INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 24, No. 1, p. 179-188, 2024

RESEARCH PAPER OPEN ACCESS

Otolith morphology of six species of Cichlidae from Lake Buyo in the South-west of Côte d'Ivoire

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Key words: Otoliths, Sagitta, allometry, Buyo lake

http://dx.doi.org/10.12692/ijb/24.1.179-188 Article published on January 08, 2024

Abstract

The morphology of otoliths is used as an indicator of various ecological processes or properties. So the present study was aimed to provide baseline data on the morphology of otoliths in six species of Cichlidae. A total of 179 individuals belonging to six species of the Cichlidae fished in Lake Buyo in June 2021 by artisanal fisheries. The sagitta of these species studied present common morphological characteristics. Indeed, they are elliptical in shape and robust with a concave internal face and a convex external face. However, there are a few differences that help distinguish each species. In the relationships between the total length of the fish and the length of the otolith, the values of the allometry coefficient "a" are between 0 and 1 (0 < a < 1) for all the species considered; they reflect a lowering allometry between the length of the fish and the length of the otolith. The values of the coefficient of determination are very high in *Sarotherodon melanotheron* (r2 = 0.8961), *Oreochromis niloticus* (r2 = 0.8469) and *Coptodon zillii* (r2 = 0.8403). These values reflect a strong correlation between the total length of the fish and the length of the otolith of each species. Our study, in the Ivorian or West African context, has the advantage of providing, on the one hand, morphological data on the otoliths of freshwater fish and, on the other hand, means of estimating the size of fish at from those of the otoliths.

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Introduction

Fish provides an accessible source of nutritious food and protein for a large portion of the world's population. In Africa, among all ingested protein sources, fish and seafood occupy fourth place, after cereals, legumes and milk (FAO, 2016). However, in developing countries, the late 1990s marked the beginning of the decline in overall catches in continental waters (FAO, 2002). It is currently accepted that fishery resources are not inexhaustible (Jamet *and* Lagoin, 1981). Thus, supplying populations constitutes a real challenge for governments, especially at a time when consumers are increasingly interested in the quality of their food, given the increasing pollution of aquatic environments. In such a context, it appears important to sustainably manage fish stocks and this necessarily requires better knowledge of the biology and ecology of fish.

The study of fish biology can concern certain organs such as otoliths which provide important information on the species concerned (Panfili *et al.,* 1990). Otolith morphology is used to indicate various ecological processes or properties (Campana *and* Casselman, 1993). Like other biological structures, otolith morphology exhibits interspecific variability. Indeed, otoliths have a distinctive shape, often characteristic of the fish species to which they belong (Veen *et al.*, 2005). This is why hydrobiologists, as well as taxonomists and archaeologists, often rely on the shape and size of preserved or undigested otoliths to determine which species and sizes of fish were eaten by predators (Olsson *and* North, 1997). The relationships between the otolith and the fish have been studied by several authors (Echeveria, 1987; Campana *et al.*, 1993; Aydin *et al.*, 2004 and Veen *et al.*, 2005). Also, some researchers have succeeded in measuring the duration of the reproductive cycle of fish (Seret *and* Opic, 2011) and calculating their age (Panfili *et al.*, 1990) using the otolith.

In Ivory Coast, most of the studies carried out in ichthyology have made it possible to understand the biodiversity of fish (Kamelan, 2014), their food ecology (Kouamélan, 1999), their reproduction (Koné, 2000) as well as their reproduction areas (N'Dri, 2020). However, the field of otolithology remains little explored. So far, the work carried out only concerns fish otoliths from the West African coasts (Veen and Hoedemakers (2005), and few data exist on freshwater fish. In these continental waters, the Cichlidae family is part of the most represented families. It constitutes, for example, 35% of the catches of fishermen from Lake Buyo; with more than eight species (N'Dri *et al.*, 2020; Goli, 2021). Thus, given the combined effect of overexploitation and climate change which threatens the breeding areas of cichlids, which could lead to the disappearance of certain species (Yao *et al.*, 2023), it appears necessary to describe their otoliths in order to archive them. The general objective of this study is therefore to determine the morphological and morphometric data of the otoliths of six species of Cichlids captured in Lake Buyo. This will firstly involve describing the morphology of the otoliths of the species collected and secondly studying the relationships between the size of the fish and that of its otolith.

Materials and methods

Study environment

With an estimated average surface area of 600 km^2, Lake Buyo (Fig .1) is the second largest hydroelectric dam lake in Côte d'Ivoire after Kossou Lake. It is between 06°54' and 07°31' west longitude and 01°14' and 07°03' north latitude with a catchment area of 75,000 km^2 (Anonymous, 1999). The hydrological regime of the lake depends on that of the Sassandra River, the primary tributary N'Zo and the rainfall of the region (Traoré, 1989). As the hydroelectric dams of Kossou and Taabo on the Bandama River, Ayamé I and II on the Bia River, that of Buyo has changed the hydrology of the main bed of the Sassandra River.

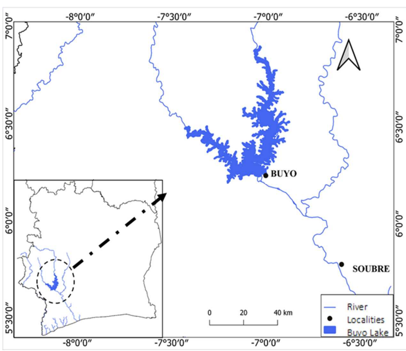

Fig. 1. Location of the Buyo dam lake (Côte d'Ivoire).

Biological materials

The biological material consists of specimens of six species of the Cichlidae family, captured in june 2021 in Lake Buyo by artisanal fisheries and landed in the landing stages of Buyo-ville and Guéssabo.

Technical equipment

An ichthyometer was used to measure the standard and total lengths of each fish. The individual weight of the fish was determined using a CONSTANT brand scale and model 14192 2088B (accuracy ± 0.1 g; range 5000 g). Otolith collection equipment includes dissecting kit, knife, cutting board, trays. The otolith measurement equipment consists of a binocular magnifying glass (LEICA EZ1) to which a digital camera is integrated. The otolith viewing tray is made of black cloth with a section of graph paper. For the weighing of the otoliths, a sensitive balance of the JEWELRY brand and model KL-50 with an accuracy of 0.001 g and a range of 120 g was used.

Dissection, measurement and description of otoliths

The fish collected were counted and then identified according to Paugy *et al.* (2003a and b). They were then measured by recording the total length to the nearest millimeter and weighed to the nearest gram (Rhodes *et al.*, 2005). Dissection of the otolith was performed according to the protocol described by Secor *et al.* (1991). Once outside, the otolith is stripped of its membrane, rinsed with water, dried and kept dry in small labeled bottles. A system consisting of a binocular loupe connected to a digital camera and a computer made it possible to capture digital images of the otoliths on a black fabric background with a section of graph paper. Using the Image-J software, the anteroposterior length of the otoliths was determined (distance from the end of the rostrum to the end of the posterior expansion of the otolith) (Nielsen *et al.,* 2010). The description of otoliths takes into account the following criteria (Tuset *et al.*, 2008), based on shape, contour and sulcus. Thus, the shape of the otolith may be: spherical, circular, square, rectangular, triangular etc. In addition, the otolith can be elongated, semi-elongated. The otolith is said to be elongated when the length/width ratio is greater than or equal to 1.75 and semi-elongated when this ratio is less than 1.75 and greater than 1.5. The contour, meanwhile, can be crenulated, toothed, lobed, irregular, entire or uniform. The sulcus can be median, supra-median or infra-median, depending on its position on the otolith (Chaine and Duvergier, 1934; Veen *et al.*, 2005; Tuset *et al.*, 2008). To illustrate, the otoliths, the model of Tuset *et al.* (2003) was adopted. This model presents the otolith following the vertical with the anterior part (rostrum and antirostrum) above and below the posterior part (cauda, posterior expansion). The description was done in the style of Veen *et al.* (2005). In this work, the sagitta is the otolith chosen for data processing.

Statistical analyzes

As part of this study, the data was analyzed using the Statistica 7.1 program. The Wilcoxon test was used to test the significance of the differences between the right and left otoliths of the same pair for each parameter (weight, length, width) in order to use them independently or not. In addition, a regression analysis made it possible to study the morphometric relationships between the fish and the otolith.

Results

Specific diversity of the Cichlidae family

A total of 179 individuals belonging to six species of the Cichlidae (*Coptodon zillii*, *Hemichromis bimaculatus*, *H. fasciatus*, *Oreochromis niloticus*, *Sarotherodon galilaeus*, *Sarotherodon melanotheron)* were sampled in this survey (Table 1; Fig. 2.).

Table 1. Taxonomic richness of fish sampled in the Buyo dam lake (Côte d'Ivoire) in June 2021.

Familie	Species	Number of individuals
Cichlidae	*Coptodon zillii* (Gervais, 1848)	42
	Hemichromis bimaculatus (Gill, 1862)	14
	Hemichromis fasciatus (Peters, 1857)	16
	Oreochromis niloticus (Linnaeus, 1758)	40
	Sarotherodon galilaeus (Linnaeus, 1758)	26
	Sarotherodon melanotheron (Rüppell, 1852)	41
1	6	179

Among the species collected, *Sarotherodon melanotheron* is a species with estuarine and/or marine affinity and *Oreochromis niloticus* is an introduced species.

Description of otolith morphology

The otoliths of the six species of fish of the Cichlidae family have common characteristics (Fig. 3.). Generally, the sagittae of the Cichlidae listed are generally elliptical in shape and robust. Their internal face is concave both in the antero-posterior and dorso-ventral direction and their external face is convex. The ventral edge is lined with more or less regular projections sometimes finely crenate or toothed. The rostrum is less prominent with a less marked antirostrum. The ventral area is wide with a curved caudal colliculum that opens posteriorly. The convexity of the otolith is visible in ventral view.

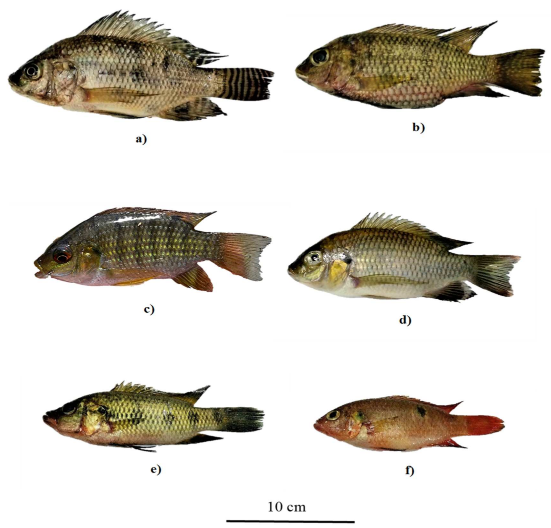

Fig. 2. Photograph of the six species of the Cichlidae family captured in the Buyo dam lake (Côte d'Ivoire) in June 2021.
(a) Oreochromis niloticus; (b) Coptodon zillii; c) Sarotherodon galilaeus; d) Sarotherodon melanotheron; (e) Hemichromis fasciatus; f) Hemichromis bimaculatus.

Coptodon zillii

This species is characterized by oval-shaped otoliths with an infra-median sulcus, delimited by protruding edges. The rostrum is not very prominent with a weak antirostrum; both delimit a narrow excisura. The ostium is narrower than the cauda which is wider and rounded. The posterior edge has a small posterior expansion. The dorsal area is shallow. The sulcus is wide with a curved caudal colliculum that opens posteriorly. The dorsal edge is crenellated in its anterior part and smooth in its posterior part. The ventral edge is lobed in its anterior part (Fig. 3-a.).

Hemichromis bimaculatus

The otolith is elliptical in shape. Its internal face is concave both in the antero-posterior and dorso-ventral direction. The ventral edge is lined with regular protrusions along its entire length. The rostrum is prominent with a less marked antirostrum. Posterior expansion is almost absent. The sulcus is deep with a curved caudal colliculum that opens posteriorly. The posterior portion of the dorsal area is smooth and not delimited by a posterodorsal angle (Fig. 3-b.).

Fig 3. Photograph of the inner side of the right otoliths of the six fish species captured in the Buyo dam lake in June 2021.
a) Coptodon zillii; b) Hemichromis bimaculatus; c) Hemichromis fasciatus; d) Oreochromis niloticus; e) Sarotherodon galilaeus; f) Sarotherodon melanotheron.

Hemichromis fasciatus

This species is characterized by slightly elongated otoliths (Fig 3-c.) with the posterior part of the cauda directly below the ventral edge. The ostium has a narrow anterior edge and the inner side is domed. The ventral edge is irregularly crenellated along its entire length. The dorsal edge is finely lobed in its anterior part. The sagitta has an elongated, pointed rostrum and a small, short antirostrum. The depression in the dorsal area is accentuated in the upper part of the sulcus. The sulcus is notched almost touching the ventral edge. The posterior part of the cauda is inclined towards the ventral edge.

Oreochromis niloticus

This species is characterized by robust and slightly elongated otoliths. The edges of the otolith are lobed, irregular, and finely notched. The transition from the ventral edge to the dorsal edge is not marked. The otolith is thick at the posterior pole and has a very narrow excisura (Fig. 3-d.). The slightly marked rostrum is rounded at its end. The well-marked antirostrum remains attached to the rest of the otolith at the level of the ostium, although it reveals a small slit. The sulcus, supra-median, is characterized by a deep colliculum and is limited by projecting crests. The dorsal and ventral areas are residual.

Sarotherodon galilaeus

This species is characterized by elliptical otoliths with irregularly crenulated and lobed edges (Fig. 3-e.). The otolith is slightly thick at its base and convex in ventral view. The rostrum and the antirostrum are barely visible and hardly delimit the excisural formation. The sulcus is well notched, long, median, deep and wide except at the level of the ostial colliculum. It has protruding lower and upper ridges. The cauda bends towards the posteroventral border. It opens into the posterior expansion via a gutter. We note the presence of a dorsal area, narrow and elongated.

Sarotherodon melanotheron

This species is characterized by oval otoliths. The dorsal edge has irregular projections. The ventral edge is finely crenellated (Fig. 3-f.). The slightly notched sulcus is wide. The depression in the ventral area is not very marked. The internal face is concave in the antero-posterior and dorso-ventral direction. The dorsal edge is rounded in its posterior part. The ventral groove is absent. The depression in the dorsal area is barely visible.

Morphometric relationships between fish and otolith

Comparison of right and left otoliths

The non-parametric Wilcoxon test was performed to compare the size of the left and right otoliths of each species (Table 2). This shows that there are no significant differences between the weight of the left and right otoliths of these species of fish studied, because $p > 0.05$ in each case. The same test carried out to compare the lengths as well as the widths of the pair of otoliths shows that there is no significant difference between them. With regard to the results of the Wilcoxon test, the left and right otoliths will be used interchangeably. As part of our study, the average of the pair (left and right) of the same specimen was used to highlight the relationships between the parameters of the otolith and the metric characteristics of the fish as did Salami *et al.* (2011) for estimating the different relationships.

Fish length-otolith length relationship

The relationships between the anteroposterior length of the otoliths (Lap) and the total length of the fish (TL) are linear. They are expressed by the equation Lap = a LT + b. The parameters of the equations are summarized in Table 3. Fig. 4 is the graphical representation of the equations in each species. The values of the allometry coefficient "a" are between 0 and 1 ($0 < a < 1$) for all the species studied (*Coptodon zillii* (0.2576), *Hemichromis bimaculatus* (0.8407), *H. fasciatus* (0. 4212), *Oreochromis niloticus* (0.2534), *Sarotherodon galilaeus* (0.2812), *S. melanotheron* (0.2703) Overall, they show a lower allometry between fish length and otolith length. The highest coefficients of determination were observed in *S. melanotheron* ($r^2 = 0.8961$), *Oreochromis niloticus* ($r^2 = 0.8469$), and *Coptodon zillii* ($r^2 = 0.8403$).These values reflect a strong correlation between the total length of the fish and the length of the otolith of these species For *Sarotherodon galilaeus* ($r^2 = 0.3077$), the value of the coefficient of determination, relatively lower, reflects a weak correlation between the total length of the fish and the length otolith.

Table 1. Results of the Wilcoxon tests to compare the left and right otoliths of the six species studied.

Species	N	Pair of variables	p-value
		Weight	0.2
Coptodon zillii	42	Length	0.43
		Width	0.108
		Weight	0.106
Hemichromis bimaculatus	14	Length	0.358
		Width	0.201
		Weight	0.315
Hemichromis fasciatus	16	Length	0.244
		Width	0.601
		Weight	0.434
Oreochromis niloticus	40	Length	0.296
		Width	0.164
		Weight	0.253
Sarotherodon galilaeus	26	Length	0.336
		Width	0.738
		Weight	0.531
Sarotherodon melanotheron	41	Length	1.1
		Width	0.648

N = Number of specimens.

Table 3. Parameters of the equations expressing the relationship between the length anteroposterior of the otolith and the total length of the fish in six species of fish caught in the Buyo dam lake (Côte d'Ivoire) in June 2021.

Species	N	a	b	r^2	*p*
Coptodon zillii	42	0.2576	1.3931	0.8403	0.000002
Hemichromis bimaculatus	14	0.8407	- 3.1468	0.6557	0.00000
Hemichromis fasciatus	16	0.4212	- 1.5504	0.597	0.000001
Oreochromis niloticus	40	0.2534	2.3897	0.8469	0.000003
Sarotherodon galilaeus	26	0.2812	1.6789	0.3077	0.000000
Sarotherodon melanotheron	41	0.2703	1.0374	0.8961	0.000000

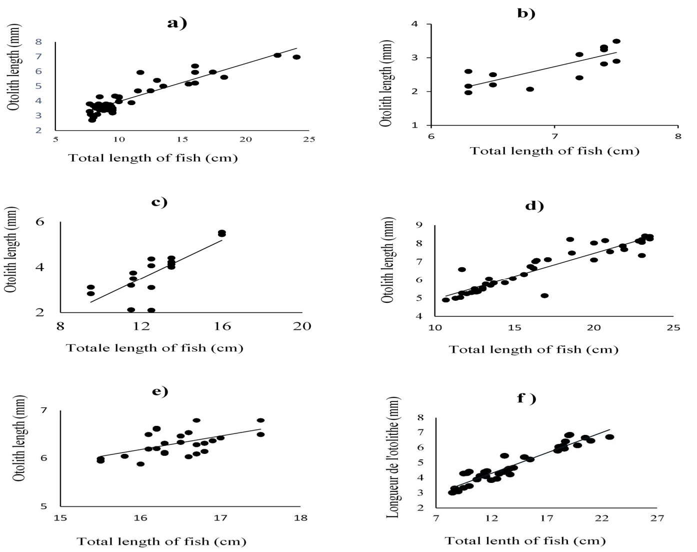

Fig 4. Relationship between the anteroposterior length of the right otolith and the length total fish in six species of the Cichlidae family caught in the Buyo dam lake (Côte d'Ivoire) in June 2021.
a= Coptodon zillii; b= Hemichromis bimaculatus; c= Hemichromis fasciatus; d= Oreochromis niloticus; e= Sarotherodon galilaeus; f= Sarotherodon melanotheron.

Discussion

The sagitta of the six cichlid species captured in Lake Buyo show common morphological characteristics. They are generally elliptical in shape and robust with a concave inner face and a convex outer face. These results are similar to those obtained by Veen *et al.* (2003) who studied the representatives of the Haemulidae family and who noticed in this family, generally oval-shaped otoliths. However, fundamental differences were observed at the level of each species which made it possible to differentiate them. The data obtained confirm those of Veen *et al.* (2005), who indicate that otoliths have a distinctive shape that is often characteristic of the genus and even the species of fish to which they belong. Indeed the sagitta plays a primordial role in the auditory and vestibular functions of fish; thus, its interspecific morphological differences may be linked to one or other of these functions (Popper and Luz, 2000).

In the present study, the right and left saccular otoliths of the six species of fish were compared in order to determine the degree of symmetry of these. Wilcoxon test results indicated that there is no significant difference between the left and right otoliths; they can therefore be used indiscriminately in the context of modeling linking their size or mass to the size of individuals. The absence of significant differences between the left and right otoliths is consistent with the observations of Hunt (1979) that the otoliths of the pair are mirror images of each other. However, in Conger conger, Salami *et al.* (2013) found that the average length of the left otoliths is significantly greater than that of the right otoliths.

In the relationships between the total length of the fish and the length of the otolith, the values of the allometry coefficient "a" are between 0 and 1 ($0 < a < 1$) for all the species considered; they reflect a lowering allometry between the length of the fish and the length of the otolith. This means that the growth in length of the fish is faster than that of the otolith. This lowering allometry in the growth of calcified parts is a fairly general case in teleosts (Panfili *et al.*, 2002). The values of the coefficient of determination are very high in *Sarotherodon melanotheron* ($r^2 = 0.8961$), *Oreochromis niloticus* ($r^2 = 0.8469$) and *Coptodon zillii* ($r^2 = 0.8403$). These values reflect a strong correlation between the total length of the fish and the length of the otolith of these species. Most of the species studied show a fairly good correlation between the length of the sagittae and the length of the fish. However, these values are lower than those obtained for *Auxis rochei* collected in Tunisian waters, Hattour (2009) ($r^2 = 0.950$). However, the level of correlation, far from attaching to body growth, would rather depend on other factors such as diet and habitat conditions (Beamish and McFarlen, 1987; Geldiay and Balik, 1996). Moreover, according to Casselman (1990), the chemical processes involved in otolith growth are more affected by temperature than by the metabolic processes involved in body growth. These results are consistent with the work of Paxton (2000) and Ramcharitar *et al.* (2001) who showed that the variability of otolith size within the same family is very high in teleosts. Overall, the high values of the correlation coefficient demonstrate the proportional relationship between the growth of the individual and that of the otolith.

Conclusion

At the end of this study, it appears that the sagitta of the six species of Cichlids captured in Lake Buyo are generally elliptical and robust in shape with a concave internal face and a convex external face. However, fundamental differences were observed that effectively distinguished each of the species. Furthermore, the results of the Wilcoxon test indicated that there is no significant difference between the right and left otoliths of the same pair and that these can be used interchangeably. In the relationships between the total length of the fish and the length of the otolith, the values of the allometry coefficient "a" are between 0 and 1 ($0 < a < 1$) for all the species considered; they reflect a lowering allometry between the length of the fish and the length of the otolith. The values of the coefficient of determination are very high in *Sarotherodon melanotheron* ($r^2 = 0.8961$), *Oreochromis niloticus* (r^2 = 0.8469) and *Coptodon zillii* (r^2= 0.8403). These values reflect a strong correlation between the total length of the fish and the length of the otolith of each species. Overall, the high values of the correlation coefficient demonstrate the proportional relationship between the growth of the individual and that of the otolith.

Acknowledgements

This study was carried out as part of a research project entitled "Identification and characterization of fish spawning grounds in the Buyo dam lake (Côte d'Ivoire)", co-financed by the Strategic Support Project for Research and Higher Education (PASRES) and the Ivorian Office of Parks and Reserves (OIPR). At the end of this work, we are particularly pleased to thank these two structures as well as all the people who contributed at various levels to the production of the manuscript.

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