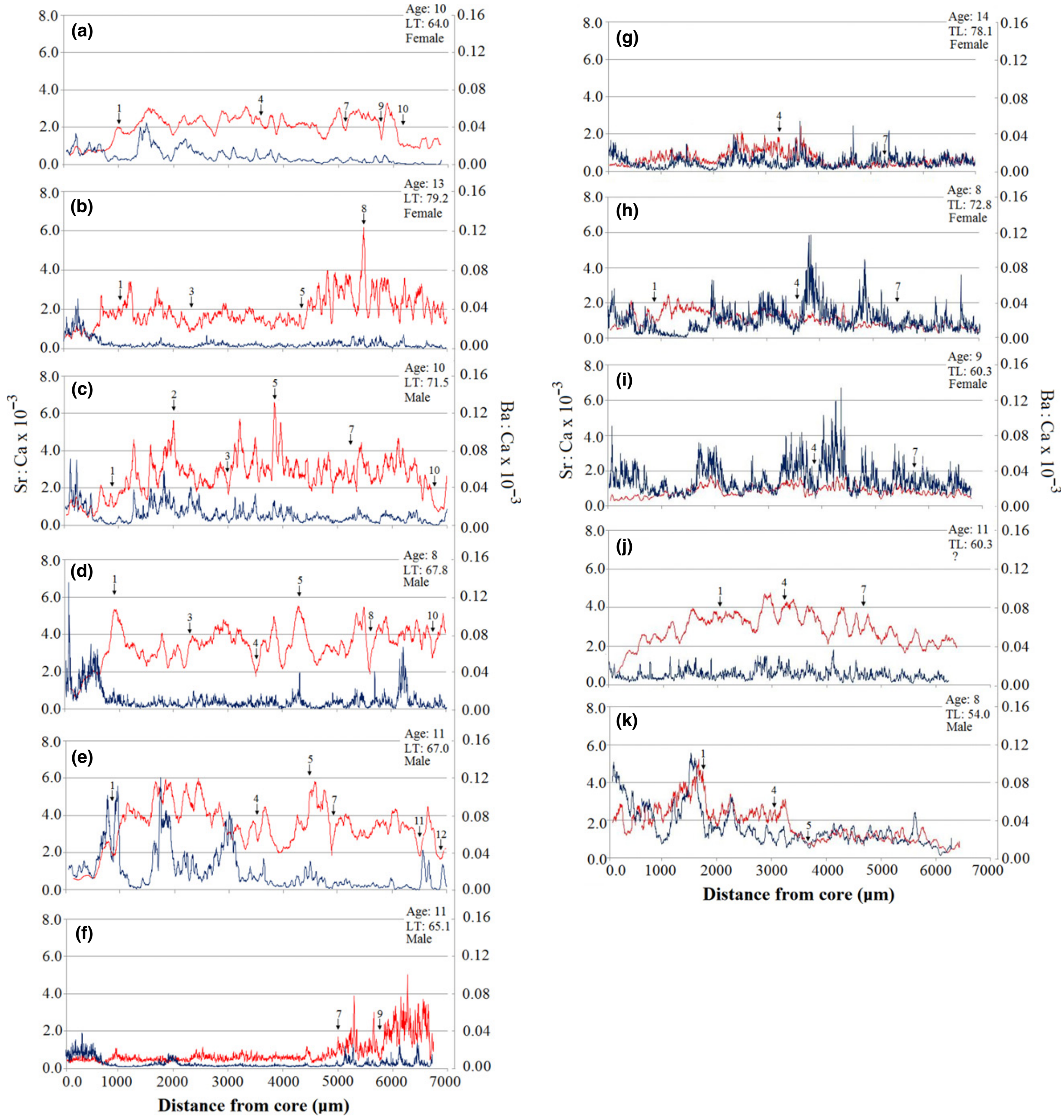

Fig. 2. Continuous profiles showing changes in otolith Sr : Ca (red line) and Ba : Ca (blue line) ratios throughout the ontogeny of *Genidens barbus* (sampling during October 2012). a–f, De la Plata River estuary (Argentina-Uruguay); j–k, Lagoa dos Patos (Brazil). Arrows = location of annuli (age). Arrows and numbers represent the point on the otolith scale (distance from core) that marks the respective age in years. TL = Total Length

different areas frequented by the species (Albuquerque et al., 2012).

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