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ARTICLE

Sagitta otolith of three demersal species in a tropical environment

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Abstract. The objective of this study was to describe the morphology and morphometry of *saggitta* otoliths of *Polydactylus virginicus, Menticirrhus cuiaranensis* and *Conodon nobilis* in a tropical environment. Fishes were caught with rod and reel in competitive fishing events promoted in 2014-2015 along the coast of Sergipe. A total of 174 pairs of *sagitta* otoliths of *P. virginicus,* 181 of *M. cuiaranensis* and 77 of *C. nobilis* was extracted. In general, the *sagitta* otoliths of all three species analyzed here presented different morphology and shape indices. The permutational multivariate analysis of variance (PERMANOVA) demonstrated significant differences among species and ontogenetic phases within each species using morphometry and shape indices. The linear discriminant analysis (LDA) presented a 98.3% correct reclassification of the otoliths by species.

Keywords. *Conodon nobilis; Menticirrhus cuiaranensis; Polydactylus virginicus;* Ontogenetic variation; Shape indices.

INTRODUCTION

Otoliths are calcium carbonate precipitated primarily as aragonite structures, present in the inner ear of fishes in three pairs: *sagittae, asterisci* and *lapilli* (Popper *et al.,* 2005). They are metabolically inert, *i.e.,* there is no chemical alteration or reabsorption after their formation. These structures assist the hearing and perception of the external environment (Ladich & Schulz-Mirbach, 2016). Otoliths are excellent tools for various studies of fish populations such as: habitat use and connectivity between populations using the chemistry of the otolith (Carvalho *et al.,* 2017; Maciel *et al.,* 2020), environmental stress indicated by the deposition of vaterita (Carvalho *et al.,* 2019a; Holmberg *et al.,* 2019), and age and growth (Soeth *et al.,* 2018; Maciel *et al.,* 2018).

Many studies correlate the ontogenetic developments of otoliths to life history and changes in habitat use as distribution in the water column (Cruz & Lombarte, 2004; Assis *et al.,* 2020). Taylor *et al.* (2020) correlated changes in the morphology and morphometry of the otoliths of *Argyrosomus japonicus* with the segregation of habitat use of juveniles and adults. The morphology and morphometry of otoliths may present sexual variation, as observed in *Atherinella brasiliensis* (Quoy & Gaimard, 1825), *Micromesistius australis* (Norman, 1937) and *Porichthys notatus* (Girard, 1854) (Carvalho & Correa, 2014; Leguá *et al.,* 2013; Bose *et al.,* 2016), as well as before and after the first maturity within the same species (Carvalho *et al.,* 2020). The intraspecific morphologies and morphometric patterns of otoliths make them an important tool for studies of trophic ecology of ichthyophagous species (Miotto *et al.,* 2017; Carvalho *et al.,* 2019b). Some of the species identified as preys are also exploited in artisanal and recreational fisheries (Cattani *et al.,* 2011; Freire *et al.,* 2017; Passarone *et al.,* 2019). *Polydactylus virginicus* (Linnaeus, 1758), *Menticirrhus cuiaranensis* (Marceniuk *et al.,* 2020) and *Conodon nobilis* (Linnaeus, 1758) are examples of species exploited by recreational fishers (Freire *et al.,* 2017) and are usually described as food items in the diet of ichthyophagous species (Tavares & Di Beneditto, 2017). Those species are demersal and distributed in the Southwestern Atlantic Ocean (Menezes & Figueiredo, 1980; Froese & Pauly, 2021).

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Menticirrhus cuiaranensis and *C. nobilis* are benthophagous (Lira *et al.,* 2019) whereas *P. virginicus* is zooplanktivore (Medeiros *et al.,* 2017).

Several studies have described the morphology and morphometry of otoliths of species important for artisanal and recreational fisheries in southeastern-southern Brazil (Siliprandi *et al.,* 2014; Brenha-Nunes *et al.,* 2016; Maciel *et al.,* 2019; Dal Negro *et al.,* 2021). Conversely, few studies have been conducted in northeastern Brazil, making it impossible future studies of connectivity or fishing stocks for species with wide distribution along the Brazilian coast (Freire *et al.,* 2017; Assis *et al.,* 2020; Bot *et al.,* 2020). Thus, this study was conducted with the objective of describing the morphology and morphometry of *sagitta* otoliths of *P. virginicus, M. cuiaranensis* and *C. nobilis,* and assessing the occurrence of ontogenetic changes to serve as basis for future studies related to diet composition and connectivity between populations.

MATERIAL AND METHODS

Samplings were performed between March 2014 and August 2015 in distinct beaches along the coast of the state of Sergipe, in northeastern Brazil (Fig. 1). Recreational fishers used rod, reel, and hook with natural bait during these events (Freire *et al.,* 2017). The specimens caught were identified, measured for total length and total weight (TL, in centimeters and W, in grams, respectively). Power relations were also estimated between total length and total weight ($W = a \cdot TL^b$) (positive allometry, $b > 3$; negative allometry, $b < 3$; and isometry, $b = 3$; Froese, 2006). The specimens were separated into six length classes (5.1-10; 10.1-15; 15.1-20; 20.1-25; 25.1-30; 30.1-35 cm) to test for ontogenetic variation. *Sagitta* otoliths were washed, dried, and stored separately in small paper envelopes. Voucher specimens are deposited in the collection of the "Acervo Zoológico da Universidade Santa Cecília" under the numbers AZUSC-UNISANTA n. 5155, 5169, and 5935.

Morphology and morphometry of otolith

The identification of otolith shape, position, type and shape of the *sulcus acusticus,* shape of the *cauda,* and *ostium* type was performed according to Corrêa & Vianna (1992), Tuset *et al.* (2008), and Volpedo & Vaz-dos-Santos (2015). The otolith length (OL, greater longitudinal distance in mm) and height (OH, greater perpendicular distance in mm) were measured (Fig. 2). Power relations were also estimated between otolith length (OL) and height (OH) and fish total length (TL): $OL = a \cdot TL^b$ and $OH = a \cdot TL^b$. The following otolith shape indices were used to verify the ontogenetic variation as well as variation among species: OL/TL, OH/OL × 100 (Volpedo & Echeverria, 2003), and ellipticity [$E = (OL - OH)/(OL + OH)$] (Tuset *et al.,* 2003).

Statistical analysis

The morphometry and shape indices did not meet the assumptions required for parametric tests in all three species analyzed here (Shapiro-Wilk: $p < 0.05$; Bartlett's test: $p < 0.05$). Hence, a Permutational Analysis of Variance (PERMANOVA) was applied to verify ontogenetic differences within species and shape variation among species using the morphometry and shape indices for all three species. A linear discriminant analysis (LDA) was performed to verify the percentage of correct

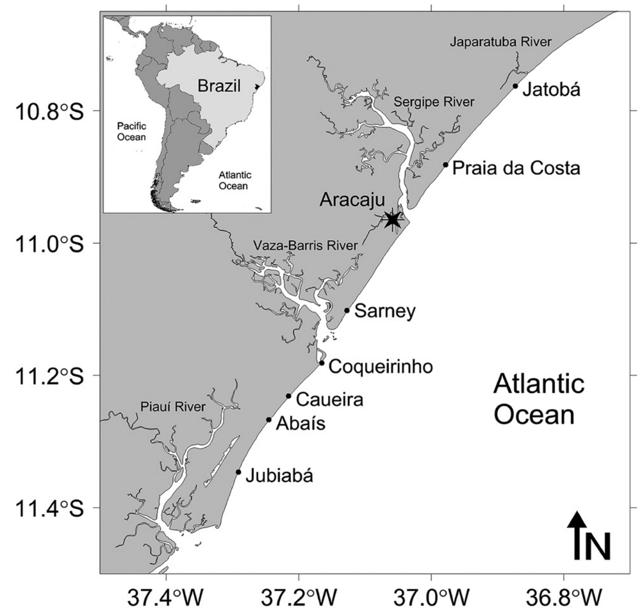

Figure 1. Map of the coastal region of the state of Sergipe showing all the beaches where samples were collected during competitive fishing events in 2014-2015.

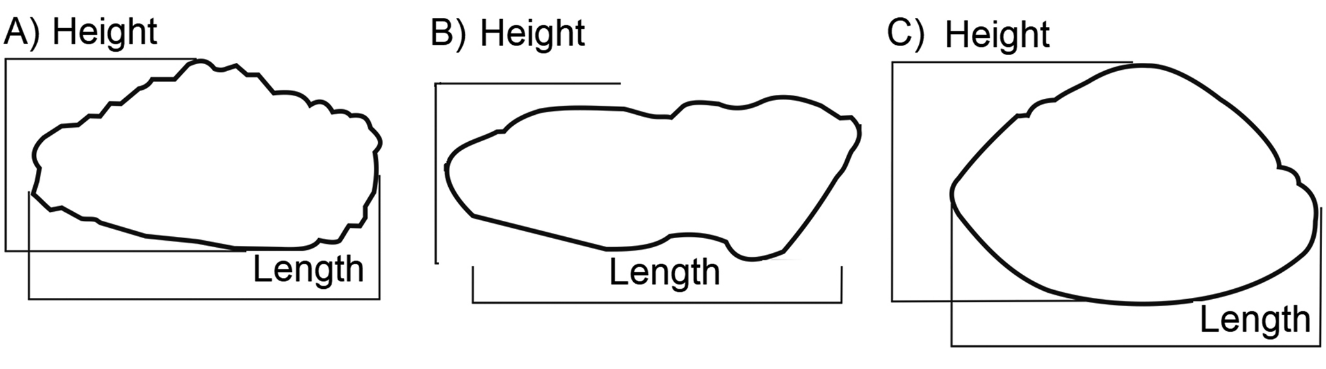

Figure 2. Length and height of sagittae otoliths for: (A) *Polydactylus virginicus;* (B) *Menticirrhus cuiaranensis;* and (C) *Conodon nobilis.*

reclassification of otoliths among the three species analyzed (Linde *et al.,* 2004). All statistical analyses were performed using the R software (R Core Team, 2020) and Past (Hammer *et al.,* 2001).

RESULTS

A total of 487 individuals of *P. virginicus* (TL = 7.2 to 27.5 cm; n = 229), *M. cuiaranensis* (TL = 12.5 to 35.5 cm; n = 182), and *C. nobilis* (TL = 7.4 to 33.5 cm, n = 76) were analyzed (Fig. 3). The morphological analysis of the otoliths indicated interspecific variation (Table 1), except for the shape of the *sulcus acusticus* and *cauda,* which are similar for all three species. The position and type of the *sulcus acusticus* are similar for *P. virginicus* and *C. nobilis,* *i.e.,* median and ostial. *Menticirrhus cuiaranensis* showed on rostrum and *P. virginicus* and *C. nobilis* showed a small and underdeveloped rostrum.

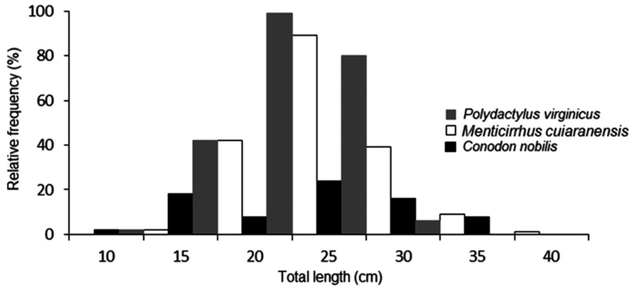

Figure 3. Frequency distribution of the total length (cm) of *Polydactylus virginicus, Menticirrhus cuiaranensis* and *Conodon nobilis* sampled in a tropical environment in Southwestern Atlantic.

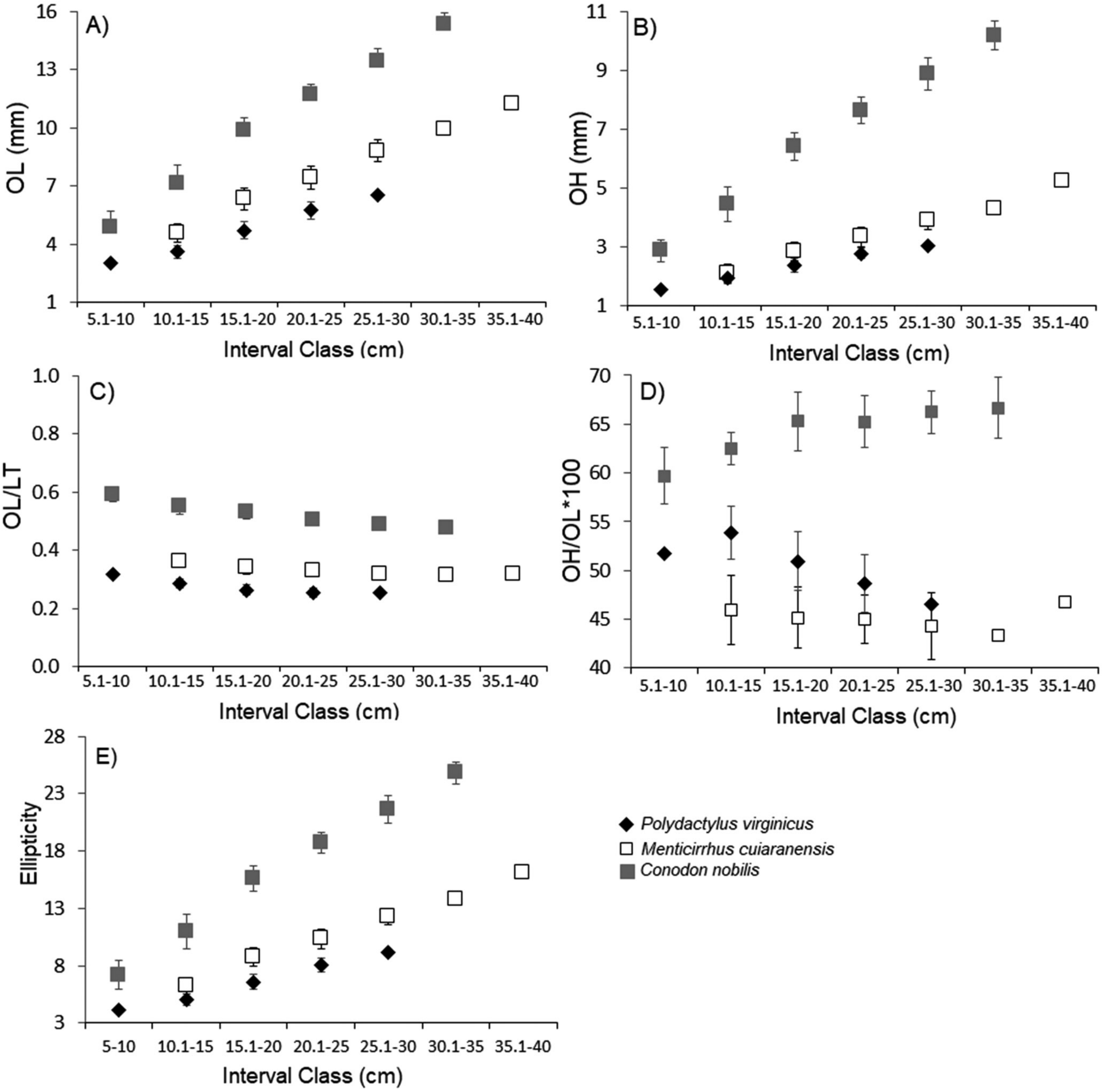

Figure 4. Box plot (mean and standard deviation) of morphometric parameters and shape indices of the otolith *sagitta* of *Polydactylus virginicus, Menticirrhus cuiaranensis* and *Conodon nobilis* per class of total length: (A) otolith length (OL), (B) otolith height (OH), (C) Aspect ratio OL/TL, (D) Aspect ratio (OH/OL) × 100 and (E) ellipticity.

Morphometry and indices demonstrated ontogenetic variation within the three species analyzed here (Fig. 4). The otoliths of *C. nobilis* tend to be more rounded along the ontogeny and the otoliths of *M. cuiaranensis* and *P. virginicus* tend to be more elongated as the ontogenetic development occurs (Fig. 4D). The otoliths of the three species show greater growth in the anteroposterior axis along the ontogeny (Fig. 4E). The results of the PERMANOVA ($F = 807.1$; $p < 0.0001$) indicated significant differences in the morphometry of otolith and shape indices among species.

Both *P. virginicus* and *M. cuiaranensis* presented positive body allometry when analyzing the weight-length relationship ($b = 3.233$ and 3.159, respectively; Fig. 5). On the other hand, *C. nobilis* showed body isometry ($b = 3.022$), with an increase in its body weight proportional to the cube of its length. At the same time, *C. nobilis* was the only species, among all analyzed, with otoliths presenting a strong positive allometry ($b = 3.744$; Fig. 5).

The LDA showed a variation in the shape of the *sagitta* otoliths: *M. cuiaranensis* presents otoliths distributed along axis 1 for presenting more elongated otoliths; and *P. virginicus* and *C. nobilis* are distributed along axis 2, which better explains the variability of the more rounded otoliths (Fig. 6). The LDA presented a 98.3% correct reclassification of the otoliths by species (Table 2).

Table 1. Morphological classification of otoliths for *Polydactylus virginicus, Menticirrhus cuiaranensis* and *Conodon nobilis* of a tropical environment.

Morphological features	*P. virginicus*	*M. cuiaranensis*	*C. nobilis*
Rostrum	Small	Absent	Developed
Shape of otolith	Rectangular	Bullet shaped	Oval
Position of *sulcus acusticus*	Median	Inframedian	Median
Type of *sulcus acusticus*	Ostial	Pseudo-ostial	Ostial
Shape of *sulcus acusticus*	Heterosulcoid	Heterosulcoid	Heterosulcoid
Shape of *cauda*	Curved	Curved	Curved
Type of *ostium*	Funnel	Lateral	Rectangular

Table 2. Reclassification of the *sagitta* otoliths for *Polydactylus virginicus, Menticirrhus cuiaranensis* and *Conodon nobilis* obtained through the linear discriminant analysis (LDA).

Species	*M. cuiaranensis*	*C. nobilis*	*P. virginicus*
P. virginicus	0 (0)	0 (0)	156 (100)
M. cuiaranensis	171 (97.1)	0 (0)	5 (2.9)
C. nobilis	0 (0)	72 (94.7)	4 (5.3)
Total	171	72	165

DISCUSSION

In general, the *sagitta* otoliths of all three species analyzed here presented different morphology. However,

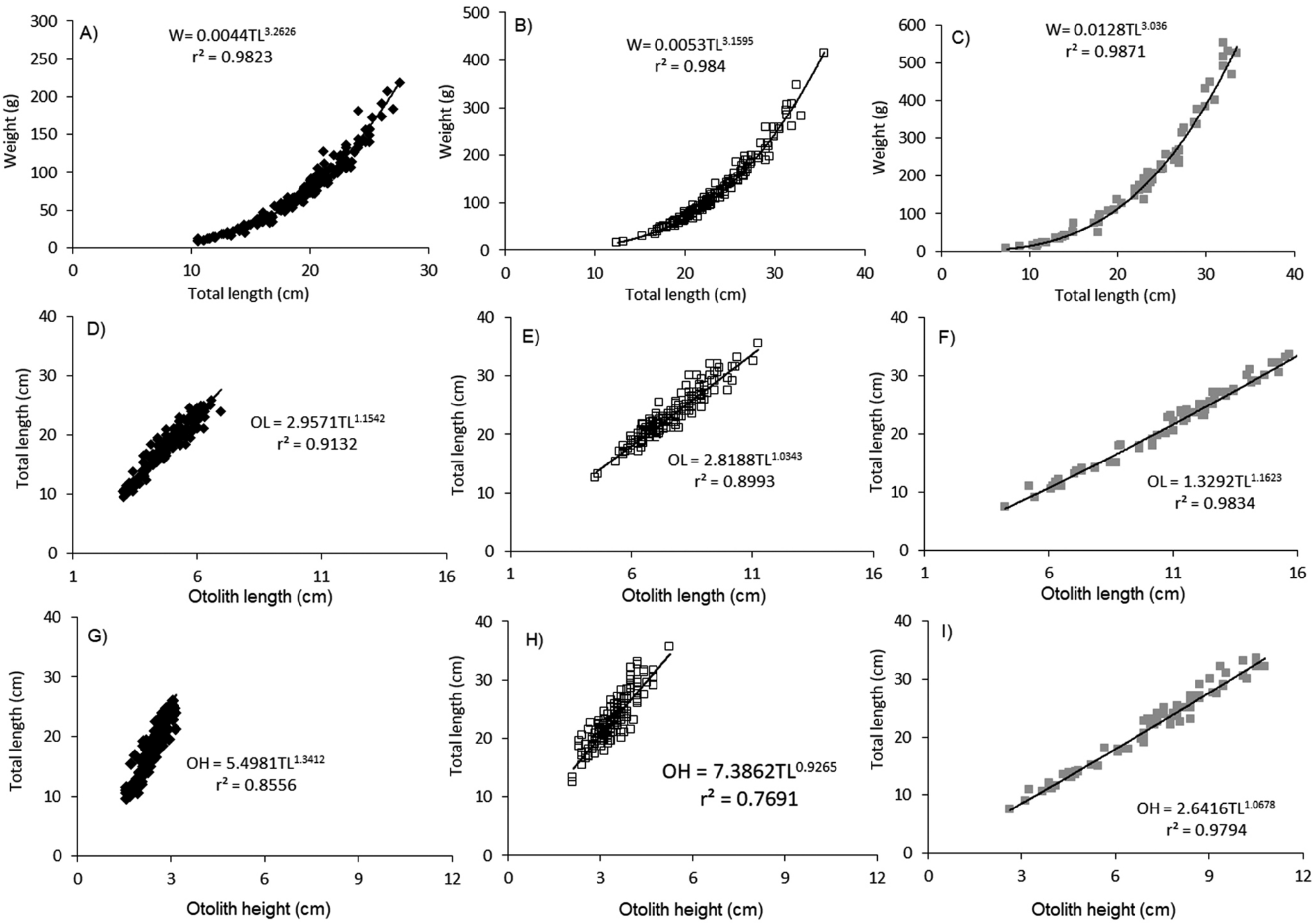

Figure 5. Length-weight relationship for (A) *Polydactylus virginicus,* (B) *Menticirrhus cuiaranensis,* and (C) *Conodon nobilis;* otolith length vs fish total length for (D) *Polydactylus virginicus,* (E) *Menticirrhus cuiaranensis,* and (F) *Conodon nobilis;* and otolith height vs fish total length for (G) *Polydactylus virginicus,* (H) *Menticirrhus cuiaranensis,* and (I) *Conodon nobilis.*

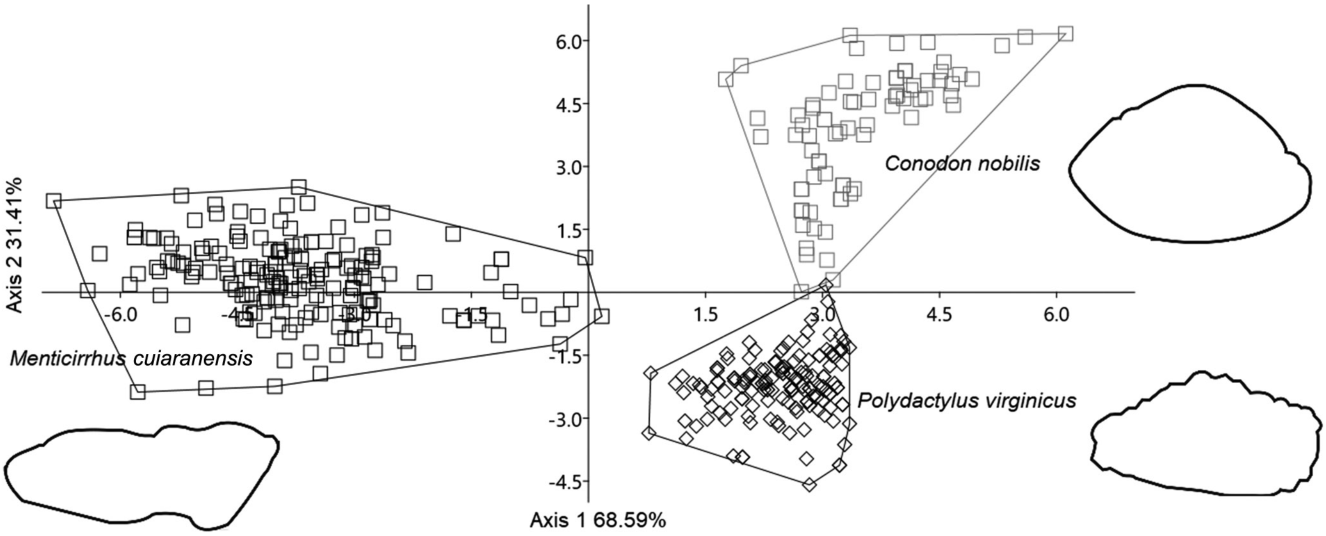

Figure 6. Scatterplot of the linear discriminant analysis of morphometry and shape indices of the *sagitta* otolith of *Polydactylus virginicus, Menticirrhus cuiaranensis* and *Conodon nobilis.*

similarities were observed in the shape of the *sulcus acusticus* and *cauda* for all of them, and also in the position and type of *sulcus acusticus* for *P. virginicus* and *C. nobilis.* Even though *P. virginicus, M. cuiaranensis* and *C. nobilis* are demersal species, the otolith shape is different among them (rectangular, bullet shaped, and oval, respectively). For Gauldie (1988), it is the shape of the *sulcus,* and not the otolith shape, that is associated with acoustic sensitivity, which in turn depends on the habitat. However, this author did not present details on how this association works. In the present study, the shape of the *sulcus acusticus* was heterosulcoid for all three demersal species analyzed. The exact mechanism that relates the *sulcus* shape with higher acoustic sensitivity would have to be better investigated in future studies. Additionally, Cruz & Lombarte (2004) pointed out that Sciaenidae and Haemulidae families, which include *M. cuiaranensis* and *C. nobilis,* respectively, belong to groups specialized in sound production. This could be associated with relatively large otoliths for better acoustic communication.

Our study was the first to evaluate the ontogenetic variation of otoliths for *P. virginicus, M. cuiaranensis* and *C. nobilis* using shape indices. Only the OH/OL x100% demonstrated a change in trend associated with ontogenetic variation mainly for *P. virginicus* and *C. nobilis.* According to Volpedo & Echeverria (2003), values of aspect ratio between 21% and 96% and the absence of *rostrum* indicate species associated with a soft bottom. Conversely, species associated with a consolidated substrate show values between 41% and 67% and a small *rostrum.* The aspect ratio and the presence of a small *rostrum* indicate that *P. virginicus* and *C. nobilis* inhabit consolidated and soft substrates, respectively (Brenha-Nunes *et al.,* 2016; Santificetur *et al.,* 2017). The absence of rostrum indicates that *M. cuiaranensis* lives in environments of unconsolidated sediment as mentioned for other species of the same genus *Menticirrhus* (Carvalho *et al.,* 2020). *Polydactylus virginicus* showed a reduction in the aspect ratio in specimens larger than 15 cm TL, when this species starts the maturation process (Freire *et al.,* 2020). This may indicate a change in habitat after maturity between juveniles and adults, or in swimming capacity associated with feeding change. On the other hand, the aspect ratio of the otoliths from *C. nobilis* increased until specimens were 20 cm TL long and kept stable onwards. Note that the length at first maturity for this species is about 21 cm TL in a neighboring area (da Silva *et al.,* 2019). Here, again, a change in habitat for juveniles and adults may be occurring. The otoliths of *Menticirrhus* are elongated (Siliprandi *et al.,* 2014; Carvalho *et al.,* 2020), as also observed for *M. cuiaranensis* in the present study, but no change was observed in the aspect ratio for the length range analyzed here.

According to Iizuka & Katayama (2008), demersal species present otoliths within two groups defined by their external shape: elongate (or elliptical) and orbicular (or ellipsoidal). This difference was evident for the three species analyzed here, with elliptical otoliths found in *P. virginicus* and *M. cuiaranensis,* and ellipsoidal in *C. nobilis.* Moreover, the former two species presented a positive allometry in the relationship between body weight and length, but negative when the same relationship was estimated for the otolith. On the other hand, *C. nobilis* presented body isometry, but a positive otolith allometry, which is related to the ellipsoidal shape of its *sagitta* otolith. Hence, otoliths of *C. nobilis* are disproportionately heavier than the other two species. One could hypothesize that *C. nobilis* presents higher acoustic sensitivity based on Lychakov & Rebane (2000), who stated that the heavier the otolith, the higher its acoustic sensitivity in lower frequency. This higher acoustic sensitivity should be further investigated in future studies involving *C. nobilis.*

The otolith shape is usually species-specific, but intraspecific geographic variation may occur due to environmental factors (Santos *et al.,* 2017; Maciel *et al.,* 2020). The morphology and morphometry of the otoliths from *P. virginicus* and *C. nobilis* were analyzed in previous studies carried on southeastern-southern Brazil (Brenha-Nunes *et al.,* 2016; Santificetur *et al.,* 2017), showing similar characteristics to specimens inhabiting northeastern Brazil. The applied methodology was not the most sensitive to determine contour variations that may show latitudinal influence. Several external factors can influence the otolith shape (Torres *et al.,* 2000; Capoccioni *et al.,* 2011; Avigliano *et al.,* 2012), including beach hydrodynamics. However, no study has been conducted in Brazil correlating these two variables. Could the differences observed in the otoliths of the three species represent a response to the beach dynamics? Future studies of the morphology and morphometry of the otoliths of such demersal coastal species should try to correlate the beach hydrodynamics with the otolith shape.

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AUTHORS' CONTRIBUTIONS

C.S.O.: Collection, data collection, data analysis and writing. K.M.F.F.: Collection, data collection, data analysis and writing. L.C.R.: Discussion of data and assistance in the preparation of the final version of the manuscript. B.M.C.: Data analysis and writing.

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