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Research Article

Age and reproduction of the southern king croaker *Menticirrhus americanus* in subtropical South Atlantic environments

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ABSTRACT. *Menticirrhus americanus* were sampled (n = 393) from two beaches (P1 is an estuarine beach near the mouth of the Paranaguá Estuarine Complex, and P2 is a beach adjacent to the Paranaguá Estuarine Complex) in the subtropical region of the western South Atlantic waters between August 2015 and June 2016. This study aimed to identify the spawning season and the age structure for *M. americanus* using two sampling methods. For sampling at the P1 beach, seine, line, and pole were used, while samples from the P2 beach were obtained from the artisanal fishers. Females were numerically dominant in all sampling months at both sites except for February when the males became dominant. The species exhibited a protected reproductive season with multiple spawning peaks between August and December. Males and females were captured at all gonadal development stages and ages between 1 and 6 from both sites. At first maturity, the length of the females was 16.3 cm, and the mean age at first maturity was 1.3 years. Individuals aged between 1 and 3 years were dominant (68%). The results suggested that young and adults of the *M. americanus* use the same habitats throughout their ontogeny.

Keywords: *Menticirrhus americanus*; estuary; sexual maturity; gill fishing; Sciaenidae

INTRODUCTION

Intraspecific biological parameters (e.g. age and reproduction) help understand the habitat use of a species (Vaz-dos-Santos et al. 2007, Soeth et al. 2018) and provide important information for decision-making in the implementation of management and conservation plans. Identifying the reproductive period and the first maturity of a fish population helps establish data-based management decisions such as defining closed seasons and determining the mesh sizes that may have a negative impact on the fish populations (Santos et al. 2015). The sex ratio makes it possible to identify if both sexes coexist in the same area and if there is a formation of reproductive aggregates (Lowerre-Barbieri et al. 2016) and the proportion of each sex necessary for the reproduction of the species. Determining the age structure enables scientists to define growth rates for understanding population dynamics (Maciel et al. 2018). Thus, describing the age, growth, and reproductive biology of a species of fisheries population that is impacted by industrial and artisanal fishing provides resource managers with critical information that can be used to establish management tools for protecting long-term population sustainability (Pita et al. 2015, Freitas et al. 2018).

On the southeast-south coast of Brazil, several fisheries target populations of common coastal fish species (Haimovici & Mendonça 1996, Chaves & Robert 2003, Andriguetto-Filho et al. 2006). Commercial

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fisheries utilize several fishing methods, including pair trawling, gillnetting "caceio," and gill fishing (Souza et al. 2007, Alves et al. 2012, Corrêa & Ávila-da-Silva 2016). The coast of the state of Paraná in southern Brazil is in the South Atlantic's subtropical area. In this coastal area, the most exploited fishery resources are two shrimp species (*Xiphopenaeus kroyeri* and *Farfantepenaeus* spp.) captured by trawl fisheries (Graça-Lopes et al. 2002, Souza & Chaves 2007, Cattani et al. 2011). Due to the low selectivity of the fishing methods used, other species are captured as bycatch (Haimovici et al. 2005, Santos et al. 2016); these include many fish species belonging to the family Sciaenidae (Cattani et al. 2011, Santos et al. 2016).

On the southeast-south coast of Brazil, the family Sciaenidae comprises 26 species that vary in average size from small to large (between 10 and 200 cm of total length) (Menezes & Figueiredo 1980). These species mostly occur in shallow water estuarine habitats (Menezes et al. 2003). The sciaenid species range from those with a short life cycle to some that are long-lived (Cardoso & Haimovici 2011, Militelli et al. 2012, Haimovici et al. 2016, Santos et al. 2017) and use multiple spawning as a reproductive strategy (Braun & Fontoura 2004, Costa et al. 2015, Carmo-Silva et al. 2016).

The sciaenid, southern king croaker *Menticirrhus americanus*, is a fish species exploited by recreational anglers and commercial fishers (Souza & Chaves 2007, Freire et al. 2016). It can reach up to 50 cm in total length (Cervigón 1993). The species' sale value depends on the specimen's size: the smaller ones are marketed at a lower value, while the larger specimens are filleted and traded for a higher value (Souza et al. 2007, Carvalho *comm. pers.*). Studies have demonstrated the ecological importance of *M. americanus* as a benthic carnivore (Rondineli et al. 2007, Halunch et al. 2009, Turra et al. 2012) and prey for larger marine predators (Bornatowski et al. 2014). *M. americanus* is widely distributed in the western Atlantic between latitudes 41°N and 51°S (Chao et al. 2015).

The spawning season for *M. americanus* appears to vary with latitude. In the northern Gulf of Mexico, spawning occurs from April to September (Clardy et al. 2014), while in southern Florida, spawning-capable individuals occur from January to November (Herrema et al. 1985). Some studies suggest that adults and juvenile *M. americanus* utilize different habitats (Gianini & Paiva-Filho 1992, Turra et al. 2012). The species appears to have a short life cycle, reaching up to 6 years of age. Moreover, it exhibits a rapid growth in these few years (McDowell & Robillard 2013, Clardy et al. 2014) with theoretical maximum longevity of 9.8 years (Gianini & Paiva-Filho 1992).

Due to this species' ecological and economic importance, the present study focused on characterizing the reproductive seasonality, age, and growth of *M. americanus* in the subtropical site for understanding important life-history parameters, which may aid in future management efforts for this species.

MATERIALS AND METHODS

Study sites

Bimonthly samples for *Menticirrhus americanus* were captured between August 2015 and June 2016 from two sampling sites (P1 and P2) within a single main sampling area located along Brazil's subtropical Atlantic coastal region. P1 is an estuarine beach (with a depth of 2 m) near in the mouth of the estuary Paranaguá Estuarine Complex dominated by tides (25°28'S-48°20'W) and P2 is a beach adjacent to the estuary on the shallow continental shelf dominated by waves and with an approximate depth of 20 m in areas of the capture of the specimens (25°36'S-48°28'W) (Ângulo et al. 2016) (Fig. 1). The main sampling was undertaken within a transitional coastal region between tropical and temperate climates (Spalding et al. 2007).

Sample collection

At the P1 sampling site, fish samples were collected using beach seines that were 2 m high, 70 m long, and had three mesh sizes of 2.5, 4, and 5 cm. During each sampling event, two people dragged the seine at a distance of 20 m parallel to the coast. At site P1, *M. americanus* samples were caught by pole and line fishing. At the P2 site, *M. americanus* were obtained from the artisanal fishers who used a gillnet "caceio" fishing with 6, 7, and 9 cm stretch mesh size.

Each *M. americanus* sample was measured for total length (TL, cm) and total weight (TW, g). Sagittal otoliths were removed, rinsed, and stored in a dry state for age determination at a later stage. The gonads were removed and weighed (WG, g), then macroscopically examined to determine sex and the reproductive phase. A portion of gonads (n = 162) was then preserved in ALFAC (80% alcohol, formaldehyde, and acetic acid) for histological processing.

Reproduction

Gonads remained in the preservative for a period of 18 to 24 h. The tissues were then processed using a standard methodology for histological paraffin embedding and hematoxylin and eosin Y staining. The histological samples' maturity and reproductive phases were assessed according to a modified version of classification based on Vazzoler (1996) and Brown-

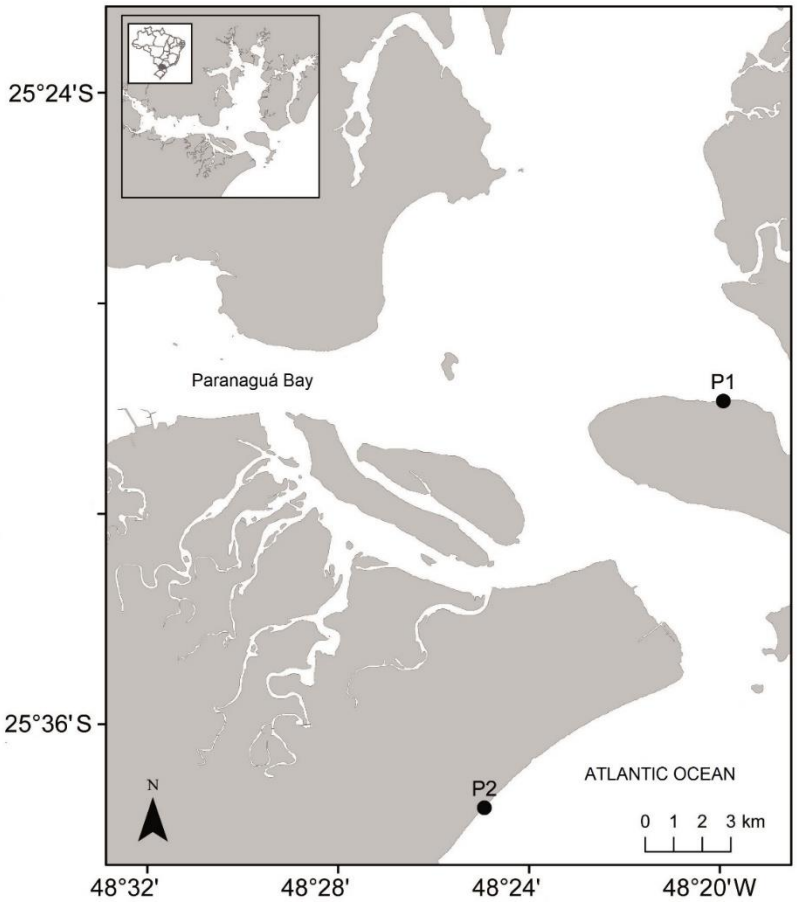

Figure 1. *Menticirrhus americanus* sampling sites in the subtropical environment of the South Atlantic. P1 is an estuarine beach, and P2 is a small-scale fishery unloading site.

Peterson et al. (2011). The gonadosomatic index (GSI), expressed by the formula GSI = (WG / TW) × 100, was determined for each individual. From the individual GSI, the mean GSI was calculated on a bimonthly basis separately for each sex.

Age and growth

The right sagittal otolith of each specimen was embedded in epoxy resin, cross-sectioned with a low-speed metallographic saw, and sanded and polished with alumina. Subsequently, the sections were photographed under a polarized-light stereomicroscope for reading the age rings of increments (each increment = one hyaline and one opaque zone; Fig. 2). Three incremental readings were taken for each otolith sample by the same reader at different times. According to McDowell & Robillard (2013) and Clardy et al. (2014), *M. americanus* forms only one annual ring.

Precision in the number of increment counts from the three readings of each otolith was determined using the coefficient of variance (CV), expressed by the formula $CV\,\frac{100}{n}\left[\sum_{=100}^{n} ni = 1\left(\frac{sdi}{\bar{a}i}\right)\right]$, where: *sdi* is the standard deviation of ages attributed to the individual *i* and

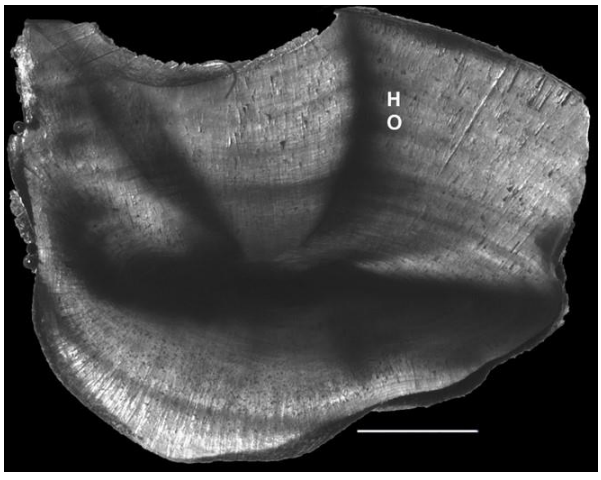

Figure 2. Cross-section of a *Menticirrhus americanus* otolith (sagitta) collected in the subtropical environment of the South Atlantic. H: hyaline rings, O: opaque rings. Scale: 2 mm.

$\bar{a}i$ the mean of the readings. After the analyses, the readings that resulted in a coefficient of variance above 8% were eliminated (Chang 1982).

Growth curves for grouped and separated sexes were obtained by adjusting the mathematical expression of Von Bertalanffy (1938) (VB) where $TL = L_\infty\left[1 - e^{-k(t-t_0)}\right]$ and by adjusting the Gompertz expression (G) $TL = L_\infty \times e\left[-e^{-k(t-t_0)}\right]$. For both expressions, e was the Napierian logarithm, TL: = total length (cm) at age t; L_∞: = asymptotic length (cm), k: = instantaneous growth rate, and t_0: = age, at a theoretical length equal to zero (Ogle 2015).

Statistical analyses

Statistical analysis was performed using the analysis of variance (ANOVA) to verify the TL differences between sexes and sites. The length-weight relationship for each sex was calculated using the following equation (Huxley 1929):

$$T_W = a \times TL^b$$

where T_W is the predicted total weight, TL the total length, a the coefficient of proportionality, and b the allometric coefficient (Carvalho et al. 2017, Possamai et al. 2018). A paired *t*-test was performed to compare length-weight relationship parameters between sex by sampled location. A chi-square test (χ^2) ($\alpha = 0.05$) was used to determine if the sex ratio deviated from 1:1.

In order to evaluate the relative health of the samples, the total condition factor (K) and the somatic condition factor (K') was expressed respectively by the formulae:

$$K = T_W / T_L^b$$

and

$$K' = T_{W-} W_G / T_L^b$$

where b is the allometric coefficient of the length-weight relationship.

The difference between K and K' makes it possible to verify the reproductive process's energy in females and males. A *t*-test was used between the total and the somatic condition factors to check the influence of gonads on each sampling site's condition factor.

The determination of the first maturity length (L_{50}) occurred through the logistic curve:

$$Fr = 1 - \left(e^{-a \times Ctm \times b}\right)$$

where Fr was the relative frequency of adult individuals; e was the Napierian logarithm; a and b were the coefficients estimated by the least-square method, and C_{tm} was the midpoint of the class interval (Possamai & Fávaro 2015).

The identification of the longevity (A), which corresponds to the time the fish takes to reach 95% of L_∞ (Santos et al. 2017), was estimated by the Taylor equation (1959):

$$A = \left(\frac{2.996}{k}\right) + t_0$$

where 2.996 was a constant, k was the instantaneous growth rate, and t_0 the age at which the fish had a theoretical length equal to zero in the von Bertalanffy curve parameters.

A *t*-test was applied between the parameters of the curve of Von Bertalanffy, Gompertz, and longevity to check for differences in growth rates between males and females. The von Bertalanffy and Gompertz models' adjustment was performed with the 'fish methods (Nelson 2017) and 'FishR' (Ogle 2015) packages in software R. The other statistical analyses were run in software R.

RESULTS

We collected 393 individuals of *Menticirrhus americanus*: 245 individuals from site P1 and 148 from site P2. The samples of both sexes from P1 presented smaller lengths than those sampled from P2 (Table 1).

Table 1. Parameters of the weight-length relationship of *Menticirrhus americanus* collected in two subtropical South Atlantic environments. F: females, M: males, n: number of individuals, TL: total length (cm) with minimum, mean and maximum, weight (g) with minimum and maximum, b: mean allometric coefficient and standard deviation, a: mean proportionality coefficient and standard deviation, and R^2: coefficient of determination of the weight-length relationship of Huxley (1929). P1: estuarine beach, P2: small-scale fishery unloading site.

Site	Sex	n	TL (cm)			Weight (g)		Parameter		
			min	mean	max	min	max	a	b	R^2
P1	F	140	12	20.34	30.9	16.5	336.53	0.001 ± 0.0058	3.195 ± 0.041	0.97
	M	105	12.8	17.75	29.8	15.3	206.67	0.005 ± 0.000	3.185 ± 0.005	0.97
P2	F	84	13.6	26.68	44.2	17.14	897.37	0.005 ± 0.00	3.188 ± 0.035	0.97
	M	64	14.1	27.44	33.3	18.33	347.88	0.005 ± 0.00	3.175 ± 0.005	0.97

Table 2. The sex ratio of *Menticirrhus americanus* collected in two subtropical South Atlantic environments. F: number of females, M: number of males, n: number of individuals, χ^2: chi-square, **P*-value <0.05. P1: estuarine beach, P2: small-scale fishery unloading site.

	P1				P2			
Month	F	M	F:M	χ^2	F	M	F:M	χ^2
Aug/15	34	10	3.4	13.0*	15	8	1.9	2.1
Oct/15	35	35	1.0	0.01	27	11	3.4	6.7*
Dec/15	22	7	3.1	7.7*	15	17	1.9	7.7*
Feb/16	20	23	0.9	0.2	7	13	0.9	0.1
Apr/16	23	18	1.3	0.6	9	4	1.1	0.1
Jun/16	8	11	0.7	0.4	11	11	1.4	0
Total	142	103			84	64		

Table 3. Microscopic characterization of the stages of ovarian and testicular development of *Menticirrhus americanus*. Oocytes: PG: primary growth, CA: cortical alveolar, Vtg: primary, secondary and tertiary vitellogenic, GVM: germinal vesicle migration, POF: post-ovulatory follicles, GVBD: germinal vesicle.

Stage of gonadal development	Microscopic characteristics	
	Females	Males
Immature	The ovaries of young females present nests of oogonia and oocytes in PG.	The testicles present the seminiferous tubules with reduced light or completely closed. The predominant cells in this stage are spermatogonia.
Developing	The developing ovaries initially present PG oocytes without cytoplasmic inclusions and CA oocytes, which present cytoplasmic vesicles. Overdevelopment, more developed oocytes in different phases of Vtg can be observed, possibly occurring in a smaller quantity of GVM oocytes.	Seminiferous tubules partially developed, with various types of male germline cells. Spermatozoa absent or in small quantity.
Spawning-capable	The ovaries in this stage present a predominance of GVM and GVBD oocytes; however, PG and Vtg oocytes are found in smaller numbers.	The testicles present developed seminiferous tubules with a predominance of spermatozoa.
Partially-spawned	This stage occurs only in species that spawn in batches. POFs and GVM oocytes are present. The initial phases of oocyte maturation may also be present (PG, Vtg).	Seminiferous tubules with a decreased quantity of spermatozoa relative to the previous stage. Empty spaces at the edges of the tubules and a small quantity of other male germline cells.
Post-spawning	Ovaries in the post-spawning stage characterize the end of the reproductive process, which includes the stages of "regressing" and "regenerating" described by Brown-Peterson et al. (2011). POFs and PG oocytes are found in disorganized ovigerous lamellae. Overdevelopment, the lamellae reorganize, the POFs are reabsorbed, and the ovaries start to be constituted by oogonia and PG oocytes.	Testicles in this stage characterize the end of the reproductive process, which includes the stages of "regressing" and "regenerating" described by Brown-Peterson et al. (2011). The seminiferous tubules present empty spaces with a small number of spermatozoa. Testicular replenishment by sperm line cells in the initial phases of development was observed.

The ANOVA demonstrated significant differences between the TL and sampling sites ($F = 461.3$; $P < 0.0001$) and between the TL and sex ($F = 10.86$; $P = 0.001$). From the relationship, it was possible to state that regardless of the location, *M. americanus* presented a positive allometric growth ($b > 3$; $P < 0.05$) for both sexes (Table 1). The *t*-test between sex by sampling site did not show significant variation (P1, $t = 0.42$, $df = 1$, $P = 0.74$; P2, $t = 1$, $df = 1$, $P = 0.5$).

There was numerical dominance of females at both sampling sites in all months sampled; the exception was observed at both sites in February 2016 and at site P1 in June 2016 (Table 2). The χ^2 test detected significant differences in the monthly sex ratio of females and males in August and December for P2 and in October and December for P1 (Table 2).

The gonadal histology allowed the characterization of six stages of oocyte and spermatogonia development. Microscopic analysis of the gonads (Table 3) revealed five phases of ovarian (Fig. 3) and testicular development (Fig. 4). The observation of partially spawned ovaries allowed the characterization of multiple spawning in the species.

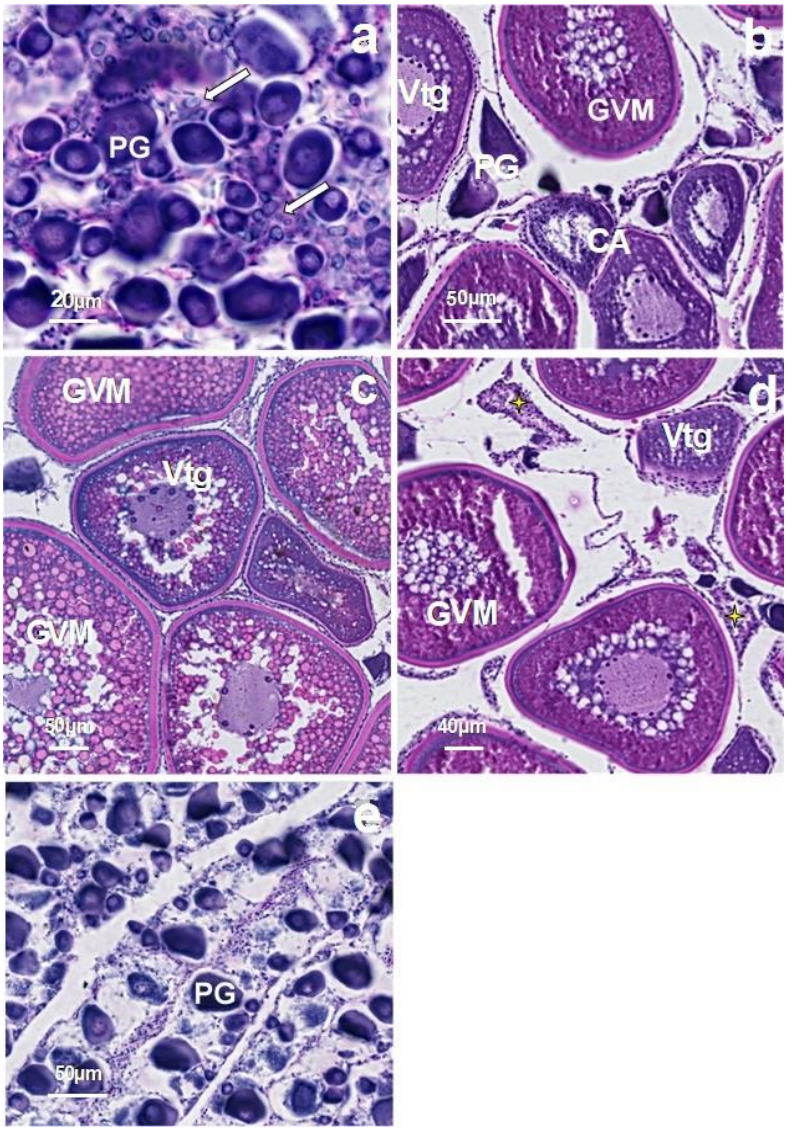

Figure 3. The scale of ovarian development. Microscopic analysis of the ovaries of *Menticirrhus americanus* in a subtropical environment of the South Atlantic. a) Immature ovary: the white arrows show initial development cells in the process of cellular division, associated with primary growth oocytes (PG), b) developing ovary: oocytes in different phases of development: PG: primary growth, CA: cortical alveolar, Vtg: vitellogenic, GVM: germinal vesicle migration, c) spawning capable ovary: predominance of oocytes in a higher degree of development (Vtg and GVM), d) partially spawned ovary: predominance of oocytes in a higher degree of development, associated with post-ovulatory follicles (POFs) (yellow star), e) post-spawning ovary: disorganized ovigerous lamellae containing oocytes in initial development phases (PG) associated with conjunctive tissue.

The bimonthly mean GSI values showed synchronization in the gonadal development of males and females at both sites: from October to December at site P1 (Figs. 5-6) and a more intense reproductive period October to February at site P2 (Fig. 6). A reduction in the mean GSI was observed at both locations from February (Figs. 5-6).

The percentage frequency of the stages of gonadal development from the histological analysis showed that females in all gonadal stages were captured from both the sampling sites. However, there was a higher occurrence of immature females at P1 relative to P2 and a predominance of partially spawned and post-spawned females between December and April at both sites (Figs. 5a, 6a).

Immature males were caught only from site P1; partially spawned and post-spawning males were more frequent from February to June. These males were histo-

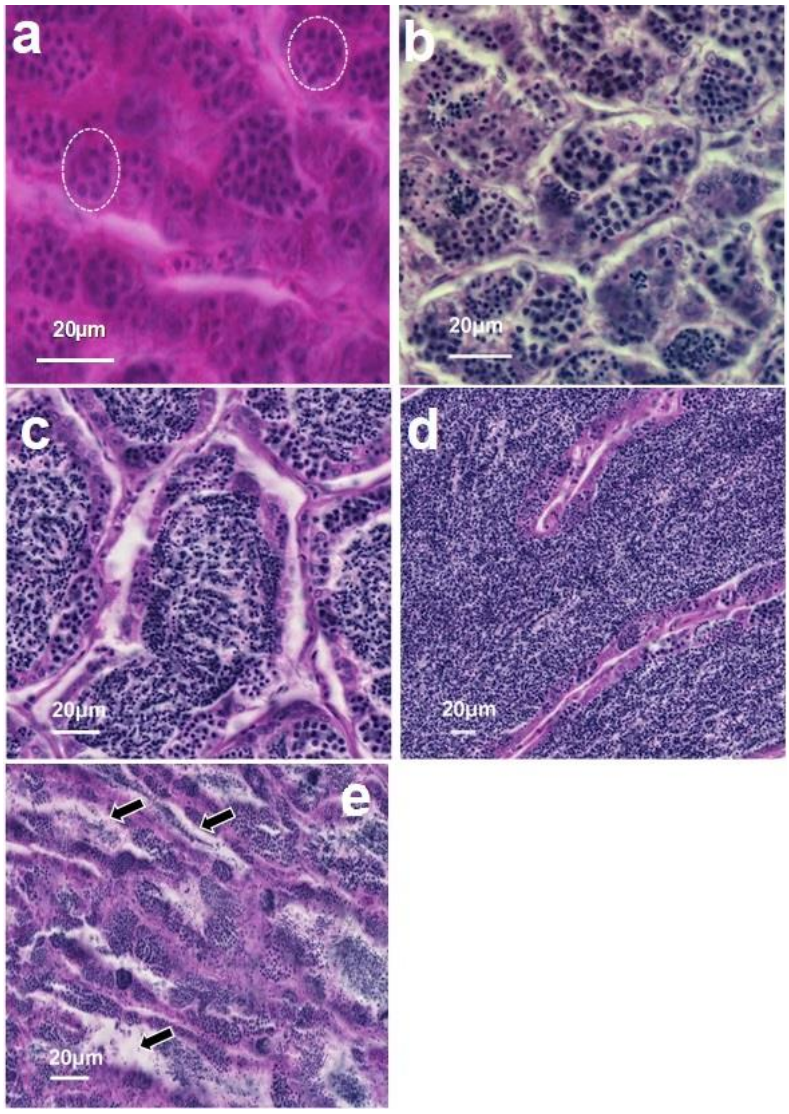

Figure 4. Scale of testicular development. Microscopic analysis of the testicles of *Menticirrhus americanus* in a subtropical environment of the South Atlantic. a) Immature testicle: circle delimits seminiferous tubules containing spermatogonia, b) developing testicle: the seminiferous tubules present different cell types of the spermatic lineage, c-d) spawning capable testicle: seminiferous tubules practically replete with spermatozoa, e) partially spawned testicle: arrows indicate empty spaces due to elimination of spermatozoa.

logically characterized by a decrease in sperma-tozoa's number corroborating with the decrease in the mean values of GSI in that period (Figs. 5b, 6b).

The total condition factor (K) and the somatic condition factor (K') presented higher values between August and October 2015 for males at both sites (Figs.7a-b); showed a second peak in February at site P2 alone (Fig.7a). For females, higher values of K and K' were found between August and October at both the sampling sites, demonstrating higher energy expenditure with the maturation of the gonads (Figs.7a-b). The *t*-test between K and K' for females was not significant for P1 ($t = 2.2$, $df = 5$, $P > 0.005$). It was different for site P2, where the *t*-test was significant between K and K' ($t = 7$, $df = 5$, $P < 0.005$). However, the *t*-test between K and K' for males showed significant differences between these parameters at both P1 ($t = 3.16$, $df = 5$, $P < 0.005$) and P2 ($t = 5$, $df = 5$, $P < 0.005$).

The L_{50} for females was 16.3 cm, and L_{100} was 22.5 cm (Fig. 8). The age estimated by counting the rings of *M. americanus* characterized the population of this species aged between 1 and 6 years to be between 1 and 3 years (68%) (Table 4); the females showed a maximum age of 6 years, and the males of 5 years (Table 5).

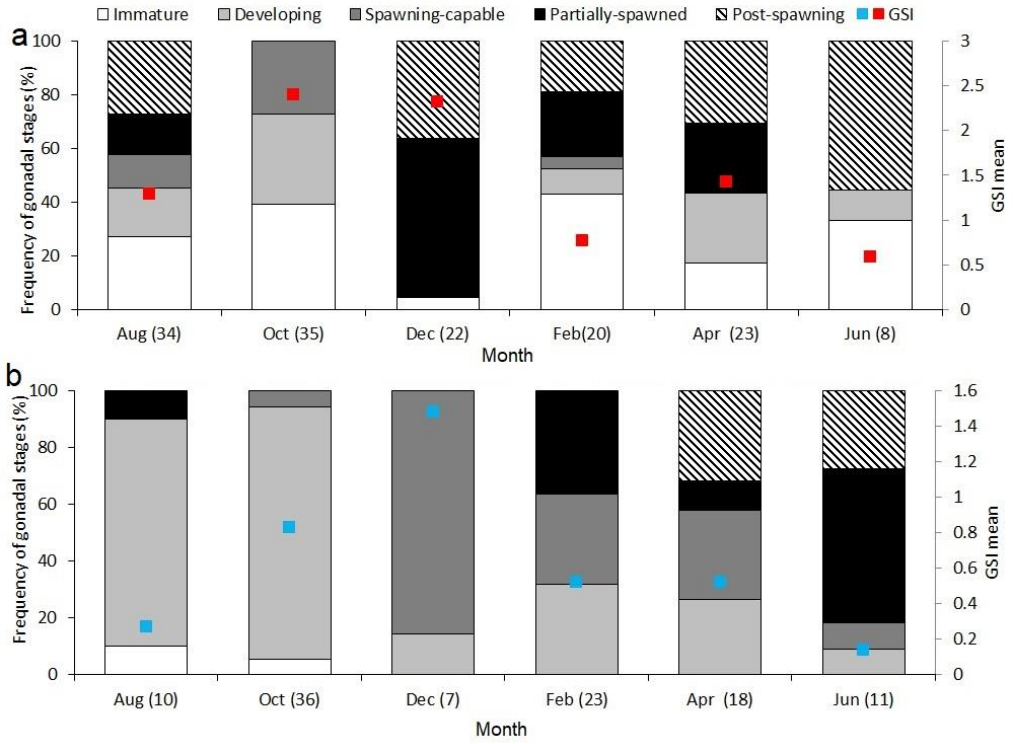

Figure 5. Frequency of occurrence of gonadal maturation phases and gonadosomatic index of *Menticirrhus americanus* a) females and b) males collected bimonthly in a subtropical environment of the South Atlantic, at site P1 (estuarine beach). (n): number of individuals by month.

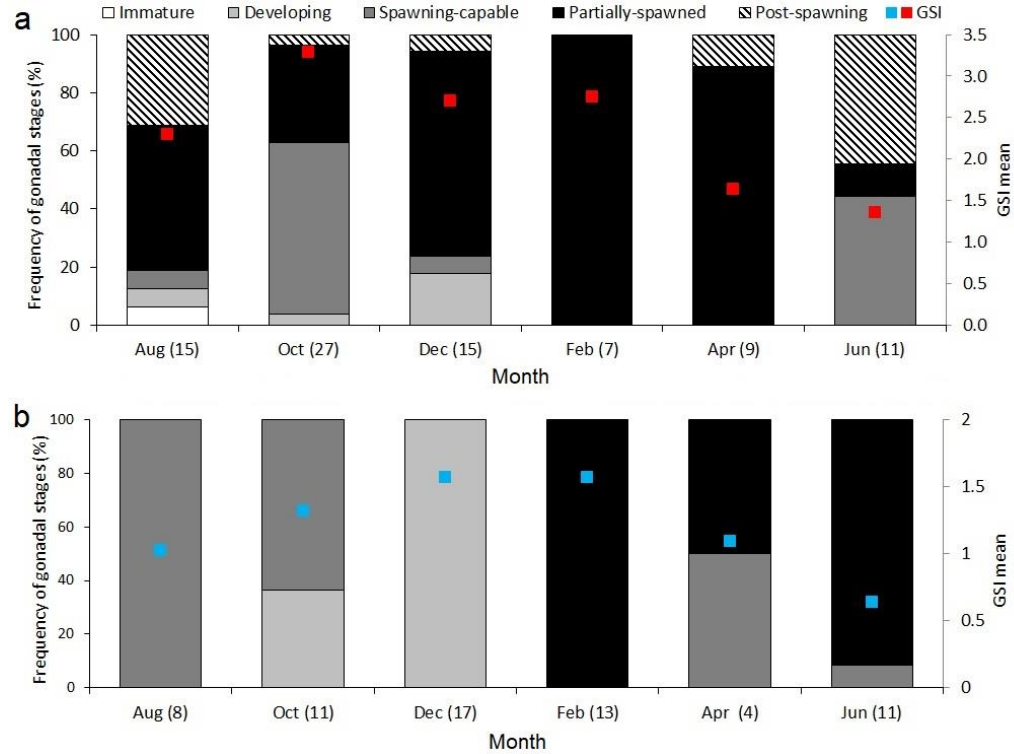

Figure 6. Frequency of occurrence of gonadal maturation phases and gonadosomatic index of *Menticirrhus americanus* a) females and b) males collected bimonthly in a subtropical environment of the South Atlantic, at site P2 (small-scale fishery). (n): number of individuals by month.

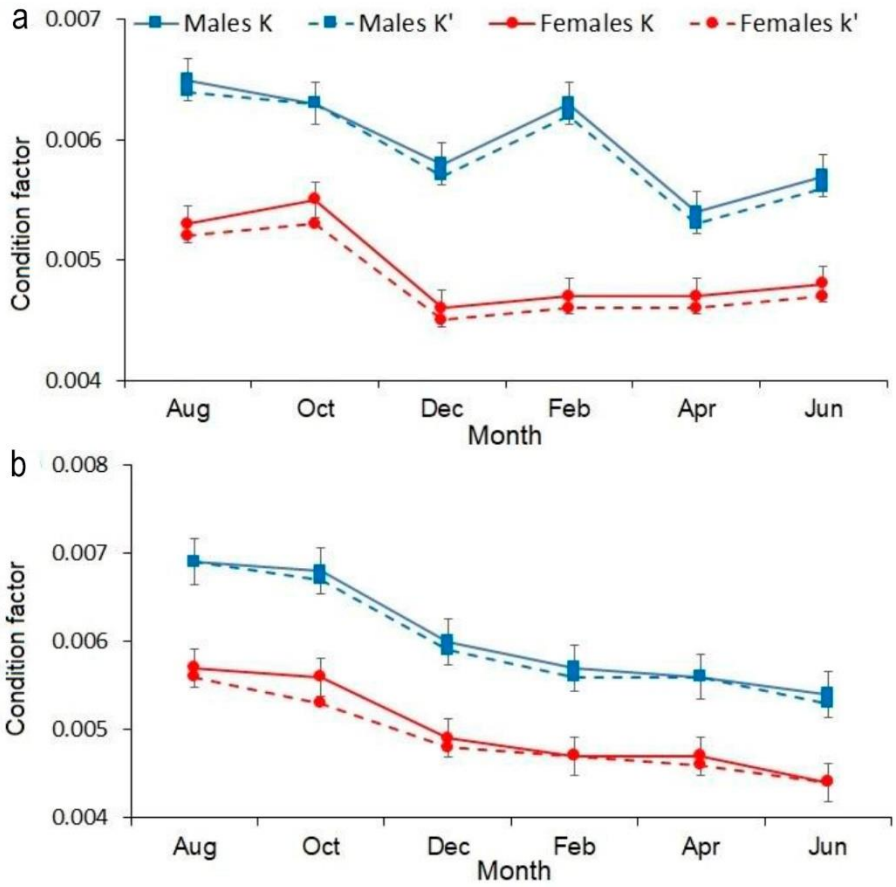

Figure 7. The total condition factor (K) and the somatic condition factor (K') of *Menticirrhus americanus* males and females collected bimonthly in a subtropical environment of the South Atlantic. a) P2: small-scale fishery unloading site and b) P1: estuarine beach.

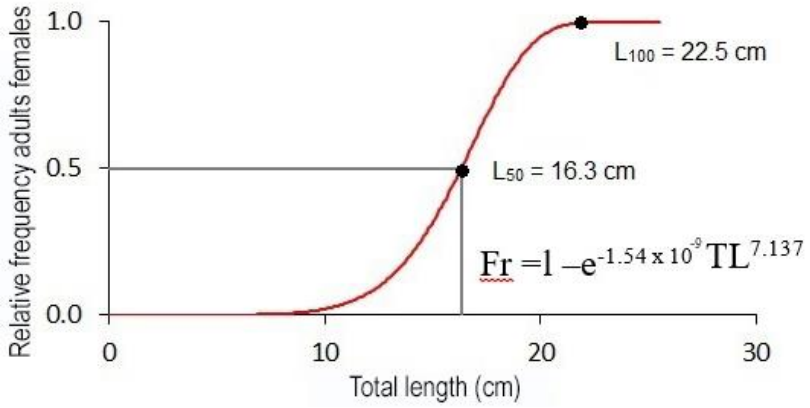

Figure 8. First maturation length of *Menticirrhus americanus* females collected bimonthly in a subtropical environment of the South Atlantic.

Specimens aged between 1 to 6 years were caught at both sites (Figs. 9a-9b). There was a predominance of specimens of ages between 1 and 2 years (66%) in P1 (Fig. 9a). In P2, there was a predominance of specimens of ages between 3 and 4 years (63%) (Fig. 9b). The highest percentage of hyaline edge occurs in April 2016 (Fig. 9c).

We observed different values of the growth parameters for grouped sexes (Fig. 10a). The growth parameters for the females and males (Figs. 10b-c).

Table 4. Age by size class in *Menticirrhus americanus* collected bimonthly in a subtropical South Atlantic environment.

Interval class (cm)	Age (years)						
	1	2	3	4	5	6	Total
11-15	15	9					24
16-20	5	21	1	1			28
21-25	2	19	12	15			48
26-30		1	25	11	13	1	51
31-35			1	8	5	1	15
35-40						2	2
Total	22	50	39	35	18	4	168

Table 5. Age by sex in *Menticirrhus americanus* collected bimonthly in a subtropical South Atlantic environment. F: females, M: males, n: number of individuals by age/sex, TL: total length (cm) ± standard deviation (SD).

Sex	Age (n, TL ± SD)						
	1	2	3	4	5	6	Total
F	18 (16.4 ± 2.7)	22 (19.6 ± 3.8)	22 (26.2 ± 3.1)	19 (29.6 ± 3.4)	9 (29.6 ± 3.4)	2 (33.9 ± 6.4)	92
M	14 (16.1 ± 1.9)	28 (19.1 ± 3.3)	21 (25.3 ± 3.9)	16 (26.7 ± 3.9)	10 (28.9 ± 1.9)		89
Total	32	50	43	35	19	2	181

Taylor's longevity was 11.27 years for grouped sexes, 12.30 years for females, and 10.27 years for males. The *t*-test of the growth curve parameters of Von Bertalanffy, Gompertz, and longevity for males and females showed no significant differences between sexes ($t = 1.37$, $df = 6$, $P > 0.005$). The mean age (A_{50}) in which 50% of females were adults was 1.3 years, and 100% occurred at 3.8 years.

DISCUSSION

The greater length of females than males was also evidenced by other researchers (Muniz & Chaves 2008, Haluch et al. 2011, Clardy et al. 2014) and is considered a frequent feature in teleosts (Fávaro et al. 2003, Braun & Fontoura 2004, Santos et al. 2015), due to the need to allocate female gonads that are larger than the male gonads (Vazzoler 1996). According to Alves et al. (2012), *M. americanus* females capable of spawning present an increased volume of the coelomic cavity and become more susceptible to capturing in the gillnet fishery. Therefore, females are more vulnerable to gill fishing during periods of higher spawning intensity than males. Moreover, this may be why the imbalance in the sex ratio and the consequent recruitment of this species increased fishing effort using these gears.

At both sites, females were numerically dominant between August and December; a shift of dominance was observed in February when males became dominant. This alternation was also observed by Muniz & Chaves (2008). In other species belonging to the family Sciaenidae, a numerical predominance of males was observed, suggesting that variation in the sex ratio was an intraspecific parameter (Braun & Fontoura 2004, Santos et al. 2015).

Multiple spawning of *M. americanus* had already been described by other authors (Haluch et al. 2011, McDowell & Robillard 2013, Clardy et al. 2014). Thus, our results confirm the phenomenon of multiple spawning and register individuals reproducing throughout the year in both locations, as demonstrated by the highest K and K' values between August and October. The highest frequency of specimens in reproductive activity occurred in the hotter periods (spring and summer) that coincided with the period of increase in the primary and secondary productivity in the studied area (Lana et al. 2001) and favored reproductive success. Thus, our results are corroborated by the increase in the abundance of post-flexion larvae of *M. americanus*, observed by Godefroid et al. (2001), during the fall in the same study area.

Determining the first maturity length is important for managing fishery resources regulating the mesh size allowed for fishing, and preventing immature individuals from getting caught (Santos et al. 2015). The first maturity length obtained for *M. americanus* females in this study was close to that calculated by other authors who worked at similar latitudes (Halunch et al. 2011, Clardy et al. 2014). However, near the southern distribution limit of *M. americanus*, there is an

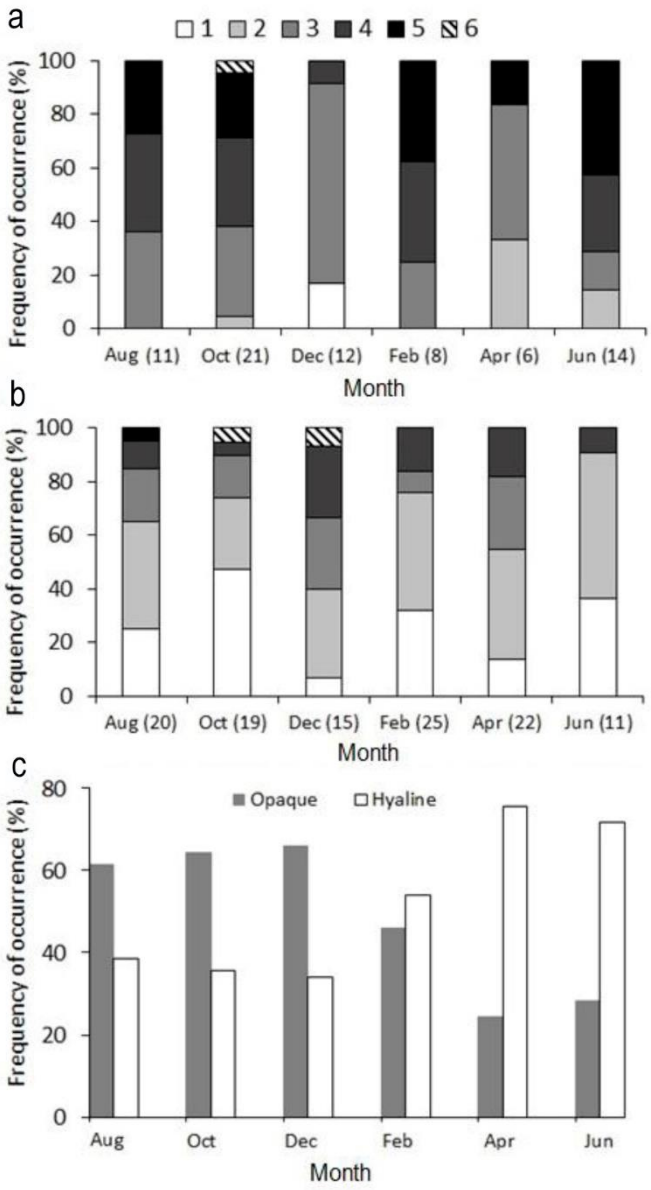

Figure 9. Monthly frequency of occurrence of the ages of *Menticirrhus americanus*. a) P1 (estuarine beach), b) P2 (small-scale fishery), c) percentage of opaque and hyaline edges in the sections of the otoliths of *M. americanus* collected bimonthly in the South Atlantic's subtropical environment. (n): number of individuals by month.

increase in the L_{50} value for both sexes, suggesting gonadal maturation at longer lengths influenced by the lower water temperature (Militelli et al. 2012; L_{50} females = 22.2 cm). The reduced capture of immature male specimens made it impossible to determine the L_{50} for males in this study. This observation corroborates that males of this species mature with lower average lengths than females, as observed for other Sciaenidae fish (Santos et al. 2015).

Regarding age determination, studies performed at higher latitudes obtained individuals with a maximum age lower than observed in this study (McDowell & Robillard 2013, Clardy et al. 2014); this may be a sampling method effect selecting only one age range. Nevertheless, regardless of the latitude and the sampling method, individuals aged ≤3 years were dominant in the analyzed environments; the age group was more representative in different populations of *M. americanus* (McDowell & Robillard 2013, Clardy et al. 2014). The variability in length among all ages of *M. americanus* (Table 5) indicates different individual growth rates. Moreover, this is a characteristic of species with split spawning that invest a great amount of energy in gonadal development. A similar observation

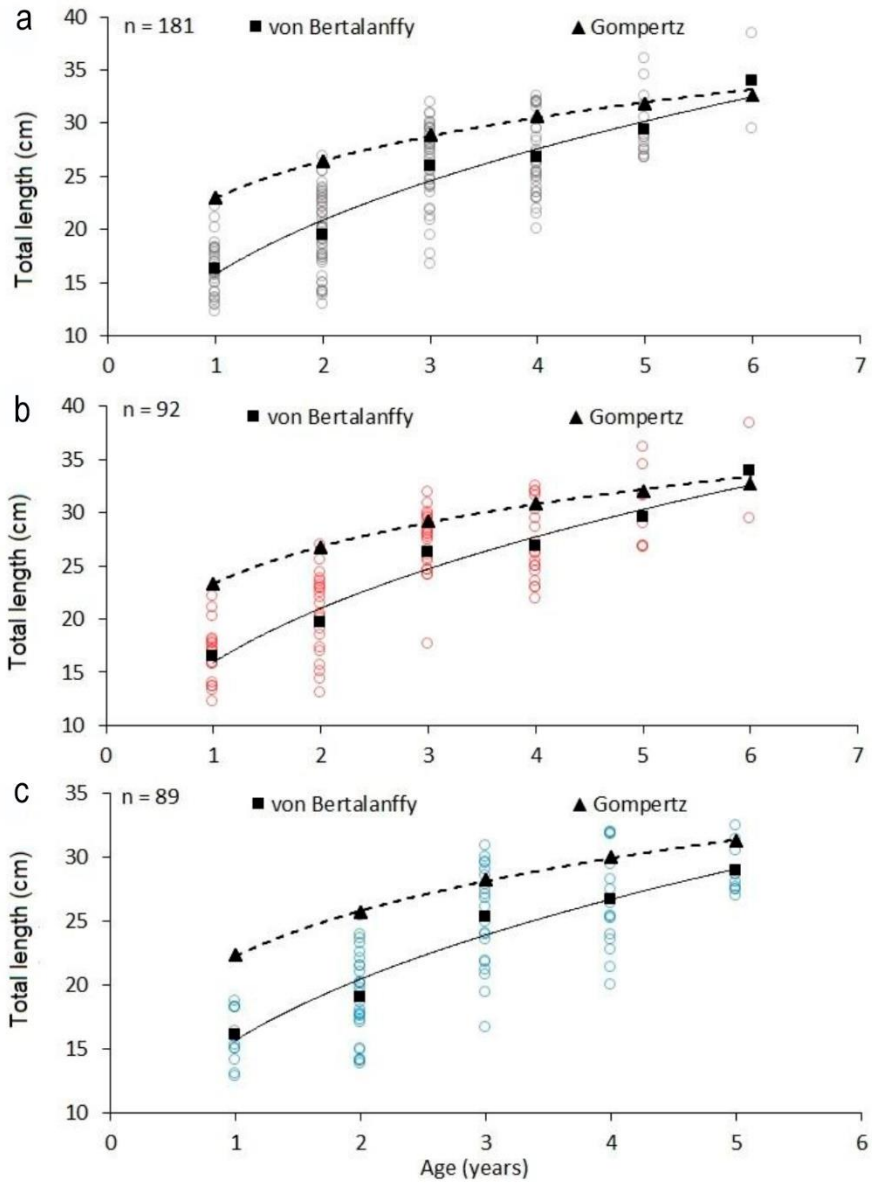

Figure 10. Growth curve fitted according to the von Bertalanffy and Gompertz model for a) grouped sexes b) females and c) males of *Menticirrhus americanus* collected bimonthly in a subtropical environment of the South Atlantic. The circles indicate the specimens.

was made by other authors (Santos et al. 2017, Maciel et al. 2018, Soeth et al. 2018). Spatially, in this study, younger individuals were dominant (1-2 years) at P1. At P2, individuals were dominant between 3 and 4 years because of selecting gillnet fishing as the capture method, wherein specimens of larger ages are captured.

Other studies corroborate the positive allometric growth of both sexes of *M. americanus* in these localities. It demonstrates that this species grows more in weight than in length in subtropical latitudes (Haluch et al. 2011, Passos et al. 2012, Dias et al. 2014, Vaz-dos-Santos & Gris 2016). Growth curve parameters and longevity also differed between the studies that analyzed *M. americanus* at different latitudes (Gianini & Paiva-Filho 1992, McDowell & Robillard 2013, Clardy et al. 2014, present study). According to Taylor (1959), variations in growth rates, longevity, and von Bertalanffy growth curve parameters are expected along a latitudinal gradient due to different environmental influences suffered by the species, mainly through the water temperature. Species of fish exposed to lower temperatures at higher latitudes tend to grow

more slowly than individuals of the same species exposed to higher temperatures at lower latitudes, which justifies the different values of the parameters obtained for *M. americanus* since different studies were performed at different latitudes (Gianini & Paiva-Filho 1992 - 23°S, McDowell & Robillard 2013 - 31°N, Clardy et al. 2014 - 30°N, present study - 25°S). Despite environmental influence, there is a pattern in the t_0 values being negative in all studies (Table 1). The lower the value of t_0, the faster the growth is in the early stages (King 1995), demonstrating that the need to grow rapidly is independent of the environmental forces.

The differences obtained in the size, age, and frequency of the life stages of the specimens captured between the sites demonstrate an influence of the sampling method's selectivity; this was also observed in *M. americanus* by Muniz & Chaves (2008). Despite the differences generated by the sampling methods, our results suggest that the occurrence of individuals of all lengths, sexes, ages, and maturity stages at both sites indicates an absence of differentiation of the habitat use. From our results, it is possible to affirm that the gill fishing practiced in the sampled area can impact the population of *M. americanus* since the females capable of spawning were more vulnerable to this kind of fishing in the season of greater spawning intensity.

Fish landing statistics for the genus *Menticirrhus* from Brazil's southeast-south region recorded landings of approximately 270 t between 2011 and 2014 (ICMBIO 2019, Gep-UNIVALI 2019). At present, it is estimated that the capture of large sciaenids has reduced by approximately 20% in a decade (Chao et al. 2015). The possible reduction in large sciaenids' stocks will generate the need to explore new fishing resources, resulting in overexploitation of the stock of species belonging to the genus *Menticirrhus*. It is advisable to create public policies that regulate *M. americanus* fishing since young and adult individuals are currently caught with several types of fishing gear from industrial to sportive fishing (Souza et al. 2007, Muniz & Chaves 2008, Cattani et al. 2011, Freire et al. 2016).

The study of the biological parameters of *M. americanus* helps to understand the use of the coastal area (continental shelf and estuary) by the species and provides subsidies for monitoring this resource. This study also helps in decision-making for sustainable management. The results obtained are of great importance because this species is commercially exploited on the South Atlantic coast, besides being a bycatch of the shrimp fishery.

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