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GROWTH OF THE BRAZILIAN CODLING, *Urophycis mystacea*, (PHYCIDAE-GADIFORMES) OF SOUTHEASTERN BRAZIL

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ABSTRACT

The Brazilian codling *Urophycis mystacea* (Phycidae-Gadiformes) is a demersal-benthic species, present at the outer shelf and slope of Southeastern Brazil. Its stock has been declining since 2001, when it became a target species for the bottom trawling fleet, which went fishing between the outer shelf and the upper slope. In this study, we present results on the annual periodicity and deposition time of otolith rings, age, growth parameters and, relationships between otolith morphometric variables and age. Males were 1 to 6 years old, and females were 1 to 12 years old. The maximum likelihood ratio test proved that von *Bertalanffy* growth equations obtained for males and females were significantly different; respectively, $Ct = 419.33[1-exp^{-0.35(t-(-0.55))}]$ and $Ct = 629.89[1-exp^{-0.17(t-(-0.89))}]$. The Potential Model presented the best fit for the relationship between the otolith morphometric variables and the fish age and its robustness, verified by the coefficient of determination values (R^2). The otolith weight, followed by length, was the most adequate variables to estimate age.

Key words: *Urophicys mystacea*; Southeast Brazil; growth; otoliths morphometry; fisheries.

CRESCIMENTO DA ABRÓTEA–DE-PROFUNDIDADE, *Urophycis mystacea*, (PHYCIDAE-GADIFORMES) NA REGIÃO SUDESTE DO BRASIL

RESUMO

A Abrótea-de-profundidade, *Urophycis mystacea,* é uma espécie demersal-bentônica, presente na plataforma externa e no talude da Região Sudeste-Sul do Brasil. Seu estoque vem diminuindo desde 2001, quando se tornou alvo da frota de arrasto de fundo, que passou a operar entre a plataforma externa e o talude superior. No presente estudo, investigamos o crescimento da espécie apresentando resultados sobre: periodicidade anual e época de formação dos anéis nos otólitos, idade e parâmetros de crescimento, além de relações entre variáveis morfométricas dos otólitos e idade. Foram encontrados machos com 1 a 6 anos e fêmeas com 1 a 12 anos de idade. A equação de crescimento de von *Bertalanffy* obtida para machos foi $Ct = 419,33[1-exp^{-0,35(t-(-0,55))}]$ e, para fêmeas, $Ct = 629,89[1-exp^{-0,17(t-(-0,89))}]$. O teste da razão de máxima verossimilhança revelou diferenças significativas no crescimento entre sexos. A relação entre variáveis morfométricas dos otólitos e idade foi melhor representada pelo Modelo Potencial, e sua robustez, verificada através do valor do coeficiente de determinação (R^2). O peso do otólito, seguido do comprimento, foram as mais adequadas para predizer a idade dos exemplares.

Palavras-chave: *Urophycis mystacea*; Sudeste-Brasil; crescimento; morfometria de otólitos; pesca.

INTRODUCTION

The determination of age in fish is one of the fundamental aspects for the understanding of biology and population dynamics, besides being essential for fishery management (Panfili et al., 2002; Green et al., 2009). One of the most used methods to determine the age in fish is realized through readings of the growth rings present in the otoliths. For some species, the reading of these rings and the validation of age have been very difficult, as is the case of deep-sea fishes (Campana, 2001; Campana and Thorrold, 2001; Morales-Nin, 2001). Several authors report that for many species of Gadiformes the reading and validation is very complex, due to the number of "checks" and false rings present in the otoliths, which may make it difficult to distinguish the rings

that actually represent years of fish life (Dery, 1988; Clay and Clay, 1991; Lang et al., 1996; Martins and Haimovici, 2000; Andrade et al., 2004).

Among the species of this order, the Brazilian codling has great economic value in Brazil. Its distribution is wide, occurring in the Western Atlantic Ocean, between the Gulf of Mexico and Argentina. The name *Urophycis mystacea* (Miranda Ribeiro, 1903), is the most widespread in Brazil, but some authors consider it as its synonym *Urophycis cirrata* (Goode and Bean, 1896), the most widely used name in the Gulf of Mexico and Argentina (Cousseau, 1993).

Urophycis mystacea is a demersal-benthic species that lives in the waters of the outer platform and on the slope, being rarely found in depths inferior to 60 m. Martins and Haimovici (2000) studied growth in the extreme South, Haimovici et al. (2006) made a diagnosis of the species in the south-eastern region, and considered the stock available of the fishery fragile, considering the estimates of exploitation rates and the biological characteristics of the species, which may lead to overfishing. The species, along with others of the genus Urophycis, compose deep-sea fisheries in the country (Haimovici et al., 2008; Perez et al., 2009). Thus, considering the economic importance that the species represents for the region and its biological characteristics, this study aimed to: 1- determine the growth and age parameters of *U. mystacea* present in the Southeastern Region of Brazil, using the readings of the rings of otolith growth; 2- determine which morphometric measure of otoliths (length, height, thickness and weight) presents the best fit to estimate, in a practical and fast way, the age of the specimens.

MATERIAL AND METHODS

The specimens of *U. mystacea* come from samplings carried out within the REVIZEE Program - Evaluation of the Sustainable Potential of Living Resources in the Exclusive Economic Zone - Southern Score, in the years 1996 (October), 1997 (May, June, August and December), 1999 (October and November), 2000 (September and October), 2001 (August, September and October) and 2002 (February, April and June). The fish were captured with bottom trawls, circular and rectangular coils (large and small), pargue lines and bottom spines. The sample area was from Cabo Frio, in Rio de Janeiro (23 ° 26'S), to the Cape of Santa Marta Grande, in Santa Catarina (31 ° 07'S), at depths of 94 to 810 meters (Figure 1).

From each specimen were obtained: total length (Ct, approximated to 1 mm), weight (approximate 0.1 gram) and sex (FAO, 1981; Sparre and Venema, 1998). The gonads were dissected, classified according to degree of maturity and weighed in scale with precision of one thousandth of a gram, following Vazzoler (1981). Frequency distributions of length, considering classes of 20 mm, were performed for males and females, being compared to each other by using the "Kruskal-Wallis" test. The sagittae otoliths were removed, washed in water, dried and packed in plastic microtubes. The frequency distribution of males and females was analyzed by grouping individuals into length classes (20 mm). Samples of

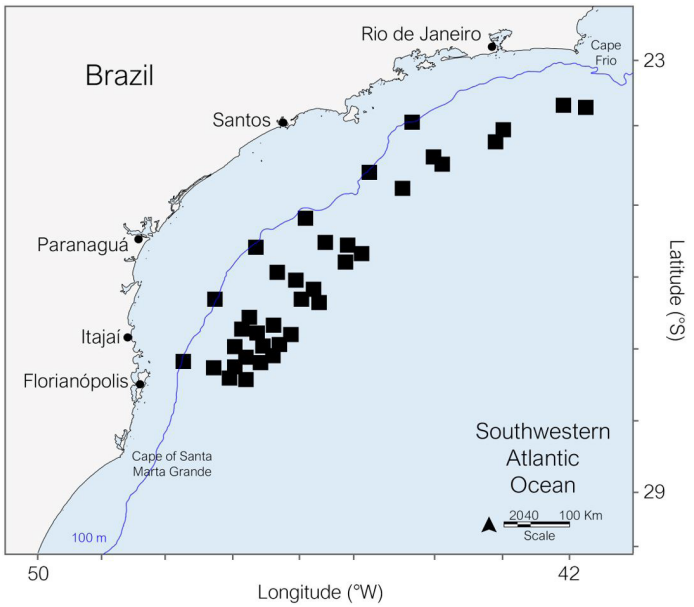

Figure 1. Sample area of the present study with the collection points of *Urophycis mystacea* indicated in black.

otoliths of males and females were obtained for each length class, and the measurements of length, height and thickness of the same ones were taken with a pachymeter with precision of 0.05 mm (Figure 2). The weight of the otoliths was measured with a scale with an accuracy of one thousandth of a gram. The homogeneity between the right and left otoliths of each individual was evaluated through the Wilcoxon Paired Combination Test, for all variables.

Then, the left otolith of each specimen was embedded in resin and, with an ISOMET TM metallographic cutter, sectioned near its core, with cuts of 0.05 mm thickness. Subsequently, the cuts were polished (Secor et al., 1991) and photographed. From the analysis of the photos, the distance between the nucleus and the edge of the otolith (radius of the otolith) and between the nucleus and the end of each ring (radius of the ring) was obtained, as well as the type of border, whether opaque or translucent (Figure 3).

The counting of the number of rings was performed under incident light, a ring being considered a translucent region, plus the adjacent opaque region. Such analyzes were performed in Carl Zeiss Discovery V12 stereomicroscope with coupled camera and AxioVision 4.8.2 image analyzer.

The counting of the rings and the verification of the type of edge of each otolith were repeated three times, by the same reader, in different periods. When divergence occurred the otolith was discarded. To verify the consistency of the readings, the coefficient of variation was applied, C.V. = $((\sigma / \mu) * 100)$, to the position of each ring relative to the radius of the otolith, where: σ = Standard Deviation and μ = mean (Zar, 2010).

For the determination of the periodicity and the time of formation of the rings, the relative percentage data of the border type of the otoliths of males and females were grouped according to the season of the year of capture of the fish, being: Autumn = March 21 to

June 21, Winter = June 21 to September 23, Spring = September 23 to December 21 and Summer = December 21 to March 21.

In order to investigate the possible influence of the breeding season on the formation of the rings, the gonadosomatic index (IGS), per season of the year, was calculated for males and females, according to Vazzoler (1981).

For the species, the length-growth equation was described by the von Bertalanffy Model: $Lt = L\infty [1\text{-}exp (-K (t\text{-}t_0)]$, where Lt is the total fish length at age t; $L \infty$ is the maximum asymptotic length; K is the constant that determines the growth rate and t_0 is the theoretical age at zero length using the Iterative Least Squares Method.

The values of the measures taken from the otoliths: length, height, thickness and weight were plotted in scatter plots, by age, and regressions were adjusted to them. The models were tested: linear, exponential, logarithmic and potential, being evaluated based on the coefficient of determination (R^2). The growth parameters obtained for males and females were compared using the maximum likelihood ratio test (Kimura, 1980).

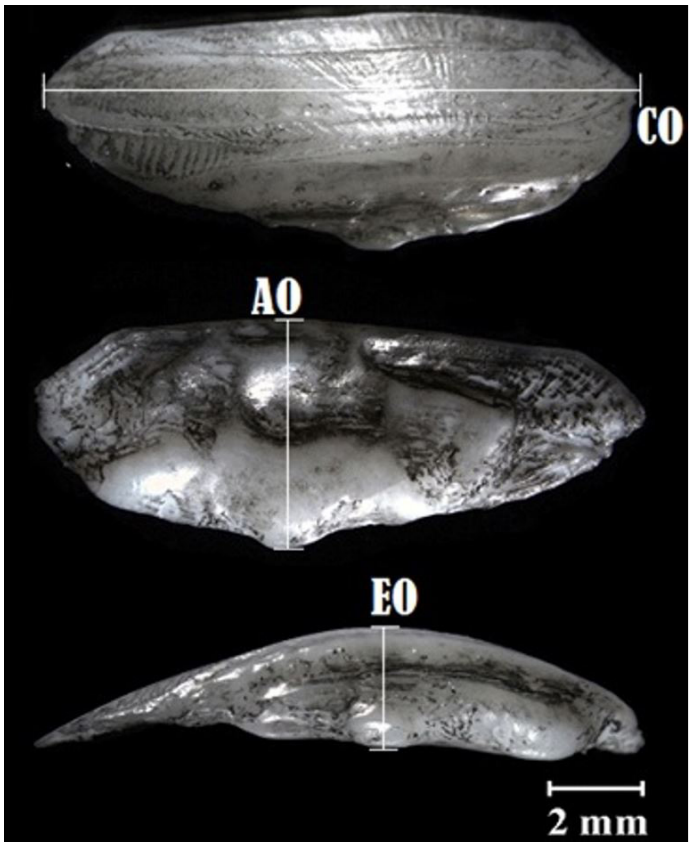

Figure 2. Measurements of the otoliths of *Urophycis mystacea*. CO = length; AO = height; EO = thickness. Adapted from Rossi-Wongtschowski et al. (2014).

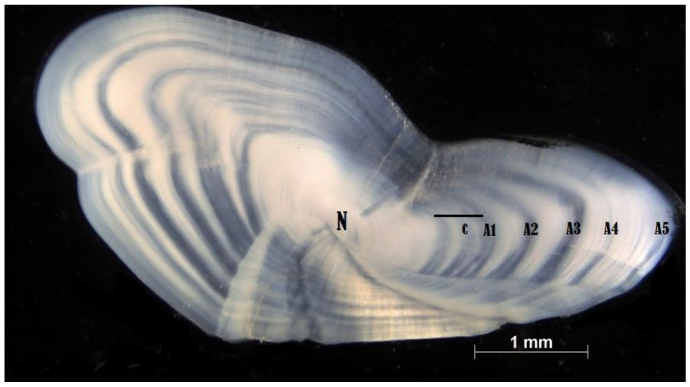

Figure 3. Photo of the cut of the otolith of a female with five rings and 480 mm of total length, presenting an opaque border. N = nucleus; A = rings; C = Checks with growth ring indicated above.

RESULTS

Of the 2,890 individuals sampled, 971 were males (33.6%), 1,578 females (54.6%) and 341 had no sex (11.8%). The overall length range was 186 to 676 mm. Regarding the total weight, the amplitude was from 41 to 2,905 grams. Considering all individuals collected, the highest proportion of males was observed until the length class of <360 mm. Females became abundant in classes ≥ 360 mm (Figure 4A). The Kruskal-Wallis test revealed heterogeneity between male and female lengths (p value <0.05).

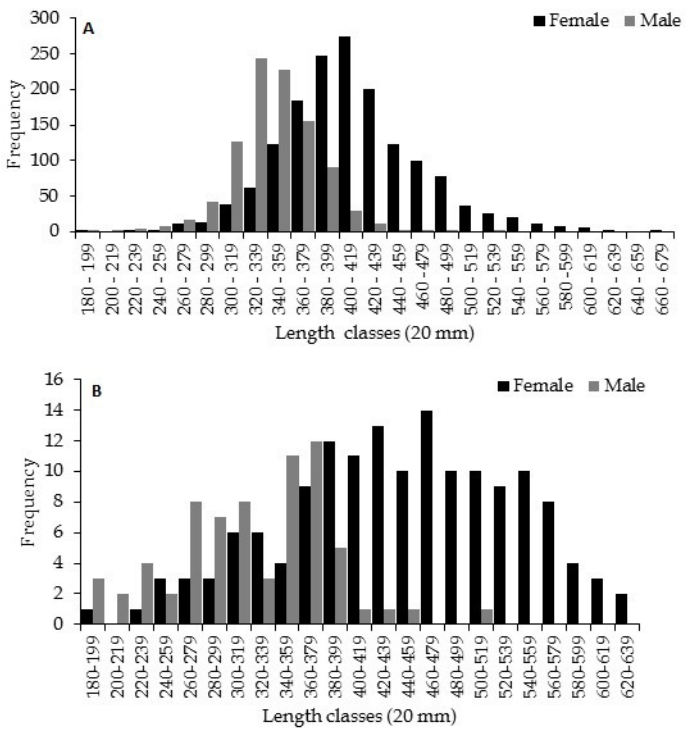

Figure 4. A. Frequency distribution, by length classes, of *Urophycis mystacea* specimens. (A) All individuals collected in the REVIZEE program; (B) Individuals used for growth analysis.

For the analysis of the ages, 221 otoliths were selected proportionally to the original sample, being 69 males (34%) and 152 females (66%) (Figure 4B). The Wilcoxon test showed homogeneity between the left otolith and the right of the same individual ($p > 0.05$) for all morphometric variables of the measured otoliths (length, height, thickness and weight). The otolith sections showed a concentric pattern in the deposition of the rings, with alternation of opaque and translucent zones around a large opaque core. The number of rings in otoliths varied from 1 to 12 for females and from 1 to 6 for males. The coincidence in the readings for the number of rings and the type of border was 99% after the third reading. The values of the coefficients of variation of the positions of the rings relative to the otolith radius were small (ranging from 4.9 to 7.3) for males and females. The analysis of the growth rings revealed annual periodicity, being formed during the autumn (Figure 5). The mean values of IGS indicated that the reproductive period of the species also occurs in autumn for males and females in the Southeast Region (Figure 6).

The maximum likelihood test revealed significant differences ($p < 0.001$) between von Bertalanffy growth curves for males and females (Figure 7).

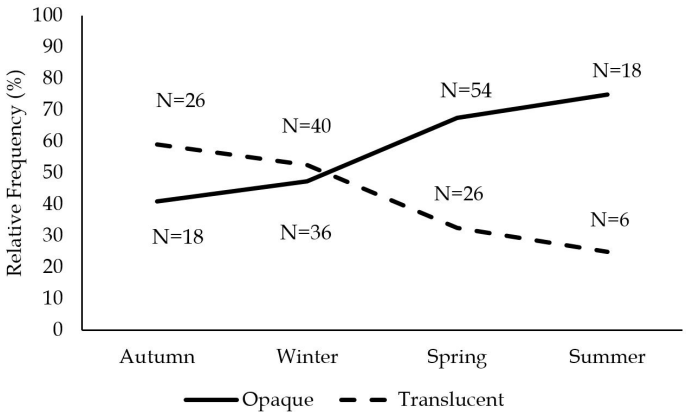

Figure 5. Relative percentage of the border type of the otoliths of males and females grouped.

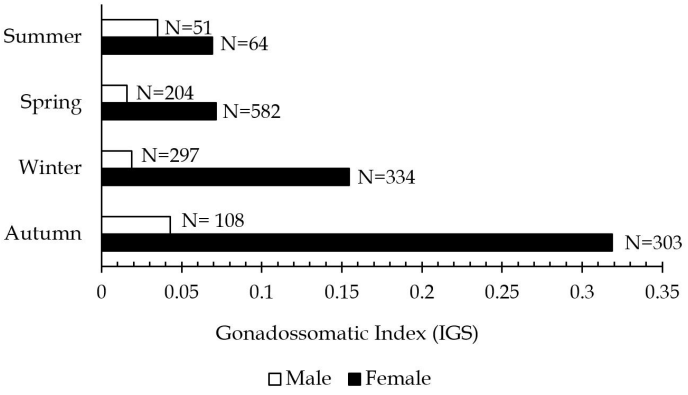

Figure 6. Value of Gonadossomatic Index (IGS), for males and females of *Urophycis mystacea*, by season.

Among the different mathematical models tested (Table 1), the Potential Model was the one that presented the best relation between the variables of the otoliths and the age, and the weight was the variable that presented the highest coefficients of determination for both sexes. Figure 8 shows the parameters of the equations obtained and the respective determination coefficients (R2). The value of the maximum likelihood test showed significant differences between males and females for all variables ($p < 0.01$).

DISCUSSION

The significant difference found between male and female lengths, with a predominance of females in larger sizes, was also reported for other species of Gadiformes (Dery, 1988; Casas and Piñeiro, 2000; Haimovici et al., 2004, 2008; Matic-Skoko et al., 2011).

For *Urophycis mystacea*, the absence of males with longer lengths is a fact that needs further investigation. Haimovici et al. (2004), in the Southern region, found an increase in the proportion of males in relation to females of *Urophycis mystacea* at greater depths, indicating a possible segregation of the sexes in relation to depth. On the other hand, Andrade et al. (2004), observed the same fact for the congenial species *Urophycis brasiliensis*, and suggested the occurrence of spatial segregation, being that during their growth, the males begin to inhabit greater depths and, therefore, are not easily sampled.

Although spatial segregation may be one of the causal factors of the absence of males, the lower longevity in this genus may have contributed to this effect in the sample. In relation to females, the males presented half of the longevity, similar to the one observed by Martins and Haimovici (2000), in the southern area of the distribution of the species.

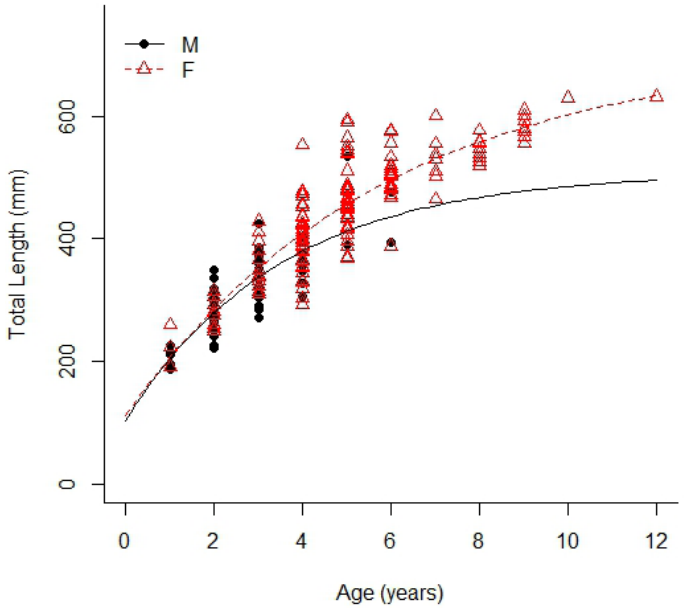

Figure 7. Male growth curves: $Lt = 419.33\ [1\text{-exp}\ (-0.35\ (t - (-0.55))]$ and females: $Lt = 629.89\ [1\text{-exp}\ (-0.17\ (t - -0.89))]$ of *Urophycis mystacea*.

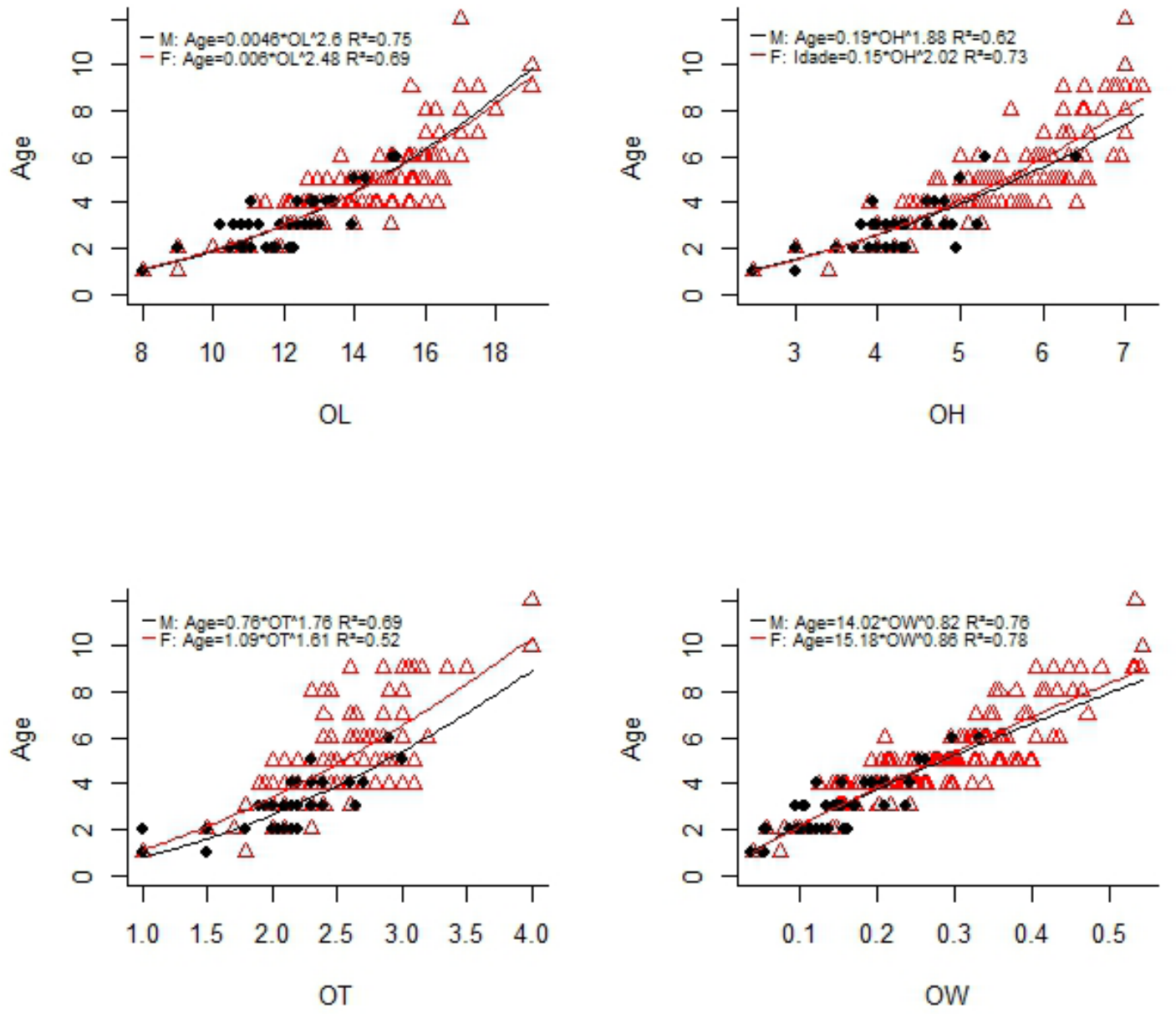

Figure 8. Graph of the relationships between the variables of otoliths: length (OL), height (OH), thickness (OT) in mm and weight (OW), in g, in relation to age (years) (M) and females (F), and respective determination coefficients (R^2).

Table 1. Values of the coefficient of determination (R^2) of the different mathematical models tested for the relationships between morphometric variables of otoliths and age.

Relations	Mathematical Models											
	Linear Model			Exponential Model			Logarithm Model			Potential Model		
	M	F	A	M	F	A	M	F	A	M	F	A
OL × Age	68.9	65.9	74.5	64.6	62.4	70.5	72.9	74	80.8	73	75.2	81.6
OH × Age	61.4	70.4	72.5	57.6	66.2	66.5	62.2	75.7	75.1	62.6	77	75.4
OT × Age	61.9	51.4	55.2	53.4	48.1	54	62.1	55	56.9	62.2	57.2	60.6
OW × Age	75.6	77.5	82.7	66.8	68.8	73.8	69.4	74	77.7	75.8	79.5	83.8

OL = length; OH = height; OT = thickness; OW= weight; M = males; F = females; A = grouped (males and females).

The growth ring reading in the otolith was complicated, mainly by the presence of numerous checks (discontinuities in the growth rings). The presence of these bundles is well discussed in the study by Martins and Haimovici (2000) and others performed with co-generic species (Dery, 1988; Clay and Clay, 1991; Lang et al., 1996; Andrade et al., 2004). The cause of their origin has not yet been elucidated (Panfili et al., 2002; Green et al., 2009).

Martins and Haimovici (2000) verified that the species presents annual periodicity in the formation of growth rings, corroborating our results. However, the results of these authors diverged from ours regarding the period of their formation, spring and autumn, respectively. Such differences may be due to the different sampled areas (South and Southeast), as well as the characteristics of the samplers and / or the periods of research in each of the studies.

In fish, the availability of food provides energy for the development of gametes, and the reproductive period is one of the events that can cause translucent markers in otoliths (Hoar and Randall, 1969; Panfili et al., 2002). In the case of Martins and Haimovici (2000) and ours, the difference in the period of higher primary productivity in the respective areas may play an important role in the reproductive cycle of the species.

Seasonal variation is marked by the presence of the South Atlantic Central Water (ACAS), a water mass inhabited by *Urophycis mystacea*, between Cabo Frio (23° 05'S) and Cape Santa Marta Grande (28 ° 40'S), area of the present study. In summer, ACAS advances on the internal platform, increasing primary productivity in the region, while the opposite occurs in winter (Matsuura, 1995; Castro and Miranda, 1998). On the other hand, in the southern extreme, between latitudes 29° S to 34° 30' S, Martins and Haimovici (2000) area of study, the highest productivity is observed in the winter and spring months (Odebrecht and Castello, 2001).

This way, we related the formation of the translucent rings in the otoliths with the reproductive period of the species, which, according to the results of the mean value of the gonadosomatic index, occurred during the autumn months. Thus, in relation to the time of growth ring formation, despite the divergence found between our results and those of Martins and Haimovici (2000), we observed the formation of only one ring per year, a periodicity also observed in other species of the genus (Dery, 1988; Clay and Clay, 1991; Lang et al., 1996; Andrade et al., 2004).

The parameters of the growth equations obtained for males and females of *U. mystacea* were distinct, but similar to those obtained by Martins and Haimovici (2000). The growth rate of males was almost double that of females. This fact would have been caused by the absence of larger males in the sample, due to their migration to greater depths or due to their shorter longevity. This is an issue to be resolved.

The high values of the coefficients of determination obtained in the relationships between age and variables of the otolith indicated that all of them are useful to predict the age of the species, but the weight of the otolith was the one that presented higher values of the coefficient of determination, thus revealing the more effective for predicting the age of *U. mystacea*.

Many authors have demonstrated that otolith weight is the best measure to predict the age of the fish (Cardinale et al., 2000; Cardinale and Arrhenius, 2004; Pino et al., 2004; Lou et al., 2007; Matic-Skoko et al., 2011). In turn, Skeljo et al. (2012) found a high correlation between otolith length and age. Our results also revealed high correlation between otolith length and age, being this variable also considered a good predictor of age for the species.

CONCLUSION

Urophycis mystacea presents differentiated lengths between males and females throughout their development. The formation of growth rings in the sagitta otolith is related to the reproduction of the species, which occurs in autumn. The variables length, height, thickness and weight of *U. mystacea* otoliths are positively related to age, especially weight and length, and can be considered good predictors of the same. This study provides basic and indispensable information to the management of the stock exploitation, in the Southeast Region of Brazil.

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