Ocean
and Coastal
Research

ORIGINAL ARTICLE

http://doi.org/10.1590/2675-2824070.22035pm
ISSN 2675-2824

Relative growth and morphometry of sagittae otoliths of weakfishes, *Cynoscion guatucupa* (Cuvier, 1830) and *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883), in the Southwestern Atlantic Ocean, Brazil

Pablo Mendonça[1,3]*, João Pedro de Mello Domingues[3], Arthur de Barros Bauer[2], Luciano Gomes Fischer[2], Marcus Rodrigues da Costa[1,3]

[1] Universidade Federal Fluminense. Instituto de Biologia - Programa de Pós-Graduação em Biologia Marinha e Ambientes Costeiros (Rua Prof. Marcos Waldemar de Freitas Reis, s/n - Campus do Gragoatá, Bloco M - São Domingos - Niterói - 24210-201 - RJ - Brazil)
[2] Universidade Federal do Rio de Janeiro - Instituto de Biodiversidade e Sustentabilidade (NUPEM/UFRJ). Av. São José Barreto, 764 - São José do Barreto - Macaé - 27965-045 - RJ - Brasil)
[3] Universidade Federal Fluminense. - Instituto de Biologia - Laboratório de Biologia do Nécton e Ecologia Pesqueira. Niterói, RJ, Brasil (Rua Prof. Marcos Waldemar de Freitas Reis, s/n - Campus do Gragoatá, Bloco M - São Domingos - Niterói - 24210-201 - RJ - Brazil)

* Corresponding author: pablomendonca@id.uff.br

ABSTRACT

The weakfishes, *Cynoscion guatucupa* and *C. jamaicensis*, are important demersal fishery resources and are targeted by multifleet operations in the Southwest Atlantic. This study describes the length-weight relationships between *sagittae* otoliths (length-O_L, height-O_H, thickness-O_T and weight-O_{WT}) and the sizes of the fish (total length-L_T, standard length-L_S, and total weight-W_T). The proportion between otolith length and height (aspect ratio-O_{AR}) was also compared between species. The samples were obtained monthly from March 2017 to February 2018 from small-scale commercial fisheries from landings of bottom trawls and gillnets on the continental shelf in the Rio de Janeiro state, southeastern coast of Brazil. The ANCOVA did not indicate significant differences in relative growth between sexes for both species ($p > 0.05$) while the length frequency was different ($p < 0.001$). *Cynoscion guatucupa* showed positive allometry, $W_T = 4E\text{-}06L_T^{3.21}$ and *C. jamaicensis* negative allometry, $W_T = 2E\text{-}05L_T^{2.90}$ ($p < 0.05$). Both species showed differences in the condition factor between the sexes ($p < 0.05$). Significant differences were observed in the measurements of the otoliths between the two species ($p < 0.001$). All regressions between fish measurements and otolith morphometry were highly significant ($p < 0.001$) for both species. The best estimates of fish size and weight were related to the otolith length: O_L *vs* L_T ($r^2 = 0.93; 0.96$); O_L *vs* L_S ($r^2 = 0.92; 0.96$); O_L *vs* W_T ($r^2 = 0.91; 0.93$) for *C. guatucupa* and *C. jamaicensis*, respectively. This information adds useful biological data for multiple types of studies, *e.g.*, food ecology (prey-predator), age and growth, reproduction, fisheries assessment and long-term landing monitoring. Our results confirmed the historical pattern of relative growth, supporting that otolith growth reflects the somatic growth of weakfishes in the study area, reinforcing the importance to determine these reference points.

Descriptors: Length-weight relationships, Otolith size , Somatic growth, Sciaenidae, Condition factor.

INTRODUCTION

Otoliths are complex, metabolically inert, intermittently growing polycrystalline structures located in the inner ear of bony fish (Volpedo and Vaz dos Santos, 2015). They are responsible for balance in the water column and sound detection (Popper et al., 2005). They function as phenotypic markers (Tuset et al., 2008; Volpedo et al., 2017), with morphological and morphometric patterns that have been used in paleontological studies (Aguilera et al., 2013; Klokler, 2020), trophic ecology of

Submitted: 15-Apr-2022
Approved: 21-Sep-2022

Associate Editor: Francesc Maynou

piscivores (Bustos et al., 2014; Miotto et al., 2017), stock identification (Avigliano et al., 2015; Zischke et al., 2016), habitat use (Avigliano et al., 2014; Carvalho et al., 2017), populational connectivity (Teimori et al., 2012; Davoren and Halden, 2014), and estimates of age and growth parameters (Vaz-dos-Santos and Rossi-Wongtschowski, 2019). Morphometric studies between species make it possible to expand the use of otoliths as key elements for understanding species and populations. The use of bivariate morphometry has been widely used to describe the relationships between fish; using otolith measurements is common (Vaz-dos-Santos et al., 2007; Perin and Vaz-dos-Santos 2014; Carvalho et al., 2014), including length-weight relationships (Tuset et al. 2003a, Lega et al., 2013). The combination of the allometric model with the study of this structure, which formed during the early development of fish, produces a powerful and precise estimate (Campana, 2001).

Length-weight relationship models (LWR) are considered an important tool in the study of fisheries biology, as they provide baseline information for estimating growth rates, age and other components of population dynamics (Haimovici and Velasco, 2000; Giariizzo et al., 2015; Barradas et al., 2016; Costa et al., 2018). The knowledge of two biological parameters (linear ***a*** and allometric ***b***, coefficients) provided by LWRs allows indirect estimates of different population characteristics, such as: i) determination of fish weight using a given length or vice versa; ii) analysis of the growth pattern as a function of the allometric coefficient, comparing populations from different regions and environmental conditions; iii) assessment of biomass and body conditions as an indicator of the species' well-being and developmental performance (*i.e.* evidence of fat accumulation and gonad development) (Froese et al., 2011). Based on the condition factor (K), inferences can be made about recent nutritional status and energy investments in cyclical activities, such as reproduction and migration, making it possible to relate environmental conditions to the behavioral aspects of the species (Vazzoller, 1996; Van Dijk et al., 2005). In this way, populations in different climatic and food situations can be compared, reproductive cycles and food activity identified, evaluating the efficiency of the use of different food sources (Weatherley, 1972).

The shape and size of the otoliths represent a pattern among bony fish families, usually species-specific (Harvey, 2000; Tuset et al., 2008). Studies demonstrating a positive correlation between otolith length and fish length and weight are common (Battaglia et al., 2010; Souza et al., 2019; Chanthran et al., 2020). Variations may occur between species and individuals, due to physiological or exogenous factors (Volpedo and Echeverría, 1999; Lombarte et al., 2003). Although many studies address these variations, otolith morphometric studies of weakfishes are scarce with only one study available on Jamaican weakfish, where a physical oceanographic influence is the main factor that affects the relative growth and otolith dimensions (Spach and Yamaguti, 1989a, b).

Sciaenidae is a family of coastal fish, abundant and widely distributed in the Southwest Atlantic, which includes some of the most important species in fisheries on the inner continental shelf of southeastern Brazil (Vazzoller et al., 1999). They have a majority share in demersal landings in small, medium and large-scale fisheries, either as target species for gillnet and bottom trawl fleets or as bycatch in shrimp fisheries (MPA, 2010; Chao et al., 2015; FIPERJ, 2020). In general, juveniles occur in estuaries and coastal lagoons, while adults inhabit the inner continental shelf and greater depths (Menezes and Figueiredo, 1980; Fischer et al., 2011).

Popularly known as croakers, drums and weakfishes, sciaenids have relatively large otoliths, with interspecific differences in shape (Monteiro et al., 2005), being considered appropriate models for studies on shape variation and function (Ramcharitar et al., 2001; Cruz and Lombarte, 2004). Otoliths of different species have been used in studies related to allometric variations (Aguirre, 2003; Monteiro et al., 2005; Bervian et al., 2006), correlations between size and sound production (Cruz and Lombarte, 2004), size and habitat use (Hoff and Buiman, 1993; Paxton, 2000), as well as for group systematics (Paxton, 2000) and prey identification, using food items recovered from the digestive tract, feces and regurgitated material from piscivorous animals (Tollit et al., 1997; Granadeiro and Silva, 2000).

Cynoscion guatucupa (Stripped weakfish, maria-mole or pescada-olhuda in Portuguese) and *Cynoscion jamaicensis* (Jamaica weakfish *or* goete in Portuguese) are sciaenids commonly captured by gillnet and bottom trawl fisheries in practically the entire southeastern and southern coast of Brazil (Haimovici and Miranda, 2005; Castro et al., 2005; FIPERJ, 2020). They have a prolonged reproductive period with multiple spawnings (Vazzoler and Braga, 1983; Vieira and Haimovici, 1993). Both are carnivorous and reach about 60 and 40 cm in total length, respectively (Haimovici and Velasco, 2000; Castro et al., 2005), attracting significant commercial interest as target species for small and large-scale fisheries in this Brazilian coastal area (Chao et al., 2015). Between 2017 and 2019, only considering the state of Rio de Janeiro, around 65 tons of *C. guatucupa* (46 t by bottom trawls and 19 t by gillnets) and 180 tons of *C. jamaicensis* (120 t by bottom trawls and 60 t by gillnets) were landed (FIPERJ, 2020). Although they represent important resources in terms of landed volume, most of what is known is about the populations of the Southern Brazilian coast, with a focus on age and growth (Vieira and Haimovici, 1993; Castro et al., 2002; Miranda and Haimovici, 2007), reproduction (Vieira and Haimovici, 1997) diet (Rondineli et al., 2007) or assessment of stocks and fisheries in the Southern and Southeastern Brazilian coast (Spach and Yamaguti, 1989a,b; Castro and Petrere Jr., 2001; Volpedo et al., 2007; Alves et al., 2020). The major information available on their biologies for the Southeastern Brazilian coast is derived from the REVIZEE program and other fishing cruises from past decades (Santos, 1963, 1968; Haimovici, 2000; Castro et al., 2002; Cergole et al., 2005). Current information is needed that can contribute to better knowledge and regional management of these resources.

Therefore, this study aims to: a) characterize the length-weight relationships (LWR) and condition factor (k) of weakfishes; b) evaluate possible differences between sexes and species; and c) characterize the relationships between the dimensions of the *sagittae* otolith and the length and weight of the fish. From this information, we provide useful data for regional studies of age and growth, reproduction, evaluation and management of these species. These results may serve as references for future comparisons to monitoring and can also be used by researchers studying the eating habits of top predators to determine the size and weight of prey-fish or reconstruction of trophic webs from recovered otoliths.

METHODS

Sampling and data acquisition

The specimens were collected monthly between March 2017 and February 2018 from small-scale fishing landings occurring next to the Municipal Fish Market of Macaé, located on the northern coast of Rio de Janeiro state, Southeastern Brazilian coast. Commercial fisheries were carried out with small-scale bottom trawlers and gillnets, in coastal waters between 15 and 50 meters deep (between Cabo de São Tomé 21°50’S and Cabo Frio 22°50’S) (Figure 1). This region is characterized by seasonal coastal upwelling events of the South Atlantic Central Water mass (SACW) caused by northeasterly winds, occurring more intensely during spring and summer (Valentin et al., 1987; Pantaleão et al., 2016).

All specimens were identified using regional identification literature (Figueiredo, 1992; Menezes et al., 2003) and measured at Total Length (L_T, ± 1 mm), Standard Length (L_S, ± 1 mm) and Total Weight (W_T, ± 1 g). Sexes were determined macroscopically by examining the gonads using the standard classification (Brown-Peterson et al., 2011). The otoliths were extracted, cleaned, dried and placed in numbered microtubes with silica gel pellets. The otoliths were measured with a digital caliper (0.01 mm) and weighed (O_{WT}) with a precision electronic balance (0.00001 g). O_L (length) was considered the greatest distance between the tip of the rostrum and the posterior margin; O_H (height) as the greatest distance between the dorsal and ventral margins; and O_T (thickness) the greatest distance between the proximal and distal faces of the otolith, in the region of the nucleus (Lombarte and Tuset, 2015). The otolith aspect ratio (O_{AR}) was calculated by dividing O_L by O_H (Figure 2).

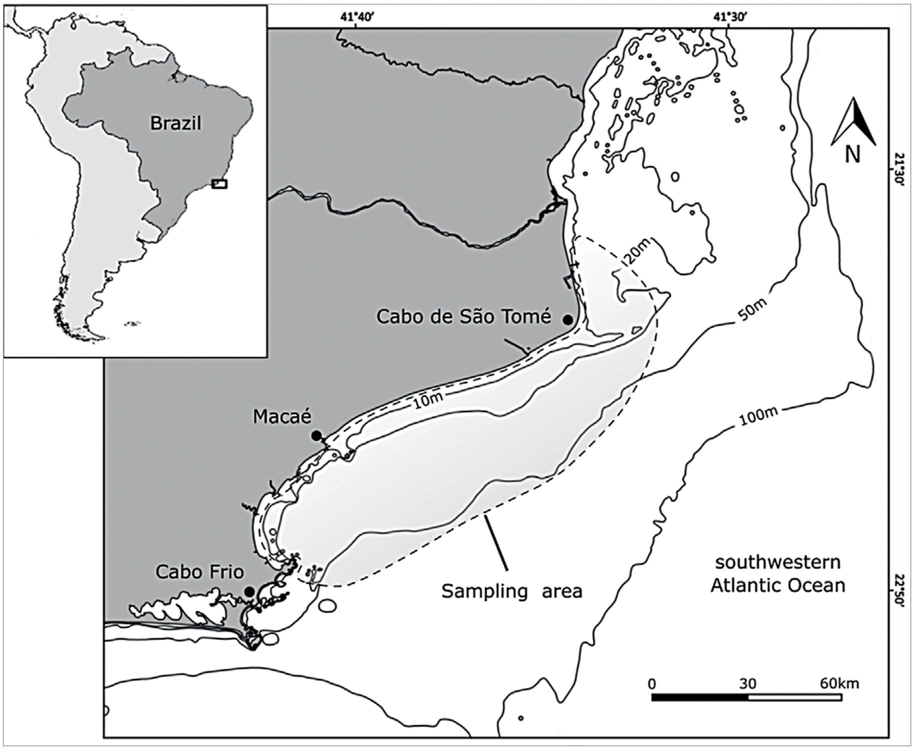

Figure 1. The northern coast of Rio de Janeiro (southeastern Brazilian coast) shows Macaé, 22ºS - 41ºW (fishery landing site) and the main small-scale fishery area (in gray bordered by the dashed line). The continuous line represents the isobaths: 10, 20, 50, and 100 meters deep.

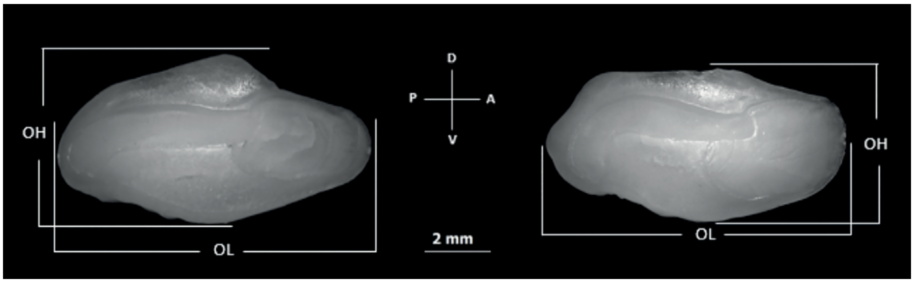

Figure 2. Left sagittae otoliths of Weakfishes, with indicated measurements, (a) *Cynoscion guatucupa*: LT =235 mm, WT =170.4g; (b) *Cynoscion jamaicensis*: LT = 234 mm, WT = 126.5g). OL, Otolith length; OH: Otolith height. Sense of direction: D = dorsal; V = ventral; P = posterior; and A= anterior.

DATA ANALYSIS

The measured data were previously tested for normality and homoscedasticity of variance, and non-parametric analyses were performed whenever the prerequisites for normality were not met (Zar, 2010). Differences in lengths (L_T, L_S) and in total weight (W_T) were tested between species and sexes using the Kruskal-Wallis test ($p < 0.05$). L_T values were distributed in a 20 mm size class and differences in sex ratio were determined using the chi-square test (χ^2, $p < 0.05$), followed by Yates correction (Zar, 2010).

The length-weight relationship (LWR) was described by the potential model: $W_T = \boldsymbol{a}T_L^{\boldsymbol{b}}$. Data were transformed into decimal logarithms for estimates of parameters ***a*** and ***b***, where ***a*** corresponds to the linear coefficient (related to body shape) and ***b*** corresponds to the angular or allometric coefficient (related to isometric growth) (Froese, 2006). For each ***b***, the Student's t-test ($t = \boldsymbol{b}\text{-}\beta_o/s_{\boldsymbol{b}}$) is the was applied to test the hypothesis that the calculated value was equal to 3.0 (Zar, 2010); where ***b*** is the parameter estimate, β_o is the parameter value hypothesized, and s_b is the standard error of parameter estimate. The 95% confidence intervals (CI) of ***a*** and ***b*** were also estimated. All outliers observed in the regression were excluded to better fit the model. Linear regression models were compared between sexes using Analysis of Covariance (ANCOVA, $p < 0.05$) (Zar, 2010). The physiological condition was quantitatively estimated through the condition factor (K), from the equation: $K = W_T/L_T^{\boldsymbol{b}}$, where k is the allometric condition factor and ***b*** is the coefficient of the potential equation of the LWR of males and females (Huxley, 1924). K values between sexes were compared using the non-parametric Kruskal-Wallis test (KW, $p < 0.05$).

No significant differences were found between the dimensions measured in the right and left otolith using the paired Student's t-test ($p < 0.05$) (Volpedo and Tompson, 1996). In this study, only data from the left otolith were used. The relationships between the dimensions measured in the otoliths (O_L, O_H, O_T, O_{WT}) and the length-weight of the fish (L_T, L_S, W_T) were determined using the least squares method, in linear regressions of decimal logarithms of the parameters (x – y): O_L *vs* L_T; O_L *vs* L_S; O_L *vs* W_T; O_L *vs* O_{WT}; O_L *vs* O_H; O_L *vs* O_T; W_T *vs* O_{WT}; O_T *vs* O_H; O_{WT} *vs* O_T; O_{WT} *vs* O_H (Battaglia et al., 2010).

The coefficient of determination (r^2) was used to verify the agreement between the models and the data collected. The Kruskal-Wallis test was used to compare otolith measurements between species. All statistical analyses were performed using PAST software (version 4.09) (Hammer et al., 2001), and regression models with Excel software (Microsoft 365) to determine and plot the relationships between otolith dimensions and fish size and weight ($p < 0.05$).

RESULTS

Significant differences were evident in body lengths and total weight between the two species ($p < 0.001$) (Table 1). The highest values of L_T, L_S and W_T were recorded for the stripped weakfish, *Cynoscion guatucupa*.

In total, 751 specimens of *C. guatucupa* were examined: 480 females, 260 males and 11 with undetermined sex. The sex ratio (1.8:1) indicated a significant dominance of females ($\chi^2 = 65.4$, $p < 0.001$). The L_T range varied between 174 and 412 mm (mean ± SD = 285 ± 41 mm), L_S between 13.5 and 350 mm (240 ± 3.6 mm) and W_T between 56.8 and 732.4 g (268.2 ± 116.2 g). There were no significant differences between sexes (KW_{LT}, $H = 0.034$, $p = 0.852$; KW_{LS}, $H = 0.288$, $p = 0.591$; KW_{WT}, $H = 0.693$, $p = 0.404$). The L_T structure showed a similar pattern for both sexes, with approximately 54% of the specimens occurring between classes of L_T 170 and 270 mm (Figure 3).

A total of 807 specimens of *C. jamaicensis* were obtained for this study: 376 females, 376 males and 55 individuals with undetermined sexes. The L_T range varied between 108 and 345 mm (234.5 ± 49 mm), L_S between 80 and 299 mm (198.1 ± 43 mm)

Table 1. Morphometric measurements (mean ± S.E) of *Cynoscion guatucupa* (n = 740) and *Cynoscion jamaicensis* (n = 752). H: Kruskal-Wallis. p-value is regarded as being significant if < 0.05. LT = Total length; LS = Standard length; WT = Total weight; O_L = Otolith length; O_H = Otolith height; O_T = Otolith thickness; O_W = Otolith weight; O_{AR} = Otolith aspect ratio.

Morphometric variables	*C. guatucupa*	*C. jamaicensis*	*H*	*d.f.*	*p*-value
LT (mm)	285 ± 0.15	234.5 ± 0.17	316.8	1	< 0.001
LS (mm)	240 ± 0.13	198.1 ± 0.15	288.6	1	< 0.001
WT (g)	268.2 ± 4.2	188.8 ± 4.07	147.4	1	< 0.001
OL (mm)	12.48 ± 1.3	11.5 ± 2.2	66.5	1	< 0.001
OH (mm)	6.5 ± 0.5	5.7 ± 0.7	419.7	1	< 0.001
OT (mm)	2.4 ± 0.4	2.4 ± 0.4	654.7	1	< 0.001
OWT (g)	0.22 ± 0.06	0.16 ± 0.08	303.6	1	< 0.001
OAR	1.9 ± 0.003	2.02 ± 0.006	301.4	1	< 0.001

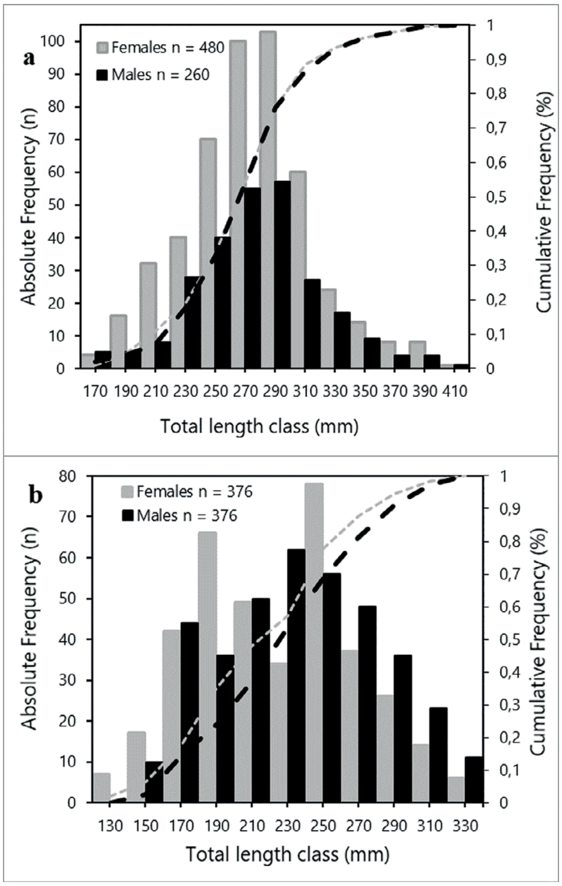

Figure 3. Absolute and cumulatuve frequency by length class (mm) of *Cynoscion guatucupa* (a), *C. jamaicensis* (b).

and W_T between 13.5 and 544 g (188.8 ± 115.8 g). Significant differences were verified between the sexes, with males larger (KW_{LT}, H = 10.82, $p < 0.001$; KW_{LS}, H = 11.24, $p < 0.001$) and heavier ($KW_{LT,}$ H= 11.43; $p < 0.001$). A similar pattern was observed in the L_T structure for both sexes, with approximately 53% of females and 57% of males occurring between classes of L_T 130 and 230 mm (Figure 3). Despite the balance observed in the sex ratio (1:1), significant differences were observed between the L_T 190 mm (female predominance) and 230 mm (male predominance) classes (χ^2 = 8.82, $p < 0.05$; χ^2 = 8.16, $p < 0.05$).

Significant differences were observed for the LWR between the species (ANCOVA, F = 185.1 df = 1, $p < 0.001$) (Figure 4). The allometric condition factor (K) also showed significant differences between species (KW, H = 1159, $p < 0.001$), with the highest values observed for *C. guatucupa*.

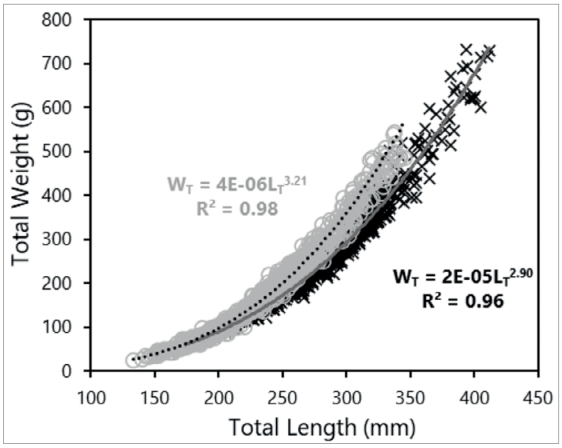

Figure 4. LWRs and regressions lines for pooled sexes of *Cynoscion guatucupa*, x (n = 740) and *Cynoscion jamaicensis*, o (n = 752) obtained from gillnet and bottom trawl small-scale fisheries in the Southwestern Atlantic Ocean (Brazil). Continuous gray line indicates the regression line for *C. guatucupa*. Dotted black line indicates regression for *C. jamaicenses*.

No evidence of differences between the sexes were found for *Cynoscion guatucupa* LWR (ANCOVA, F = 0.0004, df = 1, p = 0.98). The LWR equation for females was $W_T = 0.0000147L_T^{2.90}$ (r^2 = 0.96, n = 480) and for males $W_T = 0.000015L_T^{2.90}$ (r^2 = 0.96, n = 260) (Figure 4, data pooled). The estimate of coefficient ***b*** was less than 3 for both sexes ($t_{♀}$ = -3.34, $p < 0.05$, CI_b ± 0.04; $t_{♂}$ = -3.26, $p < 0.05$, CI_b ± 0.06), indicating a general pattern of negative allometric growth of the species with a higher rate of increase in length concerning weight gain. The condition factor (K) ranged from 0.0122 to 0.0195 (mean ± SD = 0.0153 ± 0.002), a significant difference was observed between the sexes (KW, H = 8.78, $p < 0.001$), with males showing higher condition factor than females.

The LWR did not show significant differences between the sexes for *C. jamaicensis* (ANCOVA F = 0.8774, df = 1, p = 0.35). The LWR equation for females was $W_T = 0.000062L_T^{3.22}$ (r^2 = 0.98, n = 376) and for males $W_T = 0.000067L_T^{3.20}$(r^2 = 0.98, n = 376) (Figure 4, data pooled). The ***b*** coefficient estimate was greater than 3 for both sexes ($t_{♀}$ = -4.68, $p < 0.05$, CI_b ± 0.04; $t_{♂}$ = -4.49, $p < 0.05$, CI_b ± 0.04), indicating a higher rate of increase in weight in relation to length (positive allometric growth). The condition factor (K) ranged from 0.005 a 0.008 (mean ± SD = 0.007 ± 0.0005), a significant difference was observed in the K values between the sexes (KW, $H = 145.8$, $p < 0.001$), with males showing higher condition factor than females.

Significant differences were evident for the measurements of the *sagittae* otoliths between the two species ($p < 0.001$). The highest average values of O_L, O_H, O_T, O_{WT} were registered for *C. guatucupa*, while the O_{AR} proportion was higher for *C. jamaicensis.* Regression models between species also showed statistical differences ($p < 0.001$) for morphometric relationships: O_L *vs* L_T; O_L *vs* L_S; O_L *vs* W_T; O_L *vs* O_H; O_L *vs* O_T; O_T *vs* O_{WT}; O_{WT} *vs* W_T (Table 2).

Both species did not show statistical differences in otolith measurements between the sexes ($p > 0.05$). *Cynoscion guatucupa* presented otolith length(O_L) varying between 8.4 to 16.9 mm (mean ± SD = 12.48 ± 1.3 mm), height (O_H) between 5.02 to 8.3 mm (mean ± SD = 6.5 ± 0.5 mm), thickness (O_T) between 2.07 to 5.27 (mean ± SD = 2.4 ± 0.4 mm), weight (O_W) from 0.08 to 0.91 g (mean ± SD = 0.22 ± 0.06 g), and aspect ratio (O_{AR}) from 1.63 to 2.29 (mean ± SD = 1.9 ± 0.003) for all samples examined (n = 740). *Cynoscion jamaicensis*, presented the length of the otolith (O_L) varying between 5.8 and 17.7 mm (mean ± SD = 11.5 ± 2.2 mm), height (O_H) between 2.2 and 8.04 mm (mean ± SD = 5.7 ± 0.7 mm), thickness (O_T) between 1.1 and 5.6 mm (mean ± SD = 2.4 ± 0.4 mm), weight (O_W) from 0.02 to 0.5 g (mean ± SD = 0.22 ± 0.06 g), and aspect ratio (O_{AR}) from 1.67 to 5.89 (mean ± SD = 2.02 ± 0.006) for all samples examined (n = 752).

The relationships between fish size and *sagittae* otolith dimensions were described using potential regression models between the measures, being statistically different ($p < 0.05$). The determination coefficients ranged between 0.81 and 0.96 for *C. guatucupa,* and *C. jamaicensis* from 0.63 to 0.94 (Table 2). The best equations obtained to determine the size and weight of the weakfishes were related to the length of the otolith (Figure 5): C. *guatucupa* - $L_T = 10.458O_L^{1.30}$ ($r^2 = 0.93$, n = 710); $L_S = 8.2004O_L^{1.33}$ ($r^2 = 0.92$, n = 709); $W_T = 0.016O_L^{3.82}$ ($r^2 = 0.91$, n = 713) and *C. jamaicensis* - $L_T = 16.34O_L^{1.08}$ ($r^2 = 0.96$, n = 703); $L_S = 12.779O_L^{1.11}$ ($r^2 = 0.96$, n = 704); $W_T = 0.0302O_L^{3.50}$ ($r^2 = 0.93$, n = 694). Both species presented negative allometry between O_L *vs* O_{WT}: *C. guatucupa* (t = -11.41, $p < 0.05$, CI_b ± 0.04, $r^2 = 0.94$, n = 718) and *C. jamaicensis* (t = -14.046, $p < 0.05$, CI_b ± 0.03, $r^2 = 0.96$, n = 705), corroborating the general predominant pattern of relative growth with greater increment in otolith length in relation to otolith

Table 2. Relationships (x - y) between fish sizes and *sagittae* otolith measurements of *Cynoscion guatucupa* and *Cynoscion jamaicensis* obtained from gillnet and bottom trawl small-scale fisheries in the southwestern Atlantic (Brazil). Number of specimens (*n*) and coefficients of determination (r^2) and parameters of power equations.; '***a***' and '***b***': regression parameters; CI: 95% confidence interval; OL: otolith length; OH: otolith height; OT: otolith thickness; OWT: otolith weight; LT: total length; Ls = standard length; WT: total weight. F-Test to compare regressions between especiesspecies. The p-value is regarded as being significant if < 0.05.

Relationships	***Cynoscion guatucupa***						***Cynoscion jamaicensis***						**Comparisons**	
	n	**a**	**b**	**r^2**	**± CI (a)**	**± CI (b)**	**n**	**a**	**b**	**r^2**	**± CI (a)**	**± CI (b)**	**F**	***p*-value**
O_L vs L_T	710	1.02	1.30	0.93	0.028	0.025	703	1.21	1.08	0.96	0.016	0.015	193.12	<0.001
O_L vs L_S	709	0.91	1.33	0.92	0.030	0.027	704	1.10	1.11	0.96	0.017	0.016	168.72	<0.001
O_L vs W_T	713	-1.79	3.82	0.91	0.090	0.082	694	-1.51	3.50	0.93	0.055	0.052	39.56	<0.001
O_L vs O_{WT}	718	-3.45	2.54	0.94	0.043	0.040	705	-3.59	2.59	0.96	0.032	0.030	3.08	0.079
O_L vs O_H	710	0.14	0.60	0.81	0.023	0.021	704	0.02	0.68	0.94	0.0001	0.013	35.35	<0.001
O_L vs O_T	708	-0.56	0.96	0.77	0.043	0.039	698	-0.57	0.90	0.83	0.031	0.029	7.67	0.005
O_H vs O_{WT}	718	-3.51	3.49	0.83	0.087	0.107	699	-3.55	3.59	0.92	0.048	0.063	2.24	0.134
O_T vs O_{WT}	719	-1.73	2.13	0.84	0.033	0.066	693	-1.79	2.54	0.90	0.027	0.070	63.19	<0.001
O_H vs O_T	714	-0.53	1.25	0.63	0.056	0.069	689	-0.57	1.26	0.81	0.034	0.045	0.0005	0.981
O_{WT} vs W_T	714	3.37	1.46	0.90	0.023	0.033	699	3.29	1.31	0.86	0.021	0.025	45.18	<0.001

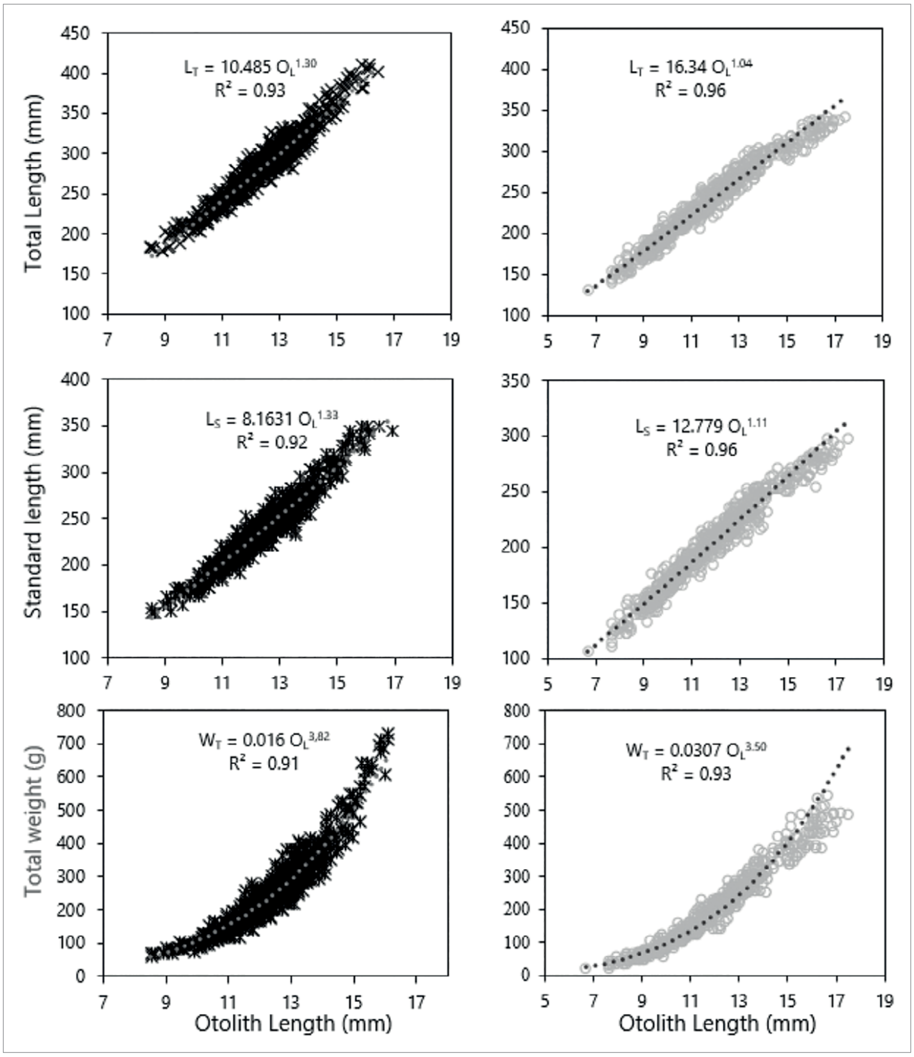

Figure 5. Relationships between fish sizes and *sagittae* otolith measurements of *Cynoscion guatucupa* (x) and *Cynoscion jamaicensis* (o) obtained from gillnet and bottom trawl small-scale fisheries in the Southwestern Atlantic Ocean (Brazil).

weight, resulting in an elongated shape, albeit less pronounced for *C. jamaicensis*. Furthermore, the relationship O_{WT} *vs* W_T showed positive allometry (*C. guatucupa*), confirming the expectation of a greater increase in fish body mass in relation to otolith mass (t = 13.87, $p < 0.05$, $CI_b \pm 0.03$, $r^2 = 0.90$, n = 714) and isometric growth (*C. jamaicensis*), indicating a proportional increase between fish body mass and otolith mass (t = 0.922, $p < 0.05$, $CI_b \pm 0.02$, $r^2 = 0.85$, n = 699).

The shape of the *sagittae* otoliths of both species is elliptical, but the significant differences in the ratio O_L/O_H ($p < 0.05$) showed an elongated shape for *C. guatucupa* and a more robust shape in *C. jamaicensis*. In both species *rostrum* and *antirostrum* are absent.

DISCUSSION

Our results may serve as a reference point for future comparisons aimed to understand the effects and causes of the spatio-temporal variations and fishing pressure on the stocks of weakfishes. The estimates of relative growth may vary in the same species (*i.e.*, *C. jamaicensis*) and between species (*i.e.*, *C. guatucupa* and *C. jamaicensis*), and represent a suitable tool for understanding the variability of fish stocks. The strong correlation between size and weight and otolith dimensions and fish sizes, indicates that the models obtained are robust predictors for estimating fish length from the morphometry of the otoliths. Likewise, Smoliński and Berg (2022) showed that the fish length-scale size relationship of Atlantic herring varies over time and between cohorts. They attribute this variation to changing environmental conditions, more specifically the temperature that presented a negative effect on stock total biomass and a positive effect on fish length when conditioned on scale size. Thus, the use of these relationships has been useful in fisheries biology, supporting other population estimates as well as stock assessment analyses.

The length structure obtained here for the two species is following the pattern described in other studies, where the greatest lengths and weights recorded for southeastern and southern Brazil are associated with the Stripped weakfish, *C. guatucupa* (Haimovici and Miranda, 2005; Castro et al., 2005). In contrast, Alves et al. (2020) reported that the Jamaica weakfish *C. jamaicensis* presents rapid growth, early maturation and small size in southern Brazil. Adults of both species perform seasonal movements along the Brazilian coast. The Striped weakfish moves north during the autumn and spring (April-September), leaving important fishing areas in Uruguay and Argentina, arriving on the southern Brazilian coast, then returning south during the summer (Miranda and Haimovici, 2007). The spatio-temporal distribution was also observed for the most age classes, with a higher proportion of juveniles (immature) using estuarine waters, while adults prefer more saline and deeper areas (Macchi and Acha, 1998; Jaureguizar et al., 2006). The Jamaica weakfish is clinal in nature, with occurrence limited to waters down to 17 °C, moving towards its southern limit of distribution (34°S) following the penetration of warm Tropical Water of Brazil Current towards the south in spring and summer (September-February) (Vazzoler and Braga, 1983; Spach and Yamaguti, 1989a). Both species are captured by a wide variety of fishing gear (*e.g.*, shrimp nets - Cazorla, 2000; recreational fisheries - Volpedo, 2000; bottom trawls and gillnets - Cergole et al., 2005, Perez Comesaña et al., 2014; paired-trawls - Miranda and Haimovici, 2007; and Beach-seines - Costa et al., 2018). The selectivity of each gear type determines the size of the population structure based on capture data. According to Fonteles-Filho (2011), fishing exploits only that portion that is accessible to fishing gear, the catchable stock. However, this is made up of the adult stock plus a part of the young stock, making up the total catch. From these data, we can assume that both the size and weight of the fish represent variables dependent upon each other in such a way that the variation in one is reflected in the other.

The variability in responses to changes in environmental conditions is of fundamental importance in the evolutionary fitness of species (Melbinger and Vergassola, 2015). The estimated length-weight relationships (LWR) showed values of the coefficients ***a*** and ***b*** like those reported in the literature for the same region of this study (Haimovici and Miranda, 2005; Castro et al., 2005). Our results show an opposite pattern between species, with negative allometric growth for *C. guatucupa* and positive allometric growth for *C. jamaicensis*. The LWR showed no significant differences between males and females for both species. Despite factors such as structure in size and gonadal maturity influence this relationship (Fonteles-Filho, 2011), we believe that this absence of differences occurs because fishing fleets operate in shallow areas, up to 50 m, of the inner continental shelf of the northern coast of Rio de Janeiro state, Brazil (FIPERJ, 2020); there, juveniles and adults share the same habitat, with the predominance of adults associated with the selectivity of the fishing gear and also with the selectivity of fishermen, seeking commercial-sized fish.

The differences observed between this and other studies, can be attributed to a combination of factors such as, the number of specimens examined, size structure, gonadal maturity, selectivity of gear and fishermen and local environmental factors (Hossain et al., 2014). Segura et al. (2012) observed a value of ***b*** = 2.92, obtained in Uruguay for individuals from 360 to 450 mm in total length (L_T), for *C. guatucupa*. Haimovici and Velasco (2000), also recorded negative allometric growth (***b*** = 2.77), slightly lower for samples collected off Rio Grande do Sul (L_T: 58 – 575 mm). Nonetheless, Muto et al. (2000), when collecting off the southeastern coast of Brazil, recorded ***b* =**

2.92, values like those reported here, even though having included smaller fish (L_T: 47 – 389 mm). For *C. jamaicensis* observed in mangrove areas in the northern region of the Brazilian coast, the value of ***b*** was 3.13, with a total length range from 20 to 216 mm (Joyeux et al., 2008). Although also collecting only small individuals (L_T: 29 – 185 mm) in the Southern Brazilian coast (coast of Paraná state), Passos et al. (2012) have obtained ***b*** values like those reported for the North Brazilian coast (***b*** = 3.13). Haimovici and Velasco (2000) also recorded positive allometric growth (***b*** = 3,14) for samples collected in Rio Grande do Sul (L_T: 140 – 329 mm). For the southeastern coast of Brazil, Vianna et al. (2004) reported ***b*** = 3.17 (LT: 80 – 260 mm); Muto et al. (2000) ***b*** = 3.14 (LT: 32 – 274 mm); and Castro et al. (2005) ***b*** = 3.14 (LT: 110 – 365 mm). The differences observed in the LWR between these species reflect distinct life history characteristics and contrary seasonal displacement patterns, being influenced by environmental conditions and differential habitat use, which affect food availability and consequently the energy directed to reproduction and the reproductive dynamics themselves (Longhurst and Pauly, 2007).

The LWR and the condition of individuals can be influenced by several intrinsic and extrinsic factors (Perin and Vaz-dos-Santos, 2014). Therefore, the variations in the condition factor (K) of both species can be correlated with total length range, reproductive period, seasons, sex of individuals, age, sexual maturity, food availability, sample size, and type of fishing gear (Haimovici and Velasco, 2000). This index (K) represents all biotic and abiotic interactions responsible for the well-being of individuals, *i.e.*, an indicator either of the recent nutritional conditions of fish or of the accumulation of energy of individuals, related to the expenditure of reserves in cyclic activities such as reproduction (Vazzoler, 1996). The differences observed between the sexes (males showing higher K than females), occurred for both species, suggesting that, in general, males invest less energy in gonadal development than in somatic growth, especially in adult individuals. However, investigations about the reproductive aspects of these populations are necessary for better statements; it is expected that the highest values of K are proportional to the largest individuals and to the sexual maturity of the adult individuals.

The morphometry of otoliths (*e.g.,* O_L, O_H, O_T, O_{WT}, O_{AR}) usually involves dimensions that are correlated with each other and are commonly also correlated with the size and weight of the fish (L_T, L_S, W_T). These correlations found in this study were expected, as similar records for otolith dimensions and somatic growth have been documented for different species groups and fish stocks (*e.g.* Battaglia et al., 2010; Munk, 2012; Souza et al., 2019). Some studies observed that fish growth rate can influence otolith size, reinforcing the link between fish size and otolith size (Huuskonen and Karjalainen, 1998). Our data demonstrate a strong association between O_L *vs* L_T (r^2 = 0.93; 0.96), O_L *vs* L_S (r^2 = 0.92; 0.96), O_L *vs* W_T (r^2 = 0.91; 0.93); and O_L *vs* O_{WT} (r^2 = 0.94; 0.96) both for *C. guatucupa* and *C. jamaicensis*, respectively. Therefore, documenting the connection between otolith and fish dimensions may help to reinforce standardized age-reading criteria in future investigations (Munk, 2012).

For the Atlantic coast off Argentina (35º - 41ºS), the morphometric relationships between the dimensions of the *sagittae* otolith and the length and weight of *C. guatucupa* were determined by Baldás et al. (1997), Waessle et al. 2003, and Perez Comesaña et al. (2014). In Brazil (between 20º18'S - 32º10'S), only the previous study by Spach and Yamaguti, (1989b) records variations in the morphometry of *sagittae* otoliths of *C. jamaicensis* (L_T: 70 – 280 mm), with the determining coefficients of the relationship O_L *vs* L_S ranging between: r^2 = 0.93 and 0.98. For all these authors, there is consensus that the otolith can be a good predictor of fish size (LT, LS, WT). Spach and Yamaguti, (1989b) observed that *C. jamaicensis* showed differences between the southeastern and southern regions of Brazil, both in the relative growth and in the dimensions of the otoliths. They attributed these differences to the oceanographic conditions of each region (*e.g.*, temperature and food availability) and the clinal nature of the morphometric variations of the species, which occupies areas with different environmental conditions along the southeastern Brazilian coast, avoiding cold waters during winter. Volpedo (2001) registered, for *C. guatucupa* on the Buenos Aires coast, a negative correlation with the temperature and a positive with salinity and latitude with the morphometric characteristics of the otoliths. She concludes that larger otoliths occur in low temperature and high latitude environments. Thus understanding this relationship is fundamental for conservation studies and the assessment of fish stocks.

The scarcity of these studies for the Brazilian coast limits the possibility of other direct comparisons with the results presented here. Despite this, the samples analyzed from the large number of individuals collected, in different strata of length, also allowed a good accuracy of the coefficients of determination, reducing the possibility of bias in the derivation of the equations and confirming the good application of this tool. Furthermore, this framework based on mathematical models provides support for taxonomic identification from *sagittae* otoliths, including studies related to feeding ecology (prey-predator), as well as age and growth, geographic variations, and a possible influences of environmental factors.

CONCLUSION

In this study, we confirmed that otoliths and body (length and weight) sizes are efficient variables for monitoring weakfishes on the Southeastern Brazilian coast, given that the development of the body and the otolith may reflect changes in the other indicators of stock health. Here we provide a descriptive note that may serve as a reference point and may support future studies to assess the potential for using these data in regional investigations to estimate some life-history parameters (*e.g.,* age and von Bertalanffy coefficient growth - k, size at maturity - L50, and gonadosomatic index - IGS) of these commercial important sciaenids. Our data indicated a species-specific pattern, which can be confirmed using analytical tools based exclusively on morphology, complementing the potential use of these rigid structures in the taxonomic identification of these species and the eventual distinction between fish stocks.

ACKNOWLEDGMENTS

We thank all the students and staff from ECOPESCA-UFF and NUPEM-UFRJ for their efforts in this cooperative project. We also thank the two anonymous reviewers.

This study was developed from a partnership between the “Instituto de Biodiversidade e Sustentabilidade (NUPEM/UFRJ)”, within the scope of the “Projeto MULTIPESCA: Ciência para a sustentabilidade da pesca, pescado e pescadores do Rio de Janeiro” and the “Laboratório de Biologia do Nécton e Ecologia Pesqueira” (ECOPESCA/UFF – Programa de Pós-Graduação em Biologia Marinha e Ambientes Costeiros-PPG-BMAC/UFF). ABB received a PhD grant from “Projeto MULTIPESCA” and actually is financied by Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ; process E-26/204.455/2021). All the steps carried out on the premises of the Fluminense Federal University (UFF) were performed with the assistance of the “Scientific Initiation Scholarship Program” (PIBIC/UFF) and “Coordination for the Improvement of Higher Education Personnel” (CAPES), where P. Mendonça holds a PhD’s degree scholarship. The Project “MULTIPESCA: Ciência para a sustentabilidade da pesca, pescado e pescadores do Rio de Janeiro” is an environmental offset measure established through a Consent Decree/Conduct Adjustment Agreement between PetroRio and the Brazilian Ministry for the Environment, with the FUNBIO as an implementer.

AUTHOR CONTRIBUTIONS

P.M.: Conceptualization; Data curation; Investigation; Formal Analysis; Writing - original draft; Writing - review & editing.

J.P.M.D.: Methodology; Investigation; Formal Analysis; Writing - original draft.

A.B.B.: Methodology; Data curation; Investigation; Visualization; Writing - review & editing.

L.G.F.: Supervision; Funding acquisition; Resources; Methodology; Visualization; Writing - review & editing.

M.R.C.: Supervision; Project Administration; Resources; Visualization; Validation; Writing - review & editing.

REFERENCES

AGUILERA, O. A., MORAES-SANTOS, H., COSTA, S., OHE, F., JARAMILLO, C. & NOGUEIRA, A. 2013. Ariid sea catfishes from the coeval Pirabas (Northeastern Brazil), Cantaure, Castillo (Northwestern Venezuela), and Castilletes (North Colombia) formations (early Miocene), with description of three new species. *Swiss Journal of Paleontology*, 132(1), 45-68, DOI: http://dx.doi.org/10.1007/s13358-013-0052-4

AGUIRRE, H. 2003. Allometric growth of the sulcus in *Cynoscion* spp. (Sciaenidae). *Journal of Fish Biology*, 63, 1341-1346.

ALVES, A. V., HAIMOVICI, M. & CARDOSO, L. G. 2020. Long-term changes in the life history of the Jamaican weakfish, *Cynoscion jamaicensis* (Vaillant and Bocourt, 1883), in southern Brazil. *Regional studies in Marine Science*, 34, 100163, DOI: https://doi.org/10.1016/j.rsma.2020.101063

AVIGLIANO, E., COMTE, G., ROSSO, J. J., MABRAGAÑA, E., PAOLA, D. R., SANCHEZ, S., VOLPEDO, A. V., ROSSO, F. D. & SCHENONE, N. F. 2015. Identificación de stocks pesqueros de la corvina de río (*Plagioscion ternetzi*) de los ríos Paraguay y Paraná, mediante el análisis morfométrico de sus otólitos. *Latin American Journal Aquatic Research*, 43(4), 718-725.

AVIGLIANO, E., MARTINEZ, C. F. R. & VOLPEDO, A. V. 2014. Combined use of otolith microchemistry and morphometry as indicators of the habitat of the silverside (*Odontesthes bonariensis*) in a freshwater-estuarine environment. *Fisheries Research,* 149, 55-60.

BALDÁS, M. I., PÉREZ MACRI G., VOLPEDO A. V. & ECHEVERRÍA, D. D. 1997. Morfología de la Sagitta de peces marinos de la costa bonaerense de la Argentina I: Carangidae, Sciaenidae, Mullidae. *Atlântica*, 19, 99-112.

BARRADAS, J. R. S., LERMEN, I. S., LARRÉ, G. G., MARTINS T. P. & FONTOURA, N. F. 2016. Polyphasic growth in fish: a case study with *Corydoras paleatus* (Siluriformes, Callichthyidae). *Iheringia, Série Zoologia*, 106, e2016017, DOI: http://dx.doi.org/10.1590/1678-4766e2016017

BATTAGLIA, P., MALARA, D., ROMEO, T. & ANDALORO, F. 2010. Relationships between otolith size and fish size in some mesopelagic and bathypelagic species from the Mediterranean Sea (Strait of Messina, Italy). *Scientia Marina*, 74(3), 605-612.

BERVIAN, G., FONTOURA, N. F. & HAIMOVICI, M. 2006. Statistical model of variable allometric growth: otolith growth in *Micropogonias furnieri* (Actinopterygii, Sciaenidae). *Journal of Fish Biology*, 68, 196-208.

BROWN-PETERSON, N. J., WYANSKI, D. M., SABORIDO-REY, F., MACEWICZ, B. J. & LOWERRE-BARBIERI, S. K. 2011. A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries*, 3(1), 52-70, DOI: https://doi.org/10.1080/19425120.2011.555724

BUSTOS, R. L., DANERI, G. A., VOLPEDO, A. V., HARRINGTON, A. & VARELA, E. A. 2014. The diet of the South American sea lion (*Otaria flavescens*) during the summer season at Río Negro, Patagonia, Argentina. *Aquatic Biology*, 20, 235-243.

CAMPANA, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology,* 59(2), 197-242.

CARVALHO, B. M. & CORRÊA, M. F. M. 2014. Morphometry of the sagittal otolith from *Atherinella brasiliensis* (Quoy & Gaimard, 1824) (Actinopterygii – Atherinopsidae), at the coast of Paraná. *Tropical Oceanography*, 42(1), 1-6.

CARVALHO, M. B., VOLPEDO, A. V., VAZ-DOS-SANTOS, A. M. & SPACH, H. L. 2017. Use of otolith microchemistry as habitat indicator of *Anchoa tricolor* (Spix & Agassiz, 1829) in a subtropical estuary. *Latin American Journal of Aquatic Research*, 45(2), 457-465.

CASTRO, L. A. B. & PETRERE JUNIOR, M. 2001. Estrutura populacional e mortalidade de *Micropogonias furnieri*, *Macrodon ancylodon* e *Cynoscion jamaicensis*, no sudeste do Brasil, de 1982 a 1996. *Boletim do Instituto de Pesca*, 27(1), 61-76.

CASTRO, P. M. G., CARNEIRO, M. H., CERGOLE, M. C., SERVO, G. J. M. & MUCINHATO, C. M. D. 2005. *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883) Estoque Sul. *In*: CERGOLE, C., ÁVILA-DA-SILVA, A. O. & ROSSI-WONGTSCHOWSKI, C. L. B. (eds.). *Análise das principais pescarias comerciais da região sudeste-sul do brasil: dinâmica populacional das espécies em explotação*. São Paulo: Série documentos REVIZEE – SCORE SUL/Instituto Oceanográfico – USP, pp. 40-45.

CASTRO, P. M. G., CERGOLE, M. C., CARNEIRO, M. H., MUCINHATO, C. M. D. & SERVO, G. J. M. 2002. Crescimento, mortalidade e taxa de explotação do goete *Cynoscion jamaicensis* (Perciformes: Sciaenidae), na região sudeste-sul do Brasil. *Boletim do Instituto de Pesca*, 28(2), 141-153.

CAZORLA, A. L. 2000. Age structure of the population of weakfish *Cynoscion guatucupa* (Cuvier) in the Bahía Blanca waters, Argentina. *Fisheries Research*, 46(1-3), 179-286.

CERGOLE, C., ÁVILA-DA-SILVA, A. O. & ROSSI-WONGTSCHOWSKI, C. L. B. 2005. *Análise das principais pescarias comerciais da região Sudeste-Sul do Brasil: dinâmica populacional das espécies em explotação*. São Paulo: Série documentos REVIZEE – SCORE SUL/ Instituto Oceanográfico – USP.

CHANTHRAN, S. S. D., LIM, P. E., POONG, S. W., DU, J. & LOH, K. H. 2020. Relationships between sagittal otolith size and body size of *Terapon jarbua* (Teleostei, Terapontidae) in Malaysian waters. *Journal of Oceanology and Limnology*, 39, 372-381, DOI: https://doi.org/10.1007/s00343-019-9193-7

CHAO, N. L., FRÉDOU, F. L., HAIMOVICI, M., PERES, M. B., POLIDORO, B., RASEIRA, M., SUBIRÁ, R. & CARPENTER, K. 2015. A popular and potentially sustainable fishery resource under pressure-extinction risk and conservation of Brazilian Sciaenidae (Teleostei: Perciformes). *Global Ecology Conservation*, 4, 117-126, DOI: https://doi.org/10.1016/j.gecco.2015.06.002

COSTA, M. R., TUBINO, R. A. & MONTEIRO-NETO, C. 2018. Length-based estimates of growth parameters and mortality rates of fish populations from a coastal zone in the Southeastern Brazil. *Zoologia*, 35, e22235, DOI: http://dx.doi.org/10.3897/zoologia.35.e.22235

CRUZ, A. & LOMBARTE, A. 2004. Otolith size and their relationship with colour pattern and sound production. *Journal of Fish Biology*, 65(6), 1512-1525.

DAVOREN, G. K. & HALDEN, N. M. 2014. Connectivity of capelin (*Mallotus villosus*) between regions and spawning habitats in Newfoundland inferred from otolith chemistry. *Fisheries Research*, 159, 95-104, DOI: http://doi.org/10.1016/j.fishres.2014.05.010

FIGUEIREDO, J. L. 1992. Sobre a aplicação dos nomes *Cynoscion striatus* (Cuvier, 1829) e *Cynoscion guatucupa* (Cuvier, 1830) (Teleostei: Sciaenidae). Comunicações do Museu de Ciências da PUCRS. *Série Zoologia*, 5(8), 117-121.

FIPERJ (Fundação Instituto de Pesca do Estado do Rio de Janeiro). 2020. Estatística Pesqueira do Estado do Rio de Janeiro. PMAP-RJ, Projeto de Monitoramento da Atividade Pesqueira no Estado do Rio de Janeiro (2018-2019) [online]. In: FIPERJ, (org.). Projeto de Monitoramento da Atividade Pesqueira no Estado do Rio de Janeiro. Relatório Técnico Consolidado Final – RTF. Rio de Janeiro: FIPERJ. Available at: http://www.fiperj.rj.gov.br/index.php/publicacao/index/1 [Accessed: 2022 Feb 02].

FISCHER, L. G., PEREIRA, L. E. D. & VIEIRA, J. P. 2011. *Peixes estuarinos e costeiros*. 2nd ed. Rio Grande: Instituto de Oceanografia – FURG.

FONTELES-FILHO, A. A. 2011. *Oceanografia, biologia e dinâmica populacional de recursos pesqueiros*. Fortaleza: UFC (Universidade Federal do Ceará).

FROESE, R. 2006. Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. *Journal Applied Ichthyology,* 22(4), 241-53, DOI: http://dx.doi.org/10.1111/j.1439-0426.2006.00805.x

FROESE, R., TSIKLIRAS, A. C. & STERGIOU, K. I. 2011. Editorial note on weight-length relations of fishes. *Acta Ichthyologica et Piscatoria*, 41(4), 261-263, DOI: https://doi.org/10.3750/AIP2011.41.4.01

GAGLIANO, M. & MCCORMICK, M. I. 2004. Feeding history influences otolith shape in tropical fish. *Marine Ecology Progress Series*, 278, 291-296.

GIARRIZZO, T., OLIVEIRA, R. R. S., ANDRADE, M. C., GONÇALVES, A. P., BARBOSA, T. A. P., MARTINS, A. R. & SOUSA, L. M. 2015. Length-weight and length-length relationships for 135 fish species from the Xingu River (Amazon Basin, Brazil). *Journal Applied Ichthyology*, 31(2), 415-424, DOI: https://doi.org/10.1111/jai.12677

GRANADEIRO, J. P. & SILVA, M. A. 2000. The use of otoliths and vertebrae in the identification and size estimation of fish in predator-prey studies. *Cybium*, 24(4), 383-393.

HAIMOVICI, M. 2000. *Recursos pesqueiros demersais da região Sul - Subsídios para o levantamento do estado da arte dos recursos vivos marinhos do Brasil.* Rio Grande: Programa REVIZEE/MMA/FURG.

HAIMOVICI, M. & MIRANDA, L. V. 2005. *Cynoscion guatucupa* (Cuvier, 1830). Estoque Sul. *In*: CERGOLE, C., ÁVILA-DA-SILVA, A. O. & ROSSI-WONGTSCHOWSKI, C. L. B. (eds.). *Análise das principais pescarias comerciais da região Sudeste-Sul do Brasil: dinâmica populacional das espécies em explotação*. São Paulo: Série documentos REVIZEE – SCORE SUL/Instituto Oceanográfico – USP, pp. 46-51.

HAIMOVICI, M. & VELASCO, G. 2000. Length-weight relationships of marine fishes from southern Brazil. *Naga ICLARM Quartely*, 23(1), 19-23.

HAMMER, Ø., HARPER, D. A. T. & RYAN, P. D. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica* [online], 4(1), 9. Available at: https://www.nhm.uio.no/english/research/infrastructure/past/ [Accessed: 2022 Jan 10].

HARVEY, J. T., LOUGHLIN, T. R., PEREZ, M. A. & OXMAN, D. S. 2000. *NOAA - Technical Report NMFS, 150 - Relationship between fish size and otolith length for 63 species of fishes from the Eastern North Pacific Ocean* [online]. Washington: U.S. Department of Commerce NOAA. Available at: https://repository.library.noaa.gov/view/noaa/3159 [Accessed: 2020 Mar 05].

HOFF, G. R. & BUIMAN, L. A. 1993. Morphometry and composition of red drum otoliths: changes associated with temperature, somatic growth rate, and age. *Comparative Biochemistry and Physiology*, 106a(2), 209-219.

HOSSAIN, M. Y., RAHMAN, M. M., AHMED, F., AHMED, Z. F. & OHTOMI, J. 2014. Length-weight and length-length relationships and form factor of three threatened fishes from the Ganges River (NW Bangladesh). *Journal Applied Ichthyology*, 30(1), 221-224, DOI: https://doi.org/10.1111/jai.12251

HUUSKONEN, H. & KARJALAINEN, A. 1998. A preliminary study on relationship between otolith increment width, metabolic rate, and growth in juvenile whitefish. *Archives of Hydrobiology*, 142(3), 371-383.

HUXLEY, J. S. 1924. Constant differential growth-ratios and their significance. *Nature*, 2877(114), 895-986.

JAUREGUIZAR, A. J., RUARTE, C. O. & GUERRERO, R. A. 2006. Distribution of age-classes of striped weakfish (*Cynoscion guatucupa*) along an estuarine-marine gradient: correlations with the environmental parameters. *Estuarine, Coastal and Shelf Science*, 67(1), 82-92.

JOYEUX, J. C., GIARRIZZO, T., MACIEIRA, R. M., SPACH, H. L. & VASKE JUNIOR, T. 2008. Length-weight relationships for Brazilian estuarine fishes along a latitudinal gradient. *Journal Applied Ichthyology*, 25(3), 350-355.

KLOKLER, D. 2020. Fishing for “lucky stones”: symbolic uses of otoliths in Brazilian shell sites. *Journal of Anthropological Archaeology*, 58, 101167, DOI: https://doi.org/10.1016/j.jaa.2020.101167

LOMBARTE, A., TORRES, G. J. & MORALES-NIN, B. 2003. Specific *Merluccius* otolith growth patterns related to phylogenetics and environmental factors. *Journal of the Marine Biological Association of the United Kingdown*, 83(2), 277-281.

LOMBARTE, A. & TUSET, V. 2015. Morfometria de Otólitos. Capítulo 3. *In*: VOLPEDO, A. V. & VAZ-DOS-SANTOS, A. (eds.). *Métodos de estudios con otólitos: principios y aplicaciones Métodos de estudos com otólitos: princípios e aplicações.* Buenos Aires: Ministerio de Educación.

LONGHURST, A. R. & PAULY, D. 2007. *Ecologia dos oceanos tropicais.* São Paulo: Universidade de São Paulo/Edusp.

MACCHI, G. J. & ACHA, E. M. 1998. Aspectos reproductivos de las principales especies de peces en la Zona Comun de Pesca Argentino-Uruguaya y en El Rincón. *INIDEP Informe Técnico* [online], 21, 67-89. Available at: http://www.ctmfm.org/upload/biblioteca/201708/cg_enlace-11-150211215672.pdf [Accessed: 2020 Nov 20].

MELBINGER, A. & VERGASSOLA, M. 2015. The impact of environmental fluctuations on evolutionary fitness functions. *Scientific Reports*, 5, 15211, DOI: https://doi.org/10.1038/srep15211

MENEZES, N. A., BUCKUP, P. A., FIGUEIREDO, J. L. & MOURA, R. L. 2003. *Catálogo das espécies de peixes marinhos do Brasil*. São Paulo: Museu de Zoologia de Universidade de São Paulo, pp. 1-159.

MENEZES, N. A. & FIGUEIREDO, J. L. 1980. *Manual de peixes marinhos do sudeste do Brasil. IV. Teleostei (3).* São Paulo: Universidade de São Paulo.

MIOTTO, M., CARVALHO, B, M., SPACH, H. L. & BARBIERI, E. 2017. Ictiofauna demersal na alimentação do gaivotão (*Larus dominicanus*) em um ambiente subtropical. *Ornitologia Neotropical*, 28, 27-36.

MIRANDA, L. V. & HAIMOVICI, M. 2007. Changes in the population structure, growth and mortality of striped weakfish *Cynoscion guatucupa* (Sciaenidae, Teleostei) of southern Brazil between 1976 and 2002. *Hydrobiologia*, 589, 69-78, DOI: https://doi.org/10.1007/s10750-007-0721-7

MONTEIRO, L. R., DI BENEDITTO, A. P. M., GUILHERMO, L. H. & RIVERA, L. A. 2005. Allometric changes and shape differentiation of Sagitta otolithis in sciaenid fishes. *Fisheries Research*, 74, 288-299.

MPA (MINISTÉRIO DA PESCA E AQUICULTURA). 2010. *Boletim estatístico da pesca e aquicultura - 2008-2009* [online]. Brasília: MPA. Available at: https://www.icmbio.gov.br/cepsul/images/stories/biblioteca/download/estatistica/est_2008_2009_nac_pesca.pdf [Accessed: 2020 Mar 10].

MUNK, K. M. 2012. *Somatic-otolith size correlations for 18 marine fish species and their importance to age determination*. *Alaska Department of Fish and Game, Regional Information Report, 5j12-13, Anchorage* [online]. Alaska: Department of Fish and Game. Available at: https://www.adfg.alaska.gov/fedaidpdfs/RIR.5J.2012.13.pdf [Accessed: 2020 Nov 20].

MUTO, E. Y., SOARES, L. S. H. & ROSSI-WONGTSCHOWSKI, C. L. D. B. 2000. Length-weight relationship of marine fish species off São Sebastião system, São Paulo, southeastern Brazil. *Naga ICLARM Quartely*, 23(4), 27-29.

PANTALEÃO, F., CARVALHO-BATISTA, A., FRANSOZO, A. & COSTA, R. C. 2016. The influence of upwelling on the diversity and distribution of marine shrimp (Penaeoidea and Caridea) in two tropical coastal areas of southeastern Brazil. *Hydrobiologia*, 763(1), 381-395, DOI: https://doi.org/10.1007/s10750-0152429-4

PASSOS, A. C., SCHWARZ JUNIOR, R., CARTAGENA, B. F. C., GARCIA, A. S. & SPACH, H. L. 2012. Weight-length relationship of 63 demersal fishes on the shallow coast of Paraná, Brazil. *Journal Applied Ichthyology*, 28(5), 845-847.

PAXTON, J. R. 2000. Fish otoliths: do sizes correlate with taxonomic group, habitat, and/or luminescence? *Philosophical Transactions of The Royal Society of London,* 355(1401), 1299-1303.

PEREZ-COMESAÑA, J. E., BECHTHOLD, C., ARIAS, K., CARRIZO, G. R. & RIESTRA, C. 2014. Estimación de la longitude de la Pescadilla de red (*Cynoscion guatucupa*) (Achtinopterygii: Sciaenidae) utilizando relaciones morfométricas de huesos del cráneo y de la cintura escapular, otolitos y medida específicas del cuerpo. *Revista del Museo argentino de Ciencias Naturales*, 16(1), 89-93.

PERIN, S. & VAZ-DOS-SANTOS, A. M. 2014. Morphometry and relative growth of the Brazilian sardine, Sardinella brasiliensis (Steindachner, 1879) in the southeastern Brazilian bight. *Arquivos de Zoologia*, 45, 63-72, DOI: https://doi.org/10.11606/issn.2176-7793.v45iespp63-72

POPPER, A.N., RAMCHARITAR, J. & CAMPANA, S. E. 2005. Why otoliths? Insights from inner ear physiology and fisheries biology. *Marine and Freshwater Research*, 56, 497-504.

RAMCHARITAR, J., HIGGS, D. M. & POPPER, A. N. 2001. Sciaenid inner ears: a study in diversity. *Brain Behavior and Evolution,* 58, 152-162.

RONDINELI, G. R., BRAGA, F. M. DE S., TUTUI, S. L. S. & BASTOS, G. C. C. 2007. Dieta de *Menticirrhus americanos* (Linnaeus, 1758) e *Cynoscion jamaicensi*s (Vaillant & Bocourt, 1883) (Pisces, Sciaenidae) no Sudeste do Brasil, Estado de São Paulo. *Boletim Institutos de Pesca*, 33(2), 221-228.

SANTOS, E. P. 1963. Growth of goete: quantitative aspects. *Boletim do Instituto de Oceanografia,* 13(1), 185-190.

SANTOS, E. P. 1968. Estudo populacional do goete, *Cynoscion petranus* (Ribeiro, 1915). *Boletim do Instituto de Oceanografia*, 17(1), 17-31.

SEGURA, A. M., TRINCHIN, R., RABELLINO, J., SCARABINO, F., TEIXERA-DE MELLO, F. & CARRANZA, A. 2012. Length-weight relationships of 14 coastal fish species from Punta del Diablo (Rocha, Uruguay). *Journal Applied Ichthyology*, 28(5), 852-853.

SMOLIŃSKI, S. & BERG, F. 2022. Varying relationships between fish length and scale size under changing environmental conditions – multidecadal perspective in Atlantic herring. *Ecological Indicators*, 134, 108494, DOI: https://doi.org/10.1016/j.ecolind.2021.108494

SOUZA, G. M., TUBINO, R. A., MONTEIRO-NETO, C. & COSTA, M. R. 2019. Relationships between fish and otolith dimensions of Pomatomus saltatrix (Linnaeus, 1766) (Perciformes: Pomatomidae) in southeastern Brazil. *Neotropical Ichthyology*, 17(1), e180032, DOI: https://doi.org/10.1590/1982-0224-20180032

SPACH, H. & YAMAGUTI, N. 1989a.Variação geográfica de *Cynoscion jamaicensis* (Pisces: Sciaenidae) entre as latitudes 20°18'S (Vitória, ES) e 32°10'S (Barra do Rio Grande, RS) II - caracteres morfométricos. *Nerítica*, 4(1), 77-104.

SPACH, H. & YAMAGUTI, N. 1989b. Variação geográfica de *Cynoscion jamaicensis* (Pisces: Sciaenidae) entre as latitudes 20°18'S (Vitória, ES) e 32°10'S (Barra do Rio Grande, RS) III - Otólito Sagitta. *Nerítica*, 4(1), 105-117.

TEIMORI, A., SCHULZ-MIRBACH, T., ESMAEILI, H. R. & REICHENBACHER, B. 2012. Geographical differentiation of Aphanius dispar (Teleostei: Cyprinodontidae) from Southern Iran. *Journal of Zoological Systematics and Evolutionary Research*, 50(4), 289-304, DOI: http://doi.org/10.1111/j.1439-0469.2012.00667.x

TOLLIT, D. J., STEWARD, M. J., THOMPSON, P. M., PIERCE, G. J., SANTOS, M. B. & HUGHES, S. 1997. Species and size differences in the digestion of otoliths and beaks: implications for estimates of pinniped diet composition. *Canadian Journal of Fish Aquatic Science*, 54(1), 105-1197.

TUSET, V. M., LOMBARTE, A. & ASSIS, C. A. 2008. Otolith atlas for the western Mediterranean, north and central eastern Atlantic. *Scientia Marina*, 72(Suppl 1), S7-S198, DOI: https://doi.org/10.3989/scimar.2008.72s17

VALENTIN, J. L., ANDRE, D. L. & JACOB, S. A. 1987. Hydrobiology in the Cabo Frio (Brazil) upwelling: two-dimensional structure and variability during a wind cycle. *Continental Shelf Research*, 7(1), 77-88.

VAN DIJK, P. L. M., HARDEWIG, I. & HÖLKER, F. 2005. Energy reserves during food deprivation and compensatory growth in juvenile roach: the importance of season and temperature. *Journal of Fish Biology*, 66(1), 167-181, DOI: https://doi.org/10.1111/j.0022-1112.2005.00590.x

VAZ-DOS-SANTOS, A. M. & ROSSI-WONGTSCHOWSKI, C. L. D. B. 2019. *Growth in fisheries resources from the Southwestern Atlantic*. São Paulo: IOUSP.

VAZ-DOS-SANTOS, A. M., SANTOS-CRUZ, N. N. & ROSSI-WONGTSCHOWSKI, C. L. D. B. 2007. Caracterização dos otólitos sagitta do peixe-lagarto *Bembrops heterurus* Miranda-Ribeiro, 1903 (Teleostei: Percophidae) da região Sudeste-Sul do Brasil. *Bioikos*, 21(1), 69-78.

VAZZOLER, A. E. A. M. 1996. *Biologia de peixes teleósteos: teoria e prática.* Paraná: Editora da Universidade Estadual de Maringá.

VAZZOLER, A. E. A. M. & BRAGA, F. M. S. 1983. Contribuição para o conhecimento da biologia de *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883) na área entre Cabo de São Tome (22°04S) e Torres (29°21'S), Brasil. *Boletim do Instituto de Oceanografia*, 32(2), 125-136.

VAZZOLLER, A. E. A. M., SOARES, L. S. H. & CUNNINGHAM, P. T. M. 1999. Ictiofauna da costa brasileira. *In*: LOWE-MC CONNELL, R. H. (ed.). *Estudos ecológicos de comunidades de peixes tropicais*. São Paulo: Edusp, pp. 535.

VIANNA, M., COSTA, F. E. S. & FERREIRA, C. N. 2004. Length-weight relationship of fish caught as by-catch by shrimp fishery in the southeastern Coast of Brazil. *Boletim do Instituto de Pesca*, 30(1), 81-85.

VIEIRA, P. C. & HAIMOVICI, M. 1993. Idade e crescimento da pescada-olhuda *Cynoscion striatus* (Pisces, Sciaenidae) no sul do Brasil. *Atlântica*, 15, 73-91.

VIEIRA, P. C. & HAIMOVICI, M. 1997. Reprodução da pescada-olhuda *Cynoscion guatucupa*, syn., *C. striatus* (Sciaenidae, Teleostei) no sul do Brasil. *Atlântica,* 19, 133-144.

VOLPEDO, A. 2001. *Estudio de la morfometría de las sagittae en poblaciones de sciaenidos marinos de aguas cálidas del Perú y aguas templado-frías de Argentina* [online]. MSc. Buenos Aires: Facultad de Ciencias Exactas y Naturales - Universidad de Buenos Aires. Available at: http://digital.bl.fcen.uba.ar/Download/Tesis/Tesis_3334_Volpedo.pdf [Accessed: 2022 Aug 02].

VOLPEDO, A. V., BIOLÉ, F. G., FORTUNATO, R. G. C., TOMBARI, A. D. & THOMPSON, G. A. 2017. Otolitos de peces de la costa bonaerense. *In*: VOLPEDO, A. V., THOMPSON, G. A. & AVIGLIANO, E. (eds.). *Atlas de otólitos de Peces de Argentina*. Buenos Aires: CAFP-BA-PIESCI, pp. 181-248.

VOLPEDO, A. V. & ECHEVERRIA, D. D. 1999. Morfología de los otolitos *sagittae* de juveniles y adultos de *Micropogonias furnieri* (Desmarest, 1923) (Sciaenidae). *Thalassas*, 15, 19-24.

VOLPEDO, A. V., MIRETZKY, P. & CIRELLI, A. F. 2007. Stocks pesqueros de *Cynoscion guatucupa* y *Micropogonias furnieri* (Pisces, Sciaenidae), em la costa atlântica de Sud América: comparación entre métodos de identificación. *Memoria de la Fundación La Salle de Ciencias Naturales*, 165, 115-130.

VOLPEDO, A. V. & THOMPSON, G. A. 1996. Diferencias en el crecimiento de las *sagittae* de *Prionotus nudigula* Ginsburg, 1950 (Pisces: Triglidae) en relación al sexo. *Boletín del Instituto Español de Oceanografía*, 12(1), 3-16.

VOLPEDO, A. V. & VAZ-DOS-SANTOS, A. M. 2015. *Métodos de estúdios com otolitos: principios y aplicaciones*. Buenos Aires: Ministerio de Educación.

WAESSLE, J. A., LASTA, C. A. & FAVERO, M. 2003. Otolith morphology and body size relationships for juvenile Sciaenidae in the Río de la Plata estuary (35-36ºS). *Scientia Marina*, 67(2), 233-240.

WEATHERLEY, A. H. 1972. *Growth and ecology of fish populations*. London: Academic Press.

ZAR, J. H. 2010. *Biostatistical analysis*. 5th ed. New Jersey: Prentice-Hall Pearson.

ZISCHKE, M. T., LITHERLAND, L., TILYARD, B. R., STRARFORD, N. J., JONES, E. L. & WANG, Y. G. 2016. Otolith morphology of four mackerel species (*Scomberomorus* spp.) in Australia: species differentiation and prediction for fisheries monitoring and assessment. *Fisheries Research*, 176, 39–47.