

DO *SICYDIUM PUNCTATUM* ADULTS MOVE IN THE CARIBBEAN ESTUARIES? NEW INSIGHT FROM STRONTIUM ISOTOPES

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MIGRATIONS
OTOLITH MICROCHEMISTRY
STRONTIUM
INSULAR RIVERS
SICYDIINAE.

ABSTRACT. – Strontium isotopic variations ($^{87}\text{Sr}:^{86}\text{Sr}$) were investigated in otoliths of an amphidromous goby, *Sicydium punctatum*, coming from a tropical insular river and showing contrasted depositional patterns of barium:calcium in otolith ($\text{Ba}:\text{Ca}_{\text{otolith}}$). In our study, varying as well as non-varying $\text{Ba}:\text{Ca}_{\text{otolith}}$ individuals exhibited unchanged $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ throughout the adult phase with values typical of stream water flowing through volcanic substrate (0.7053 ± 0.0003). These results unambiguously discard the $\text{Ba}:\text{Ca}_{\text{otolith}}$ peaks as markers of migrations between freshwater and brackish estuarine water during the adult phase of the species and open on investigations of sources of variations on microhabitats or unknown physiological effects.

INTRODUCTION

The life traits of most amphidromous fish (McDowall 1988) living in the tropical insular rivers are not well-known despite their major contribution to the diversity of fish communities in the Indo-Pacific and the Caribbean insular systems. These species have the highest levels of endemism (Keith 2003) and undergo an increasing anthropogenic pressure. This leads researchers to explore the otolith composition in order to reconstruct their life traits and develop relevant management tools.

A recent study (Lord *et al.* 2011) on Gobiidae Sicydiinae species highlighted $\text{Sr}:\text{Ca}_{\text{otolith}}$ variations after the recruitment mark, which were thought to be linked to downstream migrations to the estuary and behavior plasticity of adults. Such migration at the spawning time is interpreted as an advantage as it may reduce the migration time for larvae to reach the estuary and increase their survival (Keith *et al.* 2008). Investigations on *Sicydium punctatum* Perugia, 1896 (Teleostei: Gobioidi), a Caribbean Sicydiinae species from Guadeloupe rivers (French West Indies), pointed out post-recruitment cyclic $\text{Ba}:\text{Ca}_{\text{otolith}}$ variations in the outer regions of otolith (Tabouret *et al.* 2011) but only for a part of the individuals sampled at a same location. $\text{Ba}:\text{Ca}_{\text{otolith}}$ variations were suggested to reflect individual migrations to the estuary zone since Ba concentrations are expected to be enhanced at mid to low salinities (Coffey *et al.* 1997). No increase of $\text{Sr}:\text{Ca}_{\text{otolith}}$ occurred concomitantly to the $\text{Ba}:\text{Ca}_{\text{otolith}}$ peaks, as it would be expected during a migration to the

brackish waters. However, at low salinity (< 5), $\text{Sr}:\text{Ca}_{\text{water}}$ may be too low to induce a significant increase of the $\text{Sr}:\text{Ca}_{\text{otolith}}$. In the absence of spatial and temporal water chemistry database, the hypothesis of behavioral plasticity for *S. punctatum* in these tropical environments was unresolved.

Sr and Ba, especially $\text{Sr}:\text{Ca}$, $\text{Ba}:\text{Ca}$ and $^{87}\text{Sr}:^{86}\text{Sr}$ ratios in the otolith, are commonly used to describe life traits of diadromous fish (Elsdon *et al.* 2008; Walther & Limburg 2012). These ratios are trapped in the otolith primarily, in proportion to the ambient water (Elsdon & Gillanders 2004). Even if physiological effect cannot be excluded in the case of $\text{Sr}:\text{Ca}_{\text{otolith}}$ and $\text{Ba}:\text{Ca}_{\text{otolith}}$ (Webb *et al.* 2012), $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ ratio is not expected to be fractionated neither by biological processes neither during the uptake from dietary or water sources (Barnett-Johnson *et al.* 2008; Walther & Limburg 2012). Additionally, in rivers draining volcanic substrates, $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ is systematically less radiogenic (Barnett-Johnson *et al.* 2008, Walther & Limburg 2012) than the seawater ratio (Allègre *et al.* 2010), allowing thereby migration to brackish waters to be easily solved. In volcanic insular systems, this ratio appears as a complementary tool to $\text{Ba}:\text{Ca}$ and $\text{Sr}:\text{Ca}$ ratios to investigate the life traits of migration fishes.

In this study, we propose for the first time to analyze strontium isotopic composition of *S. punctatum* otoliths on which $\text{Ba}:\text{Ca}_{\text{otolith}}$ varying and non-varying composition was previously observed. As both dissolved Sr and $^{87}\text{Sr}:^{86}\text{Sr}$ ratios generally mix conservatively across salinity gradients (Walther & Limburg 2012), we modelled the

expected $^{87}\text{Sr}:^{86}\text{Sr}_{\text{water}}$ trend in the estuary gradient. The objective was to compare $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ variations with model values to infer possible movement of *S. punctatum* to saline habitats.

MATERIAL AND METHODS

Fish were sampled at two stations (upstream/downstream) on the Pérou River in Guadeloupe (French West Indies; Fig. 1) as described by Tabouret *et al.* (2011). Among *S. punctatum*

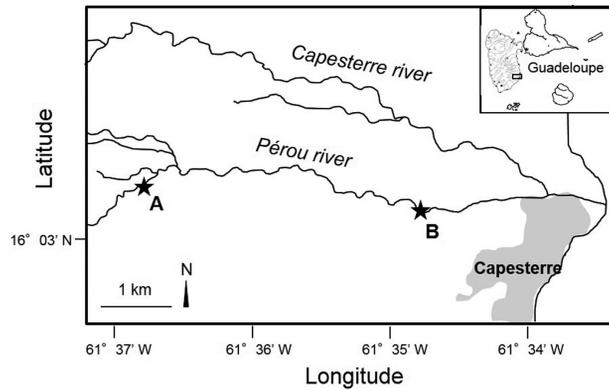


Fig. 1. – Location of the sampling sites (black stars) on the Pérou/Capesterre system in Guadeloupe, French West Indies.

otoliths studied by Tabouret *et al.* (2011), four were selected for $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ analysis. These otoliths previously showed $\text{Sr}:\text{Ca}_{\text{otolith}}$ and $\text{Ba}:\text{Ca}_{\text{otolith}}$ profiles representative of both elemental patterns observed in the sampled population ($n = 62$). They came from two individuals (total length: 43 mm and 54 mm) caught in the lower part and two individuals (total length: 44 mm and 60 mm) caught in the upper part of the river. For each site, we chose one otolith with almost invariable $\text{Ba}:\text{Ca}_{\text{otolith}}$

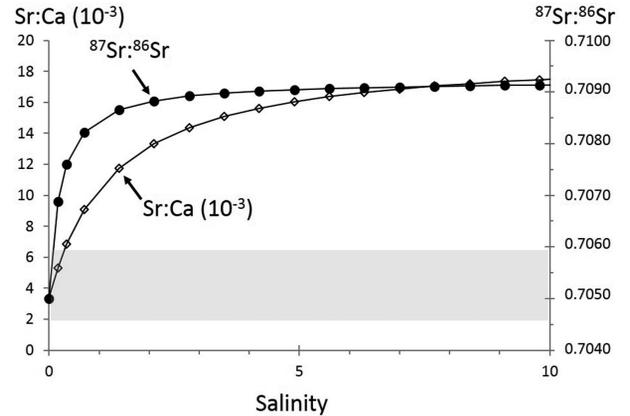


Fig. 2. – Modelled estuary mixing curves of $\text{Sr}:\text{Ca}$ and $^{87}\text{Sr}:^{86}\text{Sr}$ in the Pérou/Capesterre system. Modelisation is based on Sr and $^{87}\text{Sr}:^{86}\text{Sr}$ endmembers from Guadeloupe freshwater and marine water provided by Rad *et al.* (2007). Grey zone: $^{87}\text{Sr}:^{86}\text{Sr}$ range found in *S. punctatum* otolith after recruitment.

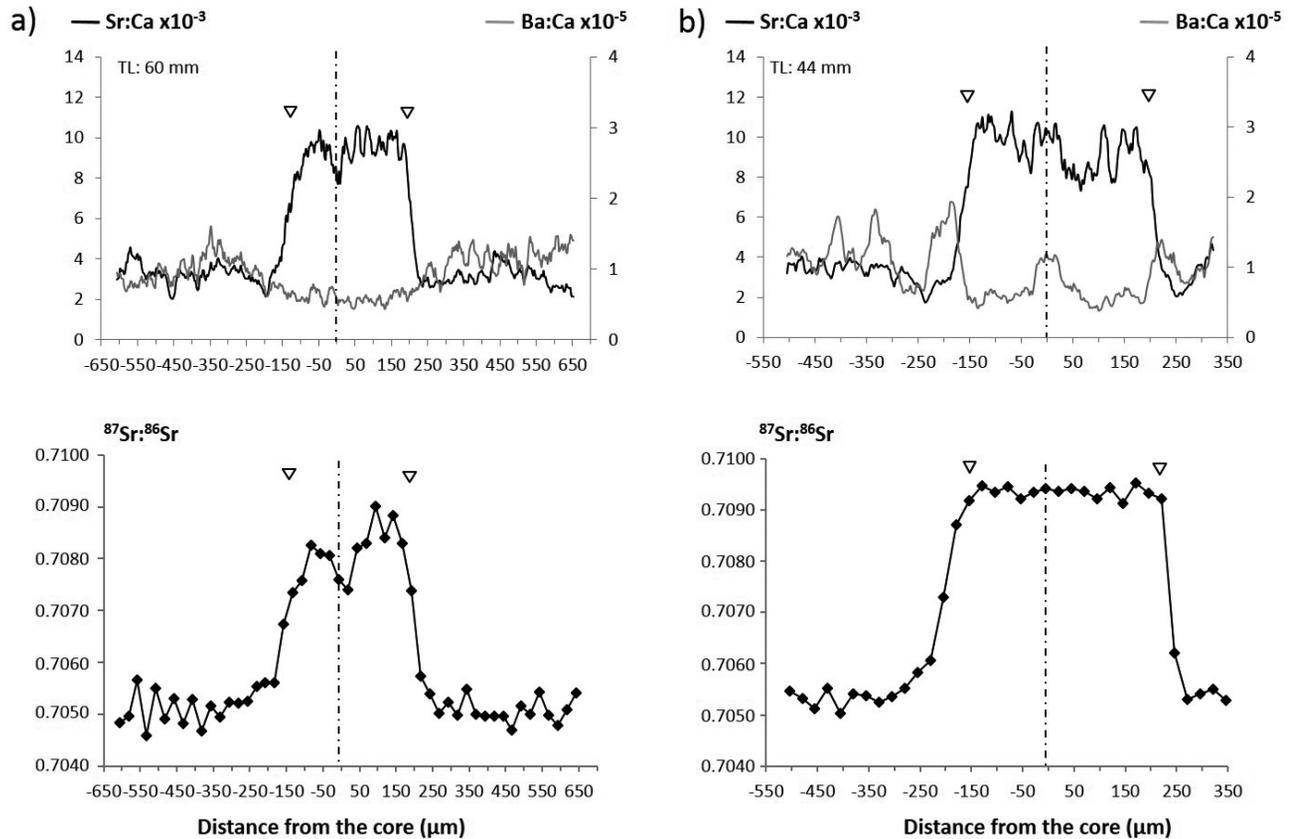


Fig. 3. – Relationship between the distance from the otolith core and the $\text{Sr}:\text{Ca}$, $\text{Ba}:\text{Ca}$ (adapted from Tabouret *et al.* 2011) and $^{87}\text{Sr}:^{86}\text{Sr}$ composition in *S. punctatum* from the upstream site: (a) an individual without $\text{Ba}:\text{Ca}$ peak, (b) an individual with $\text{Ba}:\text{Ca}$ peaks. Dotted line: otolith core; triangle: check mark (end of the larval phase); TL: total length.

after recruitment and one that displayed significant and cyclic Ba:Ca_{otolith} variations. Otolith preparation was previously described in Tabouret *et al.* (2011).

⁸⁷Sr:⁸⁶Sr_{otolith} ratios were analyzed using a multicollector inductively-coupled-plasma mass-spectrometer (MC-ICP-MS *Nu Instruments*, UK) coupled to a high repetition rate IR 1030 nm femtosecond laser ablation (*fs-LA*, *Alfamet-Novalase*, France). A 30 μm linear raster scan ablation was performed adjacent to the raster ablated for elemental measurements (Tabouret *et al.* 2011) crossing the otolith from one edge to the other through the central part. The operating conditions were those previously described by Martin *et al.* (2013). Reproducibility and method accuracy were checked using fish otolith reference material Nies 22 (NIES, Japan) as stated in Martin *et al.* (2013). Mean ⁸⁷Sr:⁸⁶Sr value of Nies 22 for the *Sicydium* otolith run (0.7093 ± 0.0002, 2 SD, *n* = 10) agreed with mean value obtained throughout several weeks of *fs-LA-MC-ICP-MS* analyses (0.7093 ± 0.0001, 2 SD, *n* = 113).

Since Sr, Ca and the ⁸⁷Sr:⁸⁶Sr isotopic ratio behave conservatively across salinity gradients, Sr:Ca_{water} and ⁸⁷Sr:⁸⁶Sr_{water} can be easily modelled at any location along the mixing gradient between freshwater and marine water with a two-endmember equation (Brown & Severin 2009, Walther & Limburg 2012). Average endmember concentrations and ratios of 405.9 ppm (Ca), 7.6 ppm (Sr) and 0.7092 (⁸⁷Sr:⁸⁶Sr_{water}) for oceanic-like water (Brown & Severin 2009; Allègre *et al.* 2010) and 14 ppm

(Ca), 47 ppb (Sr), and 0.7049 (⁸⁷Sr:⁸⁶Sr) for Guadeloupe rivers (Rad *et al.* 2007) were used to model Sr:Ca_{water} and ⁸⁷Sr:⁸⁶Sr_{water} against salinity.

RESULTS AND DISCUSSION

⁸⁷Sr:⁸⁶Sr_{water} in Guadeloupe and Martinique rivers is less radiogenic (0.7041 to 0.7055, Rad *et al.* 2007) than seawater (0.7092 ± 0.0001) as it is generally observed in rivers draining volcanic substrate (Allègre *et al.* 2010). The difference of Sr concentration observed between these rivers and marine water (17-90 ppb and 7.6 ppm, respectively; Rad *et al.* 2007) induces a steep increase of ⁸⁷Sr:⁸⁶Sr_{water} and Sr:Ca_{water} resulting in ratios close to marine water at salinities above 2 and 5, respectively (Fig. 2). According to the ⁸⁷Sr:⁸⁶Sr_{water} trend across the salinity gradient, fish that resided in water with salinities above 0.5 can be easily detected using the ⁸⁷Sr:⁸⁶Sr_{otolith}.

In *S. punctatum* otolith, ⁸⁷Sr:⁸⁶Sr_{otolith} showed similar trend for all the individuals analyzed whatever the site and the Ba:Ca_{otolith} patterns (Figs 3, 4). Mean ⁸⁷Sr:⁸⁶Sr_{otolith} values between the nucleus and the check mark, indicating the recruitment, were comprised between 0.7082 ± 0.0010 and 0.7094 ± 0.0004 (Figs 3, 4). These values are close to seawater values (Allègre *et al.* 2010) and consistent with a

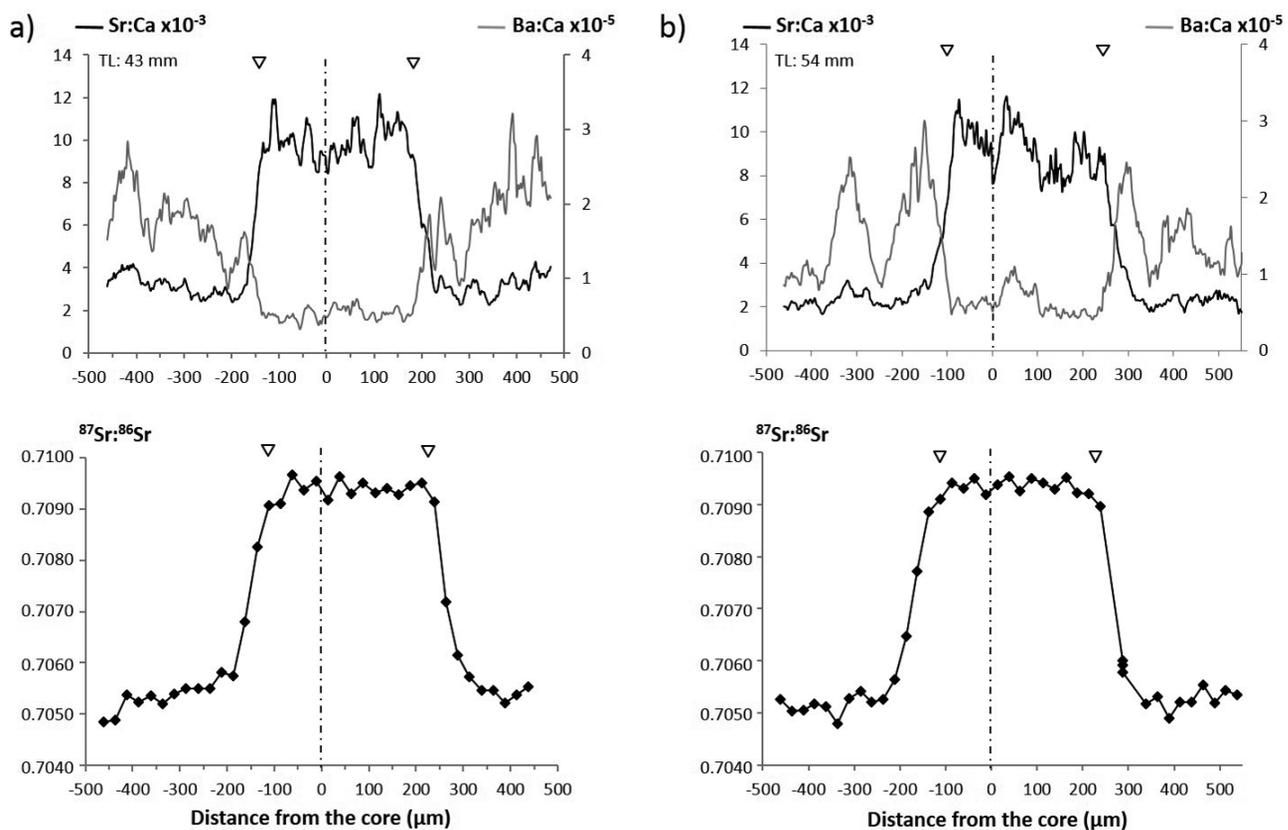


Fig. 4. – Relationship between the distance from the otolith core and the Sr:Ca, Ba:Ca (adapted from Tabouret *et al.* 2011) and ⁸⁷Sr:⁸⁶Sr composition in *S. punctatum* from the downstream site: (a) an individual with low Ba:Ca peaks, (b) an individual with significant Ba:Ca peaks. Dotted line: otolith core; triangle: check mark (end of the larval phase); TL: total length.

marine larval phase (Tabouret *et al.* 2011). After the check mark, $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ decreased drastically and remained constant until the edge. The decrease onset occurs simultaneously with the $\text{Sr}:\text{Ca}_{\text{otolith}}$ decrease and $\text{Ba}:\text{Ca}_{\text{otolith}}$ increase observed at the recruitment (Figs 3, 4). Mean $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ were similar between upstream and downstream gobies: 0.7053 ± 0.0006 and 0.7053 ± 0.0005 , respectively. At both sites, isotopic ratios were close to those observed by Rad *et al.* (2007) in Guadeloupe freshwater habitats and close to other rivers draining volcanic substrates in the world (Barnett-Johnson *et al.* 2008, Milton *et al.* 2008). Since the equilibration time of the Sr incorporation in otolith varied from 12 days to several weeks (Miller 2011), any residency of *S. punctatum* longer than three weeks in the estuary at salinity above 0.4 would induced $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ higher than 0.707 (Fig. 1). There was no evidence of such increase when $\text{Ba}:\text{Ca}_{\text{otolith}}$ peaks occurred. This result invalidates one of the hypotheses proposed by Tabouret *et al.* (2011) linking $\text{Ba}:\text{Ca}_{\text{otolith}}$ changes to movements to the upper estuary zone where desorption of Ba from suspended sediments enhanced the water $\text{Ba}:\text{Ca}$ ratio (Coffey *et al.* 1997). Although flexible migratory pattern between freshwater and brackish or marine habitats was suggested for other Sicydiinae species (Tsunagawa *et al.* 2009, Lord *et al.* 2011), our results support the sedentariness of *S. punctatum* from the Pérou River in freshwater after recruitment. Unchanged $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ does not exclude migration within the watershed. Computed $\text{Ba}:\text{Ca}_{\text{water}}$ values from springs and waters draining volcanic substrates (Louvat & Allègre 1997, Dessert *et al.* 2009) indicate that $\text{Ba}:\text{Ca}_{\text{water}}$ can be widely different in a same region. At the habitat scale, aquifer-river interactions should play an important role in the geochemistry of surface water, especially during the dry season (Rad *et al.* 2007). Tributaries or subsurface waters with significantly different $\text{Ba}:\text{Ca}_{\text{water}}$ ratios can largely contribute to a $\text{Ba}:\text{Ca}_{\text{otolith}}$ variability.

Our results urge to focus on further investigations on the Ba geochemistry in tropical insular rivers as well as on variations at microhabitat scale. A better understanding of the Ba biogeochemical cycle may lead to the validation of a new marker of freshwater habitat use in the tropical insular systems. Results also demonstrate the relevance of $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$ in a multimarker approach to describe diadromous fish behaviour in tropical rivers especially when water data are not available.

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