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Original Article

# Morphometry and morphology of fish otoliths on the coast of the state of Maranhão, Brazil

## Morfometria e morfologia de otólitos de peixes no litoral do estado do Maranhão, Brasil

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**Abstract**

The main objective of this study was to evaluate the biometric relationships between the species *Bagre bagre*, *Lutjanus synagris* and *Nebris microps* and their otoliths. The relationship between the size of the otolith (length and weight) and the size of the fish (standard length and total weight) was determined using the linear regression model (y = a + bx). For the morphological description, the otoliths of three specimens were selected by standard length class (10mm). The morphological characters analyzed were chosen according to traditional literature. Three hundred eight specimens of *B. bagre*, 200 of *L. synagris* and 237 of *N. microps* were analyzed. Throughout the collection period, the source of the capture of individuals was the municipality of Raposa. The linear correlations for fish and otolith length for *B. bagre* were 0.9129 and 0.9652, respectively. For *L. synagris*, the coefficients were 0.8634 and 0.8672, while for *N. microps*, 0.9597 and 0.8636, respectively. The morphological classification of *L. synagris* and *N. microps* is of the Saggita type, and the *B. bagre* species is of the Lapillus type. From the data presented here, it is possible to observe that otolith morphometric and morphological data can serve as a parameter to estimate the relationship between the fish and the otolith in terms of its biomass and the length of an individual and a population.

**Keywords:** morphometry characterization, *Bagre bagre*, *Lutjanus synagris*, *Nebris microps*, sagittae.

**Resumo**

O objetivo principal deste estudo foi avaliar as relações biométricas entre as espécies *Bagre bagre*, *Lutjanus synagris* e *Nebris microps* e seus otólitos. A relação entre o tamanho do otólito (comprimento e peso) e o tamanho do peixe (comprimento padrão e peso total) foi determinada através do modelo de regressão linear (y = a + bx). Para a descrição morfológica, os otólitos de três espécimes foram selecionados por classe de comprimento padrão (10mm). Os caracteres morfológicos analisados foram escolhidos de acordo com a literatura tradicional. Foram analisados trezentos e oito exemplares de *B. bagre*, 200 de *L. synagris* e 237 de *N. microps*. Durante todo o período de coleta, a fonte de captura dos indivíduos foi o município de Raposa. As correlações lineares para peixes e comprimento de otólitos para *B. bagre* foram 0,9129 e 0,9652, respectivamente. Para *L. synagris*, os coeficientes foram 0,8634 e 0,8672, enquanto para *N. microps*, 0,9597 e 0,8636, respectivamente. A classificação morfológica de *L. synagris* e *N. microps* é do tipo Saggita, e da espécie *B. bagre* é do tipo Lapillus. A partir dos resultados aqui apresentados é possível observar que os dados morfométricos e morfológicos dos otólitos podem servir de parâmetro para estimar a relação entre o peixe e o otólito em termos de sua biomassa e do comprimento de um indivíduo e de uma população.

**Palavras-chave:** caracterização morfométrica, *Bagre bagre*, *Lutjanus synagris*, *Nebris microps*, sagittae.

## 1. Introduction

The precise identification of target species for fishing is essential to understand their biology, ecological niche, and stock structure in detail (Cadrin, 2020). Fishing plays a crucial role in commercial and subsistence activities. To achieve this objective, ensuring the protection and sustainability of existing fishing resources and biodiversity is imperative. The management and evaluation of these resources face considerable challenges, mainly due to the scarcity of data available on fisheries (Despoti et al., 2020). Determining current biodiversity and fish stocks is essential to implement regulations effectively, thus promoting sustainable fishing practices (Acero, 2022).

The coast of Maranhão is a region comprising 640 km of coastline and stands out as a crucial area for exploring fishing resources in Brazil (Nunes et al., 2005). Among the notable species in this region are the catfish *Bagre bagre*

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(Linnaeus, 1766), *Lutjanus synagris* (Linnaeus, 1758) and *Nebris microps* (Cuvier. 1830), representing the families Arridae, Lutjanidae and Sciaenidae, respectively, have a wide distribution along the Brazilian coast and are highly valued commercially in the state of Maranhão (Acero, 2022; Bernardo et al., 2011; Carvalho-Neta et al., 2011; Fisher, 1978). Although past studies have addressed the fisheries biology of these species, including stock identification, population structure (Casatti et al., 2015; Correia et al., 2021) growth, and reproductive biology (Fernandes et al., 2022), as well as the weight-length relationship (Almeida et al., 2020) there is a need for further investigations to understand the population dynamics of these animals.

Several approaches to identifying species and their stocks have emerged with the advancement of technologies in recent decades. Each method has advantages and disadvantages, especially its sensitivity in detecting variations in specific characteristics of a species. Given this diversity, the frequent recommendation is to adopt a multidisciplinary approach, as highlighted by Begg and Waldman (1999), Cadrin and Secor (2009). Currently, there is a lack of data on the structure and status of stocks of many commercially exploited species, such as catfish, snapper, and hake, representing a significant portion of the annual catches of artisanal and industrial fleets in Maranhão. However, only for *L. synagris* information on otolith morphometry and isotopic composition was used in the identification and discrimination of stocks in subtropical waters from the North Atlantic to southern Brazil (Luckhurst et al., 2000; Santos et al., 2022; Schwamborn et al., 2023). Therefore, additional research strategies are needed to fill this knowledge gap and strengthen the foundations for even more sustainable fisheries management in regions where these species occur.

In recent years, fish otolith studies have emerged as an essential research tool widely adopted to guide sustainable fisheries management practices (Bremm and Schulz, 2014; Canty et al., 2018; Gebremedhin et al., 2021). Understanding growth patterns and morphometric characteristics is crucial in understanding population dynamics, providing an essential informational basis for directing management initiatives (Campana, 1999). Otoliths are an important anatomical structure in fish's inner ear. These calcified structures are used to determine the age of fish by counting concentric rings formed throughout life (Campana and Thorrold, 2001). However, these analyses are expensive and require sensitive equipment (Martinelli et al., 1988). Therefore, a more accessible and simplified approach to obtaining information about a fish population and stock is to perform otolith length and weight measurements, allowing comparative studies of their shapes.

Morphometric measurements are traditionally employed to evaluate fish taxonomic descriptions and predefined biological variations. However, new tools have been explored to discriminate fish species. These include otoliths and their morphology, representing an essential criterion in fishing activities, evidenced by a variety of identification guides, atlases, and fishing studies (Conversani et al., 2017; Granados-Amores et al., 2020; Santificetur et al., 2017; Siliprandi et al., 2016). Thus, using calcareous structures in ontogenetic studies of fish helps to understand the developmental biology of fish species, in addition to assisting subsequent systematic and taxonomic studies that can promote the identification of samples in natural environments (Nakatani et al., 2001). In general, otoliths are metabolically inert and grow according to the morphological development of the fish (Fergusson et al., 2011), thus functioning as good phenotypic markers (Capoccioni et al., 2011).

Currently, research has shown that the use of calcified structures in fish, such as otoliths, has been presented as an effective tool for understanding the dynamics of fish populations (Garcez et al., 2015; Pouilly et al., 2014; Hegg et al., 2015; Sousa et al., 2016; Hermann et al., 2016; Duponchelle et al., 2016; Santos, 2018a). Due to the variation of otoliths in their morphology and morphometry in each species, studies are needed to characterize this parameter, many of which are the basis for creating species identification keys (Morrow, 1979). Thus, considering the economic relevance of these species on the coast of Maranhão, the objective was to characterize the morphology and morphometry of the otoliths of the species *B. bagre*, *L. synagris*, and *N. microps* obtained during the fishing seasons in the rainy and dry periods acquired in the municipality of Raposa.

## 2. Material and Methods

### *2.1. Characterization of the study area*

Maranhão is located in the west of northeastern Brazil and is the second state with the largest territorial extension in Brazil (329,642.142km$^2$) (IBGE, 2021). As it presents the second largest Coastal Zone in Brazil, two well-defined regions are delimited: a western portion, called the Amazon coast, characterized by the Amazon biome, and a portion to the east, called the north coast of the northeast region, visible to aspects of the cerrado and caatinga biomes (Belfort and Nascimento, 2021). The municipality of Raposa (02º25'22'S; 44º05'21'W) has a territorial extension of 79,213 km$^2$ and is located in the Mesoregion of the Urban Agglomeration of São Luís, forming part of the Upaon-Açu-Miritiba-Alto- Preguiças, which has an expansion of 1,535,310 hectares (Santos, 2018b).

The fishing area used was between the geographic coordinates Latitude 2º23' and Longitude 44º06' (Figure 1) in the Raposa municipality, where specimens of the species covered in this study were captured through commercial fishing.

### *2.2. Sample collection*

The specimens were collected from 2018 to 2021 in the rainy (January to June) and dry (July to December) seasons. Throughout the collection period, the capture location of individuals was in the municipality of Raposa, with fishing carried out by fishermen from the region who later disembarked at Raposa Seaport. The fishing artifacts for capturing *B. bagre* and *L. synagris* were carried out using gill nets (nº0,50 e 0,60 respectively), and *N. microps* were caught by bottom trawl net (nylon nº40 and mesh nº30).

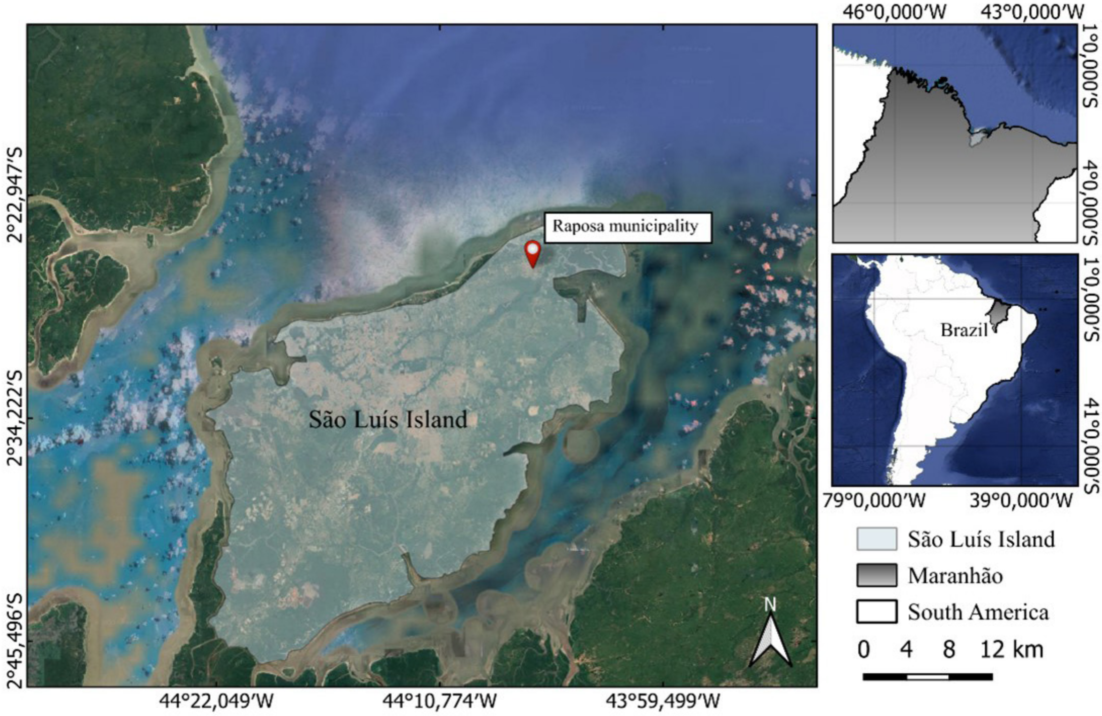


**Figure 1.** Geographic location of the collection area in the municipality of Raposa- Maranhão, Brazil.

After purchasing directly from the fisherman, the specimens were packaged in plastic bags, identified and placed in isothermal boxes to be transported to the Fisheries Biology Laboratory (BIOPESQ - UEMA), where the biological material was processed.

*2.3. Biometry*

For all collected organisms, Total Length (TL) was measured in centimeters (cm) with the aid of a measuring tape (precision: 0.01cm), and quantification of total weight (TW) and eviscerated weight (EW), with the precision scale (precision: 0.01g).

*2.4. Extraction, morphological and morphometric analysis of otoliths*

A transverse section was made perpendicular to the eye, and posteriorly, the otoliths were removed from the fish's auditory capsule (Secor et al., 1995). After extraction, the otoliths were washed in running water and 70% alcohol to remove fish residue. After drying, they were stored in an eppendorf duly labeled in the Fisheries Biology Laboratory of the State University of Maranhão collection. The characterization of otoliths was carried out based on their internal face, with the analysis divided into two stages: morphology and morphometry.

Subsequently, the following characters were individually extracted from each otolith: otolith length (measured between the end of the rostrum and the posterior margin of the otolith), otolith height (greatest distance between the lower and upper margins of the otolith) and otolith thickness (greater distance between the internal surface and the external surface) and weight (mass of the otolith) (Corrêa and Vianna, 1993) (Figure 2). An analytical scale (precision: 0.001 g) and a digital caliper (precision: 0.01 mm) were used to extract these variables.

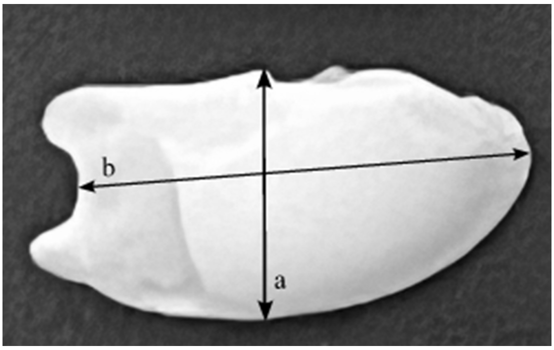


**Figure 2.** Morphometric measurements of the otolith of the species Nebris microps collected in the municipality of Raposa-MA. (a) otolith height (greatest distance between the lower and upper margins of the otolith); (b) otolith length (measured between the end of the rostrum and the posterior margin of the otolith).

For the morphological description, otoliths from three specimens were selected for each standard-length class (10mm). Morphological characters were analyzed following the protocol adapted from Corrêa and Vianna (1993) and Assis (2000), including the following characteristics: otolith type, sulcus opening shape, sulcus position, and otolith shape.

*2.5. Data analytics*

The individuals were organized into classes based on the variables for length and weight and, using the Sturges (1926) formula: NC×= 1 + 3.322(log10 n), where NC is the number of classes and n is the total number of individuals. The class interval (RC) was calculated according to the equation RC = SR / NC, where SR is the size range (total length of the largest individual - total length of the smallest individual) (Cabral Junior et al., 2021; Vaz-dos-Santos and Silveira, 2021).

Regarding the morphometry of the otoliths, a student's t-test was performed for independent samples to verify the existence of differences between the dimensions of the left and right sides of the otolith. Subsequently, the relationship between the size of the otolith (length and weight) and the size of the fish (standard length and total weight) was fitted using a linear equation (y=a+bx) (Zar, 1984). Normality assumptions were tested using the Shapiro-Wilk test. All analyses were conducted using R version 4.2.3 at a significance level of 5% (R Development Core Team, 2009).

## 3. Results

Three hundred and eight specimens of *B. bagre*, 200 of *L. synagris* and 237 of *N. microps* were analyzed. The otoliths of the species studied were categorized according to the position of the sulcus acusticus: *N. microps* species located in the lateral area (Figure 3a), *L. synagris* (Figure 3b) in the middle area and lapillus species *B. bagre* in the lower region (Figure 3c) (Table 1).

The otoliths presented lengths for the species *B. bagre* ranging from 6.58 to 12.19 mm and weight from 0.12 to 0.75 g. For *L. synagris*, the otolith length varied between 4.56 and 18.22 mm; for weight, it was 0.15 to 2.33 g. For *N. microps*, the otolith length ranged from 9.71 to 15.73 mm, and the weight ranged from 0.26 to 1.05 g (Table 2). For the three pairs respectively of each species, the Student's T test was applied, which did not show in any of the three cases significant differences ($p>0.05$) between the otolith on the left and right side. Therefore, the right otolith was used in all the analyses.

In the species *B. bagre* otolith sample, six classes were formed for the fish and the otolith length. For the length of the fish, the least representative class was 32|- 34cm with a percentage of 7%, and the most representative was 28|- 30cm with 30% representation (Figure 3). Concerning the otolith, the least representative class was 9|- 10mm with 13%, and the most representative with 21% was 11|- 12mm.

For the species *L. synagris*, seven classes were formed for the fish and the otolith length. For the length of the fish, the least representative class was 39|-42cm with a percentage of 4%, and the most representative class was 35|-38cm with 30% representation (Figure 3). Concerning the otolith, the least representative class was 11|-12mm with 7%, and the most representative class with 23% was 14|-15mm.

For *N. microps*, six classes were also formed for the length of the fish and the otolith. For the length of the fish, the least representative class was 25|-27cm with a percentage of 5%, and the most representative class was 35|- 38cm with 32% representation. Concerning the otolith, the least representative class was 09|-10mm with 7%, and the most representative was 12|-13mm with 28% (Figure 4).

The linear regressions of the lengths between the individual × otolith and weights of individuals × weight of otoliths of *B. bagre*. For the species *L. synagris*, the linear regressions of the variable weights of otoliths × of individuals and length of otoliths × and lengths between individuals (Figure 5) showed in both cases a positive linear relationship, thus indicating that the regression model fits the data well. In *N. microps*, linear regressions showed that the variable length of the individual × otolith, presented a strong positive linear relationship, where the correlation coefficient ($r^2$) was 0.9597. Similarly, for the variable otolith weight x of the individual, it showed a positive linear relationship, with the value of $r^2 = 0.8636$.

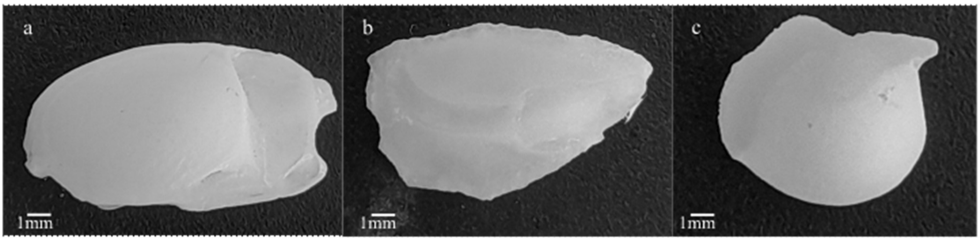


**Figure 3.** Morphological classification of the species *N. microps* (a), *L. synagris* (b) and *B. bagre* (c) captured in the municipality of Raposa-MA.

**Table 1.** Morphological classification of the species *B. bagre*, *L. synagris* and *N. microps* captured in the municipality of Raposa.

| **Characteristics** | *Bagre bagre* | *Lutjanus synagris* | *Nebris microps* |
|---|---|---|---|
| Type | *Lapillus* | *Saggita* | *Saggita* |
| Opening of the otolith sulcus acusticus | ostial | ostial | ostial |
| Position of the sulcus acusticus on the otolith | inferior | middle | lateral |
| Otolith shape | circular | elíptica | oval |

**Table 2.** Length, height, thickness and weight variables of the species *B. bagre*, *L. synagris* and *N. microps* captured in the municipality of Raposa.

| SPECIES | VARIABLE | MEAN (Ẍ) | SD | MIN | MAX |
|---|---|---|---|---|---|
| | Lenght (Lo) | 8.89mm | 0.93mm | 6.58mm | 12.19mm |
| *Bagre bagre* | Height (Ho) | 5.97mm | 1.63mm | 3.41mm | 8.51mm |
| | Thickness (To) | 5.38mm | 2.18mm | 2.07mm | 10.09mm |
| | Weight (Go) | 0.30g | 0.11g | 0.12g | 0.75g |
| | Lenght (Lo) | 15.72mm | 1.84mm | 4.56mm | 18.22mm |
| *Lutjanus synagris* | Height (Ho) | 8.84mm | 0.92mm | 5.69mm | 11.61mm |
| | Thickness (To) | 4.48mm | 0.68mm | 2.92mm | 8.56mm |
| | Weight (Go) | 0.44g | 0.20g | 0.15g | 2.33g |
| | Lenght (Lo) | 13.09mm | 1.65mm | 9.7mm | 15.7mm |
| *Nebris microps* | Height (Ho) | 6.7mm | 1.02mm | 5.4mm | 8.5mm |
| | Thickness (To) | 5.82mm | 1.04mm | 3.9mm | 7.8mm |
| | Weight (Go) | 18.45g | 113.84g | 0.26g | 1.05g |

SD = standard deviation; MIN = minimum value; MAX = maximum value.

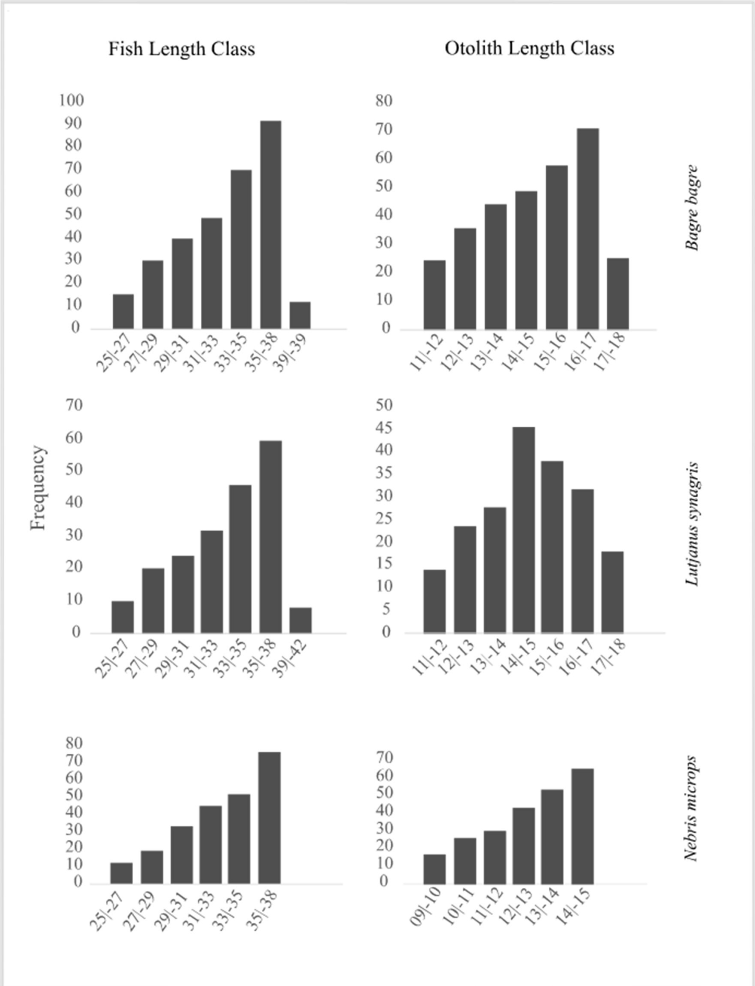


**Figure 4.** Representation of the classes regarding the variable length of the individual (cm) and the length of the otolith (mm) of the species *Bagre bagre*, *Lutjanus synagris* and *Nebris microps* collected in the municipality of Raposa-MA.

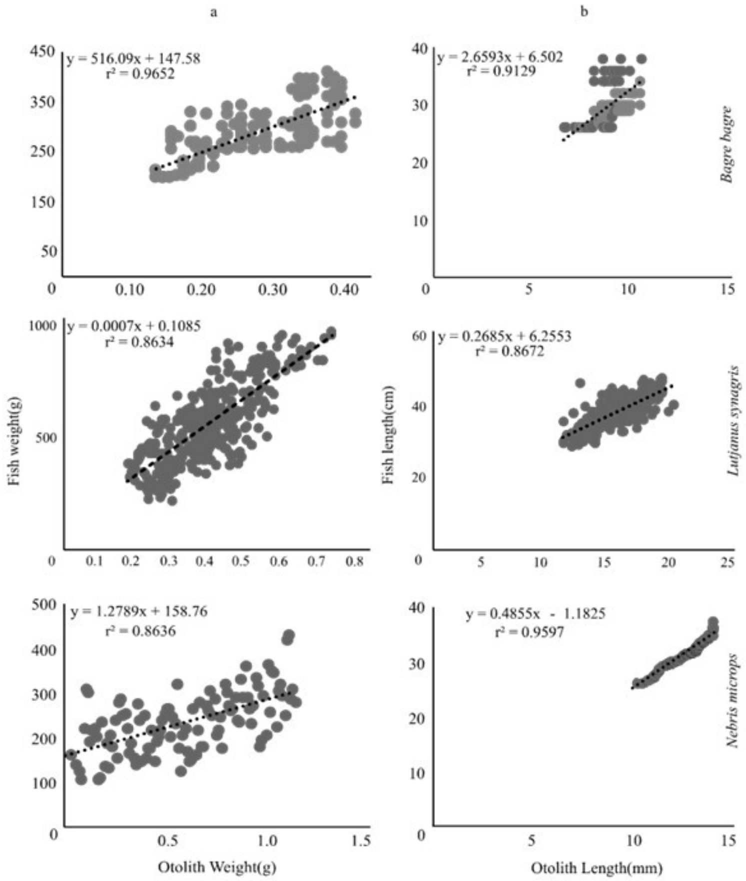


**Figure 5.** Relationship between the lengths of the organism × otolith (a) and the weight of individuals × otoliths (b) of the species of *B. bagre*, *L. synagris* and *Nebris microps* captured in the Municipality of Raposa-MA.

## 4. Discussion

The species representing the families Ariidae (*B. bagre*), Lutjanidae (*L. synagris*) and Scianidae (*N. microps*) analyzed in this study regarding the variables length and general weight are following the standard values found in the literature (Lagemann and Fialho, 2014; Marceniuk, 2005; Santander-Neto et al., 2020). These species have high economic and gastronomic importance due to their high protein value and ease of capture (trawl and gill net), featuring prominently (Almeida et al., 2011; Sousa et al., 2017).

The biometric relationships between otolith and fish measurements showed a better fit for the weight variable, with a coefficient of determination of $r^2 = 0.96$. This implies that it is possible to predict the weight of the species under study with 96% accuracy through the weight of otoliths. Likewise, fish length was explained by 91% of the variation in otolith length. These results are similar to those presented in a study carried out in the state of Paraná in 2014 with the species *Cathorops spixii* and *Genidens genidens*, belonging to the same Ariidae family, which presented high correlation coefficients for these variables who found that otolith weight is the most accurate indicator of fish biometric measurements, compared to length and width. (Carvalho et al., 2014).

Thus, the biometric relationships between otolith and fish measurements exhibited similar adjustments for the weight variable. This implies that through the length and weight of otoliths, it is possible to predict the length and weight of the species with approximately 86% accuracy. Studies carried out in Colombia in 2019 with *Lutjanus argentiventris* and another in northeastern Brazil with *Lutjanus chrysurus* in 2004 showed similar patterns to those found here (Diedhiou et al., 2004; Puentes-Granada et al., 2019).

Thus, differing from the *B. bagre* species, the biometric relationships between otolith and fish measurements exhibited a better fit for the length variable, with a coefficient of determination of $r^2 = 0.95$. In other words, the length of the species *N. microps* can be predicted through the otolith length with an accuracy of 95%. According to Aydin et al. (2004), these divergences between the levels of these correlations can be explained by dependence on other factors, such as food and fish habitat conditions, since the species in the present study have different bioecology. According to the same author, there is a stronger linear relationship between the length of the fish and the size of the otolith in younger fish than in older fish since the length of the otolith is linearly related to the length of the fish until it reaches the maximum size, from then on the otolith only increases in thickness; thus contributing to the greatest increase in weight.

Therefore, the morphometry and morphology of otoliths are essential tools in describing and studying fish development (Vaz-dos-Santos and Silveira, 2021). From the data presented here, it is possible to observe that otolith morphometric and morphological data can serve as a parameter to estimate the relationship between the fish and the otolith in terms of its biomass and the length of an individual and a population.

The dimensions of otoliths constitute an essential set of descriptors of fish development (Gomiero and Braga, 2007; Vaz-dos-Santos and Silveira, 2021). This technique can be used as an alternative to estimate the biomass and size of fish, even when undergoing complex changes in their morphological features. Furthermore, studies of the morphometry and morphology of otoliths show that, although simpler and low cost, it is still poorly implemented. This information confirms species from the Amazon basin since otolith analyses are aimed at researching age, growth and microchemistry, which are high-cost studies and depend on precision technology (Cutrim and Batista, 2005; Silva, 2022; Vaz-dos-Santos and Silveira, 2021).

This study is pioneering for the Maranhão Amazon coast region, serving as a parameter for evaluating fish biology and future age and growth studies (Almeida et al., 2020). The results acquired from the morphometric and morphological relationships between otoliths and individuals of *B. bagre*, *L. synagris* and *N. microps* can be carried out as financial, methodological and faster cost-benefit methods compared to other otolith studies. Therefore, this methodology is very effective in evaluating and managing species of commercial importance in the municipality of Raposa.

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