

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

H. TABOURET<sup>1,2\*</sup>, D. MONTI<sup>3</sup>, J. MARTIN<sup>1,4</sup>, S. BERAIL<sup>1</sup>, C. PECHEYRAN<sup>1</sup>, P. KEITH<sup>2</sup>, G. BAREILLE<sup>1</sup>

<sup>1</sup> Laboratoire de Chimie Analytique Bio-Inorganique et Environnement, Institut des Sciences Analytiques et de Physico-Chimie pour l'Environnement et les Matériaux, UMR 5254 CNRS - Université de Pau et des Pays de l'Adour, Pau, France

<sup>2</sup> Muséum national d'Histoire naturelle, Département Milieux et Peuplements Aquatiques, Biologie des Organismes Marins et Ecosystèmes Aquatiques (UMR BOREA 7208 CNRS/MNHN/UPMC/IRD), CP-026, 43 rue Cuvier, 75231 Paris, France

<sup>3</sup> Université des Antilles et de la Guyane (DYNECAR, UMR BOREA CNRS/MNHN/UPMC/IRD), Laboratoire de Biologie marine, UFR SEN, 97157 Pointe-à-Pitre, Guadeloupe, France

<sup>4</sup> IRSTEA, Estuarine Ecosystems and Diadromous Fish Research Unit, 50 avenue de Verdun, 33612 Cestas Cedex, France  
Corresponding author: helene.tabouret@univ-pau.fr

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 ( $0.7053 \pm 0.0003$ ). 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*

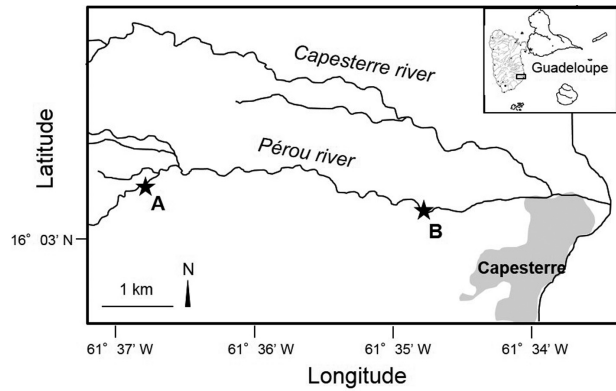


Fig. 1. – Location of the sampling sites (black stars) on the Pérou/Capesterre system in Guadeloupe, French West Indies.

otoliths studied by Tabouret *et al.* (2011), four were selected for  $^{87}\text{Sr}:^{86}\text{Sr}_{\text{otolith}}$  analysis. These otoliths previously showed Sr:Ca<sub>otolith</sub> and Ba:Ca<sub>otolith</sub> 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 Ba:Ca<sub>otolith</sub>

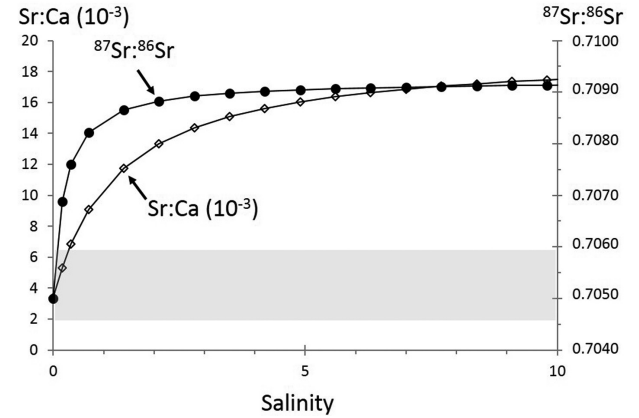


Fig. 2. – Modelled estuary mixing curves of Sr:Ca and  $^{87}\text{Sr}:^{86}\text{Sr}$  in the Pérou/Capesterre system. Modelisation is based on Sr and  $^{87}\text{Sr}:^{86}\text{Sr}$  endmembers from Guadeloupe freshwater and marine water provided by Rad *et al.* (2007). Grey zone:  $^{87}\text{Sr}:^{86}\text{Sr}$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

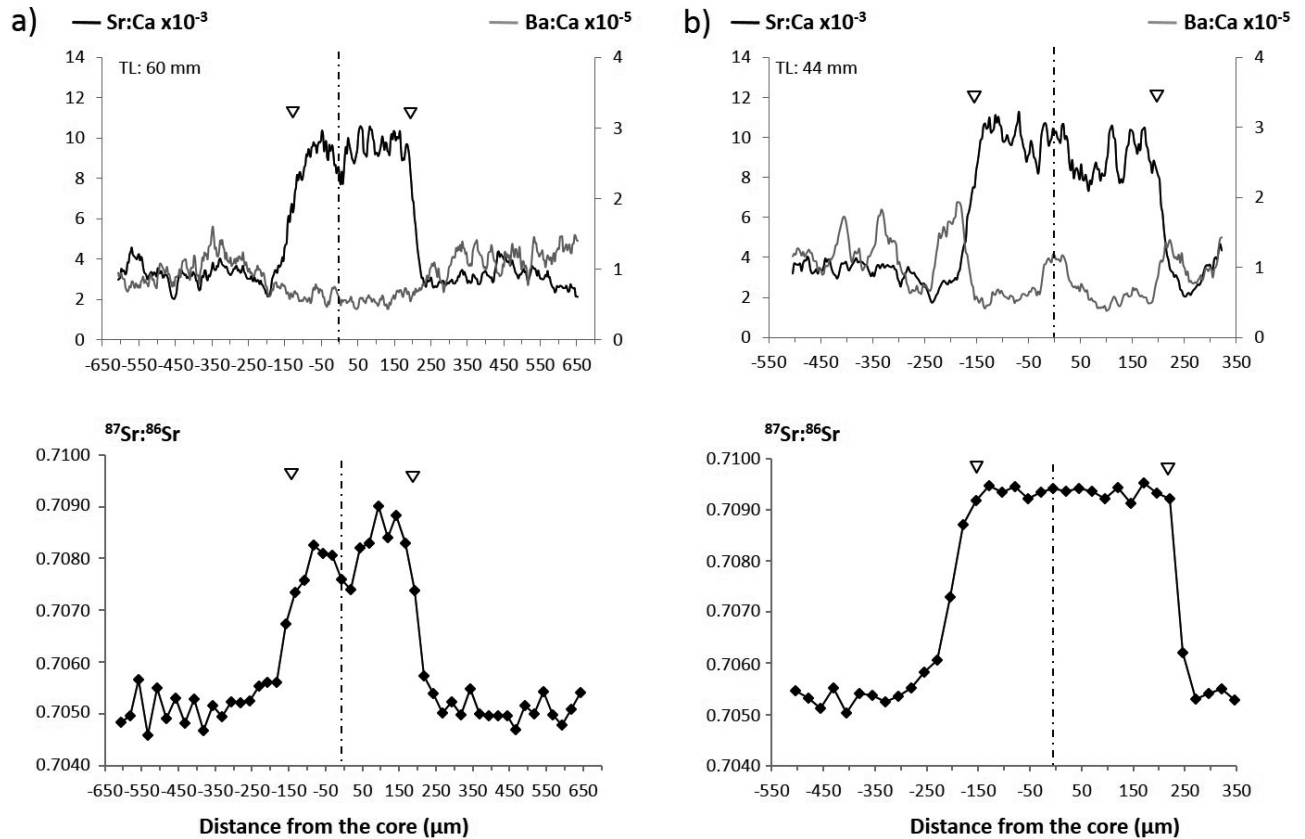


Fig. 3. – Relationship between the distance from the otolith core and the Sr:Ca, Ba:Ca (adapted from Tabouret *et al.* 2011) and  $^{87}\text{Sr}:^{86}\text{Sr}$  composition in *S. punctatum* from the upstream site: (a) an individual without Ba:Ca peak, (b) an individual with Ba:Ca peaks. Dotted line: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

after recruitment and one that displayed significant and cyclic Ba:Ca<sub>otolith</sub> variations. Otolith preparation was previously described in Tabouret *et al.* (2011).

<sup>87</sup>Sr:<sup>86</sup>Sr<sub>otolith</sub> 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 <sup>87</sup>Sr:<sup>86</sup>Sr 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 <sup>87</sup>Sr:<sup>86</sup>Sr isotopic ratio behave conservatively across salinity gradients, Sr:Ca<sub>water</sub> and <sup>87</sup>Sr:<sup>86</sup>Sr<sub>water</sub> 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 (<sup>87</sup>Sr:<sup>86</sup>Sr<sub>water</sub>) for oceanic-like water (Brown & Severin 2009; Allègre *et al.* 2010) and 14 ppm

(Ca), 47 ppb (Sr), and 0.7049 (<sup>87</sup>Sr:<sup>86</sup>Sr) for Guadeloupe rivers (Rad *et al.* 2007) were used to model Sr:Ca<sub>water</sub> and <sup>87</sup>Sr:<sup>86</sup>Sr<sub>water</sub> against salinity.

## RESULTS AND DISCUSSION

<sup>87</sup>Sr:<sup>86</sup>Sr<sub>water</sub> 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 <sup>87</sup>Sr:<sup>86</sup>Sr<sub>water</sub> and Sr:Ca<sub>water</sub> resulting in ratios close to marine water at salinities above 2 and 5, respectively (Fig. 2). According to the <sup>87</sup>Sr:<sup>86</sup>Sr<sub>water</sub> trend across the salinity gradient, fish that resided in water with salinities above 0.5 can be easily detected using the <sup>87</sup>Sr:<sup>86</sup>Sr<sub>otolith</sub>.

In *S. punctatum* otolith, <sup>87</sup>Sr:<sup>86</sup>Sr<sub>otolith</sub> showed similar trend for all the individuals analyzed whatever the site and the Ba:Ca<sub>otolith</sub> patterns (Figs 3, 4). Mean <sup>87</sup>Sr:<sup>86</sup>Sr<sub>otolith</sub> 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

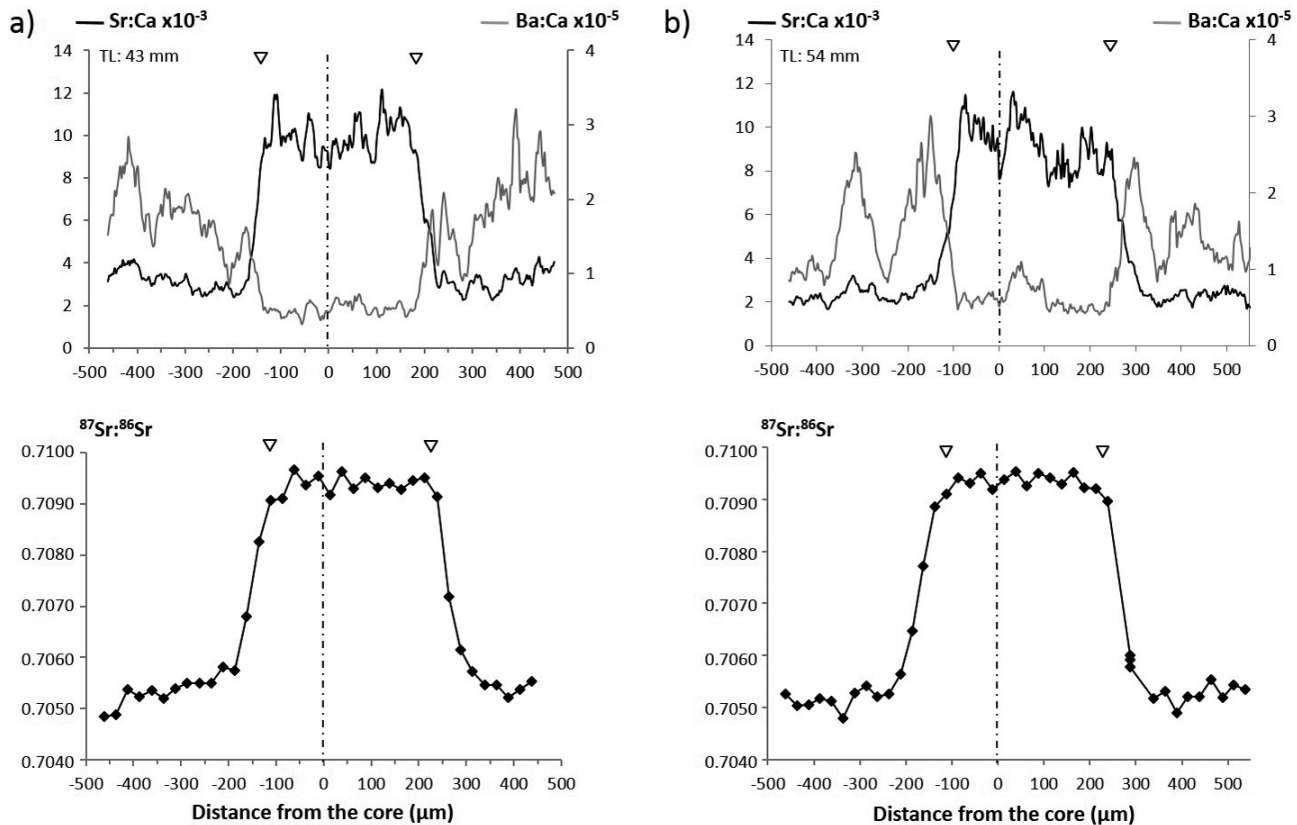


Fig. 4. – Relationship between the distance from the otolith core and the Sr:Ca, Ba:Ca (adapted from Tabouret *et al.* 2011) and <sup>87</sup>Sr:<sup>86</sup>Sr composition in *S. punctatum* from the downstream site: (a) an individual with low Ba:Ca peaks, (b) an individual with significant Ba:Ca peaks. 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:  $0.7053 \pm 0.0006$  and  $0.7053 \pm 0.0005$ , 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.

**ACKNOWLEDGMENTS.** – The authors are grateful to the staff from the Université des Antilles et de la Guyane (UAG) of Pointe-à-Pitre (Guadeloupe) for their help in the field logistics and fish sampling. We thank K Busson, a native English speaker, for her help in the manuscript revision, as well as two anonymous reviewers. This work and H Tabouret postdoctoral fellowship were supported in the framework of ANR CHLORDEXCO program.

## REFERENCES

- Allègre CJ, Louvat P, Gaillardet J, Meynadier L, Rad S, Capmas F 2010. The fundamental role of island arc weathering in the oceanic Sr isotope budget. *Earth Planet Sci Let* 292: 51-56.
- Barnett-Johnson R, Pearson TE, Ramos FC, Grimes CB, MacFarlane R 2008. Tracking natal origins of salmon using isotopes, otoliths, and landscape geology. *Limnol Oceanogr* 53: 1633-1642.
- Brown RJ, Severin KP 2009. Otolith chemistry analyses indicate that water Sr:Ca is the primary factor influencing otolith Sr:Ca for freshwater and diadromous fish but not for marine fish. *Can J Fish Aquat Sci* 66: 1790-1808.
- Coffey M, Dehairs F, Collette O, Luther G, Church T, Jickells T 1997. The behaviour of dissolved barium in estuaries. *Estuar Coast Shelf Sci* 45: 113-121.
- Dessert C, Gaillardet J, Dupre B, Schott J, Pokrovsky OS 2009. Fluxes of high- versus low-temperature water-rock interactions in aerial volcanic areas: Example from the Kamchatka Peninsula, Russia. *Geochim Cosmochim Acta* 73: 148-169.
- Eldson TS, Gillanders BM 2004. Fish otolith chemistry influenced by exposure to multiple environmental variables. *J Exp Mar Biol Ecol* 313: 269-284.
- Eldson TS, Wells BK, Campana SE, Gillanders BM, Jones CM, Limburg KE, Secor DE, Thorrold SR, Walther BD 2008. Otolith chemistry to describe movements and life-history measurements of fishes: hypotheses, assumptions, limitations, and inferences using five methods. *Oceanogr Mar Biol Annual Rev* 46: 297-330.
- Keith P 2003. Biology and ecology of amphidromous Gobiidae of the Indo-Pacific and the Caribbean regions. *J Fish Biol* 63: 831-847.
- Keith P, Hoareau T, Lord C, Ah-Yane O, Gimmoneau G, Robinet T, Valade P 2008. Characterisation of post-larval to juvenile stages, metamorphosis and recruitment of an amphidromous goby, *Sicyopterus lagocephalus* (Pallas, 1767) (Teleostei: Gobiidae : Sicydiinae). *Mar Freshw Res* 59: 876-889.
- Lord C, Tabouret H, Claverie F, Pécheyran C, Keith P 2011. Femtosecond laser ablation ICP-MS measurement of otolith Sr:Ca and Ba:Ca composition reveal differential use of freshwater habitats for three amphidromous *Sicyopterus* (Teleostei: Gobiidae: Sicydiinae) species. *J Fish Biol* 79: 1304-1321.
- Louvat P, Allègre CJ 1997. Present denudation rates on the island of Réunion determined by river geochemistry: Basalt weathering and mass budget between chemical and mechanical erosions. *Geochim Cosmochim Acta* 61: 3645-3669.
- Martin J, Bareille G, Bérail S, Daverat F, Pécheyran C, Bru N, Tabouret H, Donard OFX 2013. Spatial and temporal variations in otolith chemistry and relationships with water chemistry: a useful tool to distinguish Atlantic salmon parr from different natal streams. *J Fish Biol* 82: 1556-1581.
- McDowall RM 1988. Diadromy in fishes: migrations between freshwater and marine environments. Croom Helm, London.
- Miller JA 2011. Effects of water temperature and barium concentration on otolith composition along a salinity gradient: Implications for migratory reconstructions. *J Exp Mar Biol Ecol* 405: 42-52.
- Milton D, Halliday I, Sellin M, Marsh R, Staunton-Smith J, Woodhead J 2008. The effect of habitat and environmental history on otolith chemistry of barramundi *Lates calcarifer* in estuarine populations of a regulated tropical river. *Estuar Coast Shelf Sci* 78: 301-315.
- Rad SD, Allègre CJ, Louvat P 2007. Hidden erosion on volcanic islands. *Earth Planet Sci Let* 262: 109-124.



- Tabouret H, Lord C, Bareille G, Pécheyran C, Monti D, Keith P 2011. Otolith microchemistry in *Sicydium punctatum*: indices of environmental condition changes after recruitment. *Aquat Living Resour* 24: 379-390.
- Tsunagawa T, Suzuki T, Arai T 2009. Migratory history of *Rhinogobius* sp. OR morphotype “Shimahire” as revealed by otolith Sr:Ca ratios. *Ichthyol Res* 57: 10-15.
- Walther BD, Limburg KE 2012. The use of otolith chemistry to characterize diadromous migrations. *J Fish Biol* 81: 796-825.
- Webb SD, Woodcock H, Gillanders BM 2012. Sources of otolith barium and strontium in estuarine fish and the influence of salinity and temperature. *Mar Ecol Prog Ser* 453: 189-199.

*Received on January 16, 2015*

*Accepted on May 3, 2015*

*Associate editor: N Coineau*