Research Article

Biometric sexual and ontogenetic dimorphism on the marine catfish *Genidens genidens* (Siluriformes, Ariidae) in a tropical estuary

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ABSTRACT. This paper aims to study the ontogenetic sexual dimorphism of *Genidens genidens* in Guanabara Bay, southeastern coast of Brazil. Altogether 378 specimens were anayzed (233 females and 145 males) with total length ranging from 13.3 to 43.5 cm. Specimens were measured for 12 body measurements, sex was identified and maturity stages were recorded and classified. Pearson's linear correlation reveled a significant positive correlation between total length and all other body measures, except for base adipose fin, mouth depth and eye depth for immature females. Analyses nested PERMANOVA desing showed significant differences between maturity stages for each sex, between sexes considering or not maturity stages, indicating a variation in morphometric characteristics driven by sexual dimorphism. Differences among all maturity stages were also found, indicating an ontogenetic morphological difference. But immature individuals didn't differ between sexes indicating that differentiation patterns starts with sexual development. The most important measures differing males and females were related to head characteristics, which appears to be key parameters to evaluate sexual differences. Due to male incubation of fertilized eggs and juvenile individuals <59 mm in their oral cavity, head measures are proposed to be sex dimorphism not related to reproduction, but with post reproductive fase due to ecological and biological needs.

Keywords: *Genidens genidens*, catfish, Teleostei, morphometry, biometry, dimorphism, tropical estuary.

Biometría sexual y dimorfismo ontogenético en el bagre marino *Genidens genidens* (Siluriformes, Ariidae), en un estuario tropical

RESUMEN. Se analizó el dimorfismo sexual y ontogenético del bagre marino *Genidens genidens* en la Baía de Guanabara, costa sureste de Brasil. Se capturó un total de 378 ejemplares (233 hembras y 145 machos) con longitud total entre 13,3 y 43,5 cm. Se realizaron 12 medidas morfométricas, además de identificar el sexo y los estadios de madurez de los individuos. La correlación lineal de Pearson reveló correlación positiva significativa entre la longitud total y otras medidas corporales excepto la base de la aleta adiposa, altura de la boca y altura de los ojos en hembras inmaduras. Los análisis de PERMANOVA anidados mostraron diferencias significativas entre los estados de madurez de cada sexo, entre los sexos, considerando o no, los estados de madurez, lo que indica una variación en las características morfométricas reguladas por el dimorfismo sexual. También se encontraron diferencias entre los estadios de madurez, lo que indica una diferencia ontogenética para el sexo y estadios de madurez. Los individuos inmaduros no difirieron entre los sexos, indicando que los patrones de diferenciación se inician sólo con el desarrollo sexual. Las medidas más importantes que difieren entre machos y hembras se relacionaron con las características de la cabeza que, al parecer, serían los principales parámetros para evaluar las diferencias sexuales. Debido a que los machos realizan la incubación en su cavidade oral de los huevos fertilizados y de individuos juveniles <59 mm, se sugiere que las medidas de la cabeza corresponden a un dimorfismo sexual no relacionado con la reproducción, pero vinculado a una fase post-reproductiva debido a sus necesidades ecológicas y biológicas.

Palabras clave: *Genidens genidens*, bagre, Teleostei, morfometría, biometría, dimorfismo, estuario tropical.

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INTRODUCTION

It is well known that morphology is directly related to species life history and habitat use. Thus fish morphometric analysis represents an important tool to determine their systematic, growth variation, population parameters and environmental relationships (Kováč *et al.*, 1999; Pathak *et al.,* 2013; Sampaio *et al.*, 2013; Souza *et al*., 2014). Morphometry cover several study fields such as: ecomorphology, relating species morphology with environment characteristics and evaluating the role of environmental preasures on shaping species diet, feeding behavior, ecological strategies, niche partitioning, habitat use and trophic structure (Peres-Neto, 1999; Haas, 2010; Manimegalai *et al*., 2010; Palmeira & Monteiro-Neto, 2010; Souza *et al.*, 2014) population ecology and metapopulations studies, investigating differences in body shape among populations spatially isolated (Gunawickrama, 2007; Mwanja, 2011; Santos & Quilang, 2012; Sampaio *et al.,* 2013; Souza *et al.,* 2014) and taxonomy, to differ and describe species and taxonomic groups based on internal and external features, which can result in misidentification if the individual is of diferent life stage than the ones used for classification (Marceniuk, 2005a, 2005b). However, intraspecific characteristics are often forgotten in studies investigating species morphological diversity, mainly in taxonomic studies. When this occurs, males and females of the same species may be identified as different species, therefore information about morphological sexual variation is important to avoid species misleading identification (Rapp Py-Daniel & Cox-Fernandes, 2005; Marceniuk, 2007).

Sexual dimorphism can be an important evolutionay adaptation mechanism, conditioning sexual selection and diminishing intraspecific competition by encreasing nich partioning (Hedrick & Temeles, 1989; Herler *et al.,* 2010), being an important study fill whithin morphometric research. An organism must function properly in all life stages and function and form are strictly related (Galis *et al.,* 1994). Ontogenetic changes can determinate the success of an individual due to the importance of morphological features, environment adaptation and reproductive selection. Thus clarify how morphological changes develop throughout individuals growth is important to establish the relationship between morphology and behaviour, elucidating possible ontogenetic nich shifts and the evolutionary plasticity of an organism (Galis *et al.,* 1994).

Marine catfish of the genus *Genidens* (Siluriformes, Ariidae) are endemic of South Atlantic coasts and are commercially important estuarine fishes in Brazil (Mendoza-Carranza & Vieira, 2009; Silva-Junior *et al.*, 2013). Due to Ariidae benthic habits and broad diet, they have good potential for biomonitoring studies (Azevedo *et al.*, 2012). Furthermore studies with *Genidens genidens* (Curvier, 1829) in Guanabara Bay and Santos-São Vicente estuary suggested that they should be used as estuarine sentinels, due to their tolerance to eutrophication and others anthropogenic changes (Azevedo *et al.,* 2012; Silva-Junior *et al.,* 2013). In Guanabara Bay, a Brazilian tropical estuary, *G. genidens* is one of the most abundant species, occupying shallow waters with low salinity and low water transparency (Rodrigues *et al.,* 2007; Silva-Junior *et al.*, 2013). Guanabara Bay has great economic and social importance due to fishing and navigation activities, industrial surrounding areas and ecological relevance due its importance for many marine and freshwater lifecycle (Vasconcelos *et al.,* 2010). Despite their ecological importance *G. genidens*'s morphological sexual and ontogenetic variations are little known. This paper is the first study aiming to evaluate *G. genidens*'s morphological changes between sexes and through ontogenetic development. It will provide more detailed biometric information on the species which could assist further studies on its biology and ecology.

MATERIALS AND METHODS

Guanabara Bay is located in Rio de Janeiro State, southeastern Brazil (22°40'S, 43°02'W) (Fig. 1). It has an area of 384 km², 7.6 m of mean depth and has an average water residence time of 20 ± 5 days. It is an estuarine environment with minimum salinity of 25 and maximum of 34.5, low hydrodynamics, small grain size bottom and great influence of freshwater runoff and domestic sewage resolting in a major eutrophicated system (Kjerfve *et al.,* 1997; Quaresma *et al.,* 2000).

Specimens of *G. genidens* (voucher MNRJ 42040) were collected, twice a month, from August 2010 to September 2011. Samples were collected covering the three most important local fisheries (gill net, bottom trawl and stationary pound net) and all Guanabara Bay habitat zones. All specimens were cooled on ice and then measured for 11 body measures (by convention, always on the left side) using a ichtyometer and a electronic caliper rul with precision of 0.01 mm, without being fixed, according to metric measures proposed by Marceniuk (2005a) and Souza & Barrella (2009) (Fig. 2) (Table 1). Measures were standardized as a percentage of total length (TL), excluding total length's effect on body measures. The determination of sex and sexual maturity stages were made by gonads macroscopic observation through an adaptation of
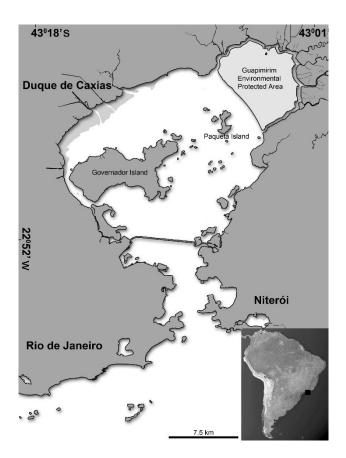
Figure 1. Study location highlighting Guanabara Bay in Rio de Janeiro state, southeastern coast, Brazil.

Vazzoler (1996): A = immature, B = in maturation process, C+D = mature.

The degree of association between *G. genidens* size and body proportions, within sex and maturity stages were tested with Pearson's linear correlation analyses using Statistica 8 software, with the significance level of 0.05.

A multivariate nested PERMANOVA design was used to evaluate differences in maturity stages within each sex [maturity (sex)] (ontogenetic differences) and between sexes within maturity stages [sex (maturity)] (sexual dimorphism). A pair-wise *post-hoc* test was performed to further investigate differences between groups. This test uses an ANOVA experimental design on the basis of any distance measure, using Monte Carlo permutation method (Anderson, 2005) and provides which factor was most important for data differences. A pair-wise *post-hoc* test was performed to analyze differences among male and female maturity stages. SIMPER analysis was performed to evaluate witch metric measurements were most important for determining group dissimilarity. These analyses were performed using Primer 6 + PERMANOVA software (Clarke & Gorley, 2006).

RESULTS

A total of 378 specimens were captured, 233 females (immature (A) = 9, in maturation process (B) = 68, mature (C+D) = 156) and 145 males (immature (A) = 27, in maturation process (B) = 53, mature (C+D) = 65). Total length ranged from 13.3 to 43.5 cm (Fig. 3).

Morphometric features and Pearson's linear correlations are presented in Table 2. Body measures were significant correlated with total length (TL), except for base adipose fin (AF), mouth depth (MD) and eye depth (ED) of immature females (Table 2). Morphometric measures showed significant differences for maturity stages within sex, sex within maturity stages and between sexes, but not for maturity stages alone (Table 3a), indicating a possible alteration in morphometric characteristics driven by sexual dimorphism along with maturation process. The *post-hoc* test showed a significant difference between sexes for all maturity stages except A, indicating that imamture individuals did not have morphological differences and the differentiation only starts at the beginning of sexual development (Table 3b). SIMPER analysis indicated maximum body depth (BD), upper caudal fin lobe length (CL), head length (HL), barbeus length (BL), interorbital distance (ID) and mouth depth (MD) as the six most important metric measurements descrimitating females from males and the group A from B and C+D.

DISCUSSION

The present study evaluated morphological onthogenetic changes in *Genidens genidens* and found a well defined sexual dimophism reveled through changes in head measures. Those differences are related to the maturity process responsible for differing male from female individuls due to their reproductive role. Sexual dimorphism may be an evolutionary adaptative mechanism favouring sexual selection, acting on males when females for choosing partners for mating and in mate competition, enhancing selection towards certain male traits (Hedrick & Temeles, 1989). When compered with other vertebrates, teleosts have a wide range of sexual dimorphism described, including color, size, shape and feeding mechanisms (Kitano *et al*., 2007; Herler *et al.,* 2010; Mcgee & Wainwright, 2013). For *G. genidens* sexual dimorphism has been observed in pelvic fins, that are higher in females compared to males (Barbieri *et al.,* 1992), but it had never been evaluated to ontogenetic variations along with sexual changes until this study.

Ontogenetic differences have been described by most studies based on morphology but they are often
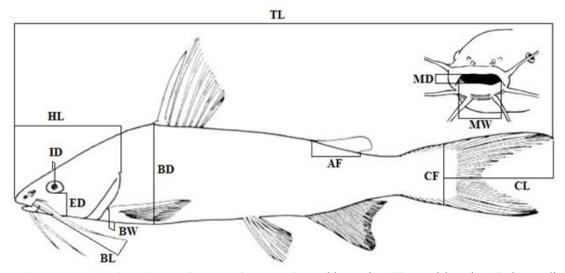
Figure 2. Body measures used to characterize *Genidens genidens*'s biometrics. TL: total length, AF: base adipose fin, CF: base caudal fin, BL: barbeus length, HL: head length, CL: upper caudal fin lobe length, ID: interorbital distance, BD: maximum body depth, ED: eye depth, BW: mouth width, MD: mouth depth. This image is a modification of Figueiredo & Menezes (1978).

Table 1. Description of body measures used to characterize *Genidens genidens*'s biometrics.

Measurements	Code	Description
Total length	TL	Greater distance between the tip of the snout and caudal fin.
Base adipose fin	AF	Distance between the beginning and end of adipose fin.
Base caudal fin	CF	Height of the top of the caudal fin.
Barbeus length	BL	Distance between the base and the end of the longest barbel.
Head length	HL	Distance from the tip of the snout to the end of the operculum.
Upper caudal fin lobe length	CL	Distance between the base of the caudal fin and the tip of the upper lobe of the caudal fin.
Interorbital distance	ID	Distance between the eyes taken from the upper portion.
Maximum body depth	BD	The longest distance between the belly and back perpendicular to the body axis.
Eye depth	ED	Taken away the eyes of the height of the iris to the womb.
Maximum body width	BW	Largest body width.
Mouth width	MW	Internal distance from the mouth when fully open.
Mouth depth	MD	Greater distance between the measured lips with mouth open, stretch the muscles without.

related to feeding habits and habitat use (Zimmerman *et al.,* 2009; Lima *et al.,* 2012) and not to diffenreces between sex. We observed differences between male and female in head measures (BD, CL, HL, BL, ID, MD), which we suggest to be the key parameters to evaluate sexual dimorphism in this species. Head measures where bigger in male than female probably due to their different roles on the reproductive process, since marine catfish have parental care where male incubates fertilized eggs and larvae in their mouth (Velasco *et al.*, 2006; Silva-Junior *et al.,* 2013). We know that *G. genidens*, beyond fertilized eggs, the incubators males may present in their oropharyngeal cavity larvae up to 59 mm (Chaves, 1994). Changes in head measures also have been observed in fish species, related with oral incubation behavior. Herler *et al*. (2010),
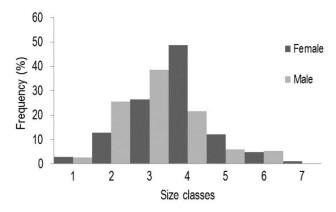

Figure 3. Frequency distribution of total length, of *Genidens genidens*, for female and male, in Guanabara Bay, Rio de Janeiro, Brazil.

Table 2. Morphometric characteristics, of G*enidens genidens,* and Pearson's linear correlation (r), for the associations between total lenght and body proportions, within sex and maturity stages. Range: minimum and maximum values; $\bar{x}$ = mean values ($\pm$ standard deviation). *$P < 0.05$. **$P < 0.001$.

Parameters	Sex	Maturity stage	Range (cm)	$\bar{x}$ ($\pm$ SD)	r
		A	14.1 - 18.9	15.7 ($\pm$ 1.5)	
	Female	B	14.1 - 41.4	26.3 ($\pm$ 6.9)	
		C+D	16.4 - 43.5	26.4 ($\pm$ 4.1)	
Total length (TL)		A	13.3 - 24.9	18.4 ($\pm$ 2.9)	-
	Male	B	16.1 - 33.4	23.0 ($\pm$ 4.1)	
		C+D	17.5 - 38.6	25.9 ($\pm$ 5.1)	
		A	0.8 - 1.1	1.0 ($\pm$ 0.1)	0.5
	Female	B	0.9 - 3.2	1.8 ($\pm$ 0.6)	0.9**
		C+D	0.6 - 3.4	1.8 ($\pm$ 0.4)	0.8**
Base adipose Fin (AF)		A	0.7 - 1.7	1.3 ($\pm$ 0.3)	0.9**
	Male	B	1.0 - 4.8	1.7 ($\pm$ 0.5)	0.7**
		C+D	0.6 - 2.9	1.8 ($\pm$ 0.5)	0.8**
		A	1.3 - 1.8	1.5 ($\pm$ 0.2)	0.9**
	Female	B	0.9 - 4.5	2.6 ($\pm$ 0.8)	0.9**
		C+D	0.7 - 6.1	2.6 ($\pm$ 0.6)	0.9**
Base caudal Fin (CF)		A	1.0 - 2.5	1.8 ($\pm$ 0.3)	0.8**
	Male	B	1.4 - 4.5	2.3 ($\pm$ 0.6)	0.6**
		C+D	1.8 - 6.2	2.6 ($\pm$ 0.7)	0.8**
		A	2.5 - 3.8	3.1 ($\pm$ 0.4)	0.7*
	Female	B	2.8 - 7.7	4.8 ($\pm$1.2)	0.9**
		C+D	3.2 - 7.9	4.8 ($\pm$ 0.8)	0.9**
Barbeus length (BL)		A	1.6 - 4.6	3.5 ($\pm$ 0.6)	0.9**
	Male	B	3.2 - 6.3	4.4 ($\pm$ 0.8)	0.9**
		C+D	3.0 - 7.9	4.7 ($\pm$ 1.0)	0.9**
		A	2.8 - 3.8	3.1 ($\pm$ 0.3)	0.9**
	Female	B	2.6 - 8.3	5.3 ($\pm$ 1.5)	1.0**
		C+D	2.3 - 9.4	5.4 ($\pm$ 1.0)	0.9**
Head length (HL)		A	2.6 - 5.8	3.6 ($\pm$ 0.8)	0.8**
	Male	B	2.5 - 7.5	4.9 ($\pm$ 1.1)	0.7**
		C+D	2.7 - 9.1	5.7 ($\pm$ 1.4)	0.9**
		A	3.1 - 3.8	3.3 ($\pm$ 0.2)	0.9*
	Female	B	2.8 - 8.3	5.2 ($\pm$ 1.4)	0.9**
		C+D	2.2 - 8.3	5.3 ($\pm$ 1.0)	0.8**
Upper caudal fin lobe length (CL)		A	2.6 - 4.5	3.6 ($\pm$ 0.5)	0.9**
	Male	B	1.6 - 6.5	4.4 ($\pm$ 1.1)	0.8**
		C+D	3.3 - 7.5	5.1 ($\pm$ 1.1)	0.9**
		A	0.9 - 1.6	1.2 ($\pm$ 0.2)	0.9*
	Female	B	0.9 - 4.1	2.2 ($\pm$ 0.8)	1.0**
		C+D	1.1 - 4.4	2.2 ($\pm$ 0.5)	0.9**
Interorbital distance (ID)		A	0.8 - 2.1	1.4 ($\pm$ 0.4)	0.9**
	Male	B	1.1 - 3.5	2.0 ($\pm$ 0.5)	0.9**
		C+D	1.2 - 4.0	2.4 ($\pm$ 0.7)	0.9**
		A	2.3 - 3.2	2.5 ($\pm$ 0.3)	0.9**
	Female	B	1.8 - 7.1	4.1 ($\pm$ 1.2)	0.9*
		C+D	1.4 - 7.0	4.1 ($\pm$ 0.7)	0.8**
Maximum body depth (BD)		A	1.5 - 3.8	2.7 ($\pm$ 0.6)	0.9**
	Male	B	2.4 -6.3	3.5 ($\pm$ 0.8)	0.9**
		C+D	2.4 - 6.3	4.0 ($\pm$ 0.9)	0.9**

Continuation

Parameters	Sex	Maturity stage	Range (cm)	$\bar{x}$ ($\pm$ SD)	r
Mouth depth (MD)	Female	A	0.8 - 1.3	1.0 ($\pm$ 0.2)	0.5
		B	0.8 - 3.1	1.8 ($\pm$ 0.5)	0.9**
		C+D	1.0 - 3.5	1.7 ($\pm$ 0.4)	0.7**
	Male	A	0.6 - 1.9	1.3 ($\pm$ 0.3)	0.5*
		B	0.9 - 3.0	1.6 ($\pm$ 0.4)	0.5**
		C+D	1.0 - 2.9	1.8 ($\pm$ 0.5)	0.8**
Eye depth (ED)	Female	A	0.6 - 1.3	0.8 ($\pm$ 0.4)	0.2
		B	0.5 - 2.0	1.1 ($\pm$ 0.4)	0.8**
		C+D	0.5 - 2.3	1.0 ($\pm$ 0.3)	0.8**
	Male	A	0.3 - 1.2	0.7 ($\pm$ 0.2)	0.6*
		B	0.5 - 2.2	0.9 ($\pm$ 0.3)	0.7**
		C+D	0.6 - 1.9	1.0 ($\pm$ 0.3)	0.8**
Maximum body width (BW)	Female	A	1.9 - 3.0	2.4 ($\pm$ 0.3)	0.9**
		B	2.2 - 6.4	4.1 ($\pm$ 1.1)	0.9**
		C+D	2.0 - 6.6	4.2 ($\pm$ 0.7)	0.9**
	Male	A	2.0 - 4.1	2.9 ($\pm$ 0.5)	0.9**
		B	2.5 - 5.6	3.6 ($\pm$ 0.7)	0.7**
		C+D	2.8 - 6.6	4.2 ($\pm$ 0.9)	0.9**
Mouth width (MW)	Female	A	0.9 - 1.3	1.1 ($\pm$ 0.1)	0.8*
		B	0.9 - 4.1	2.1 ($\pm$ 0.8)	0.9**
		C+D	1.2 - 4.1	2.1 ($\pm$ 0.5)	0.9**
	Male	A	0.8 - 2.1	1.3 ($\pm$ 0.3)	0.9**
		B	1.0 - 2.9	1.8 ($\pm$ 0.4)	0.9**
		C+D	1.4 - 4.0	2.2 ($\pm$ 0.6)	0.9**

investigated the sexual dimorphism in populations of the cichlid genus *Tropheus*, oral incubators fishes, in Lake Tanganyika, in Africa, and found significant differences in mean shape between sexes among the seven populations analyzed related to oral landmarks with larger head length and ventral area (buccal region) in females (the oral breeders). Barnett & Bellwood (2005) investigated the sexual dimorphism in seven fish species with incubation behaviour of eggs and larvae in the oral cavity, in Lizard Island, and observed that males had bigger oral volumes than females in five of them.

For some fishes, clear morphometric differences between sexes appear only in certain gonadal stages in specific body measurements, as observed in this study. Manimegalai *et al.* (2010) studied the ciclhid *Etroplus maculates* in India and observed significant correlation between body length growth and morphometric measure and suggested that body measures increases as a function of total growth. Kitano *et al.* (2007) studied *Gasterosteus aculeatus* (Gasterosteidae) and also observed sexual dimorphism only after the fish became reproductively mature. Lima *et al.* (2012) studied the development and allometric growth patterns of the Ariidae catfishes *Cathorops spixii* and *C. agassizii* and observed that after hatching, mouth-breeded free embryos of both species grow isometric in all body

regions, suggesting that they already bear most of characteristics of adult fish. They suggested that the quick growth of morphometric features related to sensorial organs before hatching, reflect the developmental priorities during the earliest stages when important sensorial organs are being developed for juvenile survival strategies. Our study suggests that the priorities in development of specific body features of *G. genidens* returns when it reaches maturity and the proportional development of body measures and individual growth can occur differently between male and female especially due different reproduction roles between sexes. Thus when sexual maturity starts males concentrate their growth in head features increasing breeding capacity and reproduction success while female maintain their normal growth.

Our study showed the importance of considering ontogenetic changes related to sex in *G. genidens* since changes in morphological measures observed around the mouth region is a feature related to male's mouth breeding behavior during reproductive period. Thus the observations made in the present study related to changes in morphometric characteristics in male *G. genidens* are important to assist future studies about species biology and morphology. Moreover our study also highlight that the same ontogenetic changes may occur with other Ariidae species due to the family's

Table 3. a) Nested PERMANOVA results, df: degrees of freedom, *F*: test value, *P* (MC): Monte Carlo asymptotic *P*-values. Significance level 95% (*P* < 0.05), b) *Post-hoc* pair-wise test between male and female for each maturity stage.

a)			
Source of variation	df	*F*	*P* (MC)
Sex	1	2.94	0.00
Maturity	3	0.98	0.51
Maturity (sex)	6	3.10	0.00
Sex (maturity)	4	3.96	0.00
b)			
Maturity Stages		*t*	*P* (MC)
A		0.97	0.46
B		2.06	0.00
C		3.70	0.00

similar reproductive behavior (Figueiredo & Menezes, 1978), thus further studies should be develop aiming to elucidate this pattern which can be essential for a better understanding of the biology, behaviour and life history of those species as well as to determine differences between populations (Kitano *et al*., 2007).

Marceniuk (2005a, 2005b) discribed Ariidae species of Brazilian coast based on morphological characteristics but didn't observed sexual variations to differenciate species groups. Those studies considered morphological characteristics, neurocranium patterns and vomero-palatine tooth patches. Despite the sex and ontogenetic variation observed in our study for *G. genidens*, Marceniuk's works are important identification guides for Ariidae family since they are based on other body characteristics besides morphometric measures.

Morphometric estimates differ in degree of precision due to variation in fixation and storage methods and sometimes body structures are injured, making accurate measurements difficult. Nevertheless, due to the importance of these structures for reproduction, we assume that this bias is minimal. The parameters obtained here are realistic and our analysis showed an important role of head measurements in sex dependent ontogenetic differentiation driven by species behavior. We suggest that these measurements are secondary sexual characters not directly related to reproduction.

ACKNOWLEDGEMENTS

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