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Population structure and morphological sexual maturity of *Achelous spinimanus* (Latreille, 1819) (Decapoda, Portunoidea), a potential fishing resource in the southeastern coast of Brazil

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Abstract. This study brings some characteristics of a population of *Achelous spinimanus* in Ubatuba, northern coast of the State of São Paulo. The main aspects evaluated were size-frequency distribution, sex ratio, and size at the onset of morphological sexual maturity. In total, 1,911 swimming crabs were captured, 502 juveniles (males and females), 350 adult males, 475 adult non-ovigerous females, and 584 ovigerous females. Males were larger (70.3 ± 18,2 mm) than females (66.2 ± 18.2 mm). The size CL at which 50% of the population is sexually mature was estimated 44.7 mm for males and 44.5 mm for females. The size-frequency distribution was polymodal for males and bimodal for females. This might suggest the occurrence of two or more age groups in the population probably due to the differential mortality and growth rates between males and females. Moreover, this study showed that the environmental conditions in Ubatuba were suitable for the establishment and growth of *A. spinimanus* during our surveys.

Keywords: Brachyura, size distribution, sex ratio, Crustacea, Ubatuba

Resumo: Estrutura populacional e maturidade sexual morfológica de *Achelous spinimanus* (Latreille, 1819) (Decapoda, Portunoidea), um recurso pesqueiro em potencial, na costa sudeste do Brasil. Este trabalho apresenta as características populacionais de *Achelous spinimanus*, na região de Ubatuba, litoral Norte do Estado de São Paulo. Foi avaliada a distribuição de frequência de indivíduos em classes de tamanho, a proporção sexual e o tamanho no qual os indivíduos atingem a maturidade sexual morfológica. Um total de 1911 indivíduos foi coletado, representados por 502 juvenis (machos e fêmeas), 350 machos adultos, 475 fêmeas adultas não ovígeras e 584 fêmeas ovígeras. Os machos (70.3 ± 18,2 mm) foram maiores que as fêmeas (66.2 ± 18.2 mm). O tamanho estimado em que 50% dos indivíduos tornam-se maduros sexualmente foi de 44.7 para machos e 44.5 mm para fêmeas. A distribuição de frequência nas classes de tamanho foi polimodal para machos e a bimodal para fêmeas. Os resultados observados podem sugerir a ocorrência de dois ou mais grupos etários na população amostrada, esse fato provavelmente ocorreu devido taxas de mortalidade ou comportamento diferencial entre os sexos. Ademais, o presente estudo evidencia o quanto a região de Ubatuba, no período amostrado, era favorável ao estabelecimento e crescimento de *A. spinimanus*.

Palavras-chave: Brachyura, distribuição de tamanho, razão sexual, Crustacea, Ubatuba

Introduction

Due to the reduction of fishing stocks in Brazil, Portunoidea crabs such as *Achelous spinimanus* (Latreille, 1819), *Callinectes danae* Smith 1869, and *Callinectes ornatus* Ordway, 1863, became the new targets of trawl fisheries (Severino-Rodrigues *et al*. 2001, Andrade *et al.* 2017). A similar situation has already been recorded in other countries (Fao-Globefish, 2013). Therefore, more studies about the population biology of these new fishing targets are necessary.

The biology of a species can be studied by characterizing several population aspects such as the size-frequency distribution of demographic groups, reproductive period, recruitment, size at the onset of sexual maturity, sex ratio, and birth and mortality rates (Lima *et al*. 2014, Garcia *et al*. 2016, Gonçalves *et al.* 2017, Silva *et al.* 2017a). Many studies on the population structure of crustaceans employ the analysis of frequency distribution of different demographic groups per size-classes (Santos *et al*. 1995, Pinheiro & Pardal, 2016, Andrade *et al*. 2017, Lopes *et al*. 2017). The estimate of the size at the onset of sexual maturity is another important parameter which indicates the morphologic and physiologic changes that juveniles undergo to be able to produce gametes, inseminate or being inseminated (Santos & Negreiros-Fransozo, 1996, Bertini *et al*. 2010). Those individuals become directly active in the mechanisms responsible for population fluctuations (Castilho *et al*. 2015, Silva *et al*. 2017b). In general, sexual maturity in crabs and other crustaceans are based on three criteria: morphometric (based on the change in morphometric relationships of secondary sexual characters), physiological (based on gonadal maturation), and functional (based on the size at which they are able to mate) (Pollock 1995, López Greco & Rodrıguez 1999). Based on morphological sexual maturity, it is possible to determine a minimum catch size that legal organs use to establish a fishing-ban.

Previous studies on the population aspects of Portunoidea decapods have been performed in the southeast and south of Brazil. Populations of *A. spinimanus* were studied in Fortaleza Bay, Armação do Itapocoroy, and Macaé by Santos *et al*. (1995), Branco *et al.* (2002), and Andrade *et al.* (2017), respectively. *Achelous spinicarpus* (Stimpson, 1871) was studied in Ubatuba and Caraguatatuba (Silva *et al*. 2017a, b), *C. ornatus* and *Arenaeus cribarius* (Lamarck, 1818) in Ubatuba (Mantelatto & Fransozo, 1996, Pinheiro & Fransozo, 1998, Silva *et al*. 2018), and *C. danae* in the Estuarine Bay Complex of São Vicente, Estuarine-Lagoon Complex of Iguape and Cananéia and in Babitonga Bay by Sant'anna *et al*. (2012), Severino-Rodrigues *et al*. (2012) and Pereira *et al.*(2009), respectively.

Given the importance of characterizing the population biology of species, we studied a population of *A. spinimanus* in Ubatuba (State of São Paulo, Brazil), covering a larger area than the ones evaluated in previous studies. Our study focused on the size-frequency distribution of demographic groups, sex ratio, and size at the onset of morphological sexual maturity. We also bring relevant information about the area from a period when the fishing activity was less intense, about 20 years ago, which may serve as reference for comparisons with current conditions.

Material and Methods

Biological Data: Individuals were captured monthly, from January 1998 to December 1999, in the bays Ubatumirim, Ubatuba and Mar Virado, in the Ubatuba region (23°30’ S; 45° 04’ W), northern coast of São Paulo (Figure 1). Six sites were sampled in each bay. Sampling was conducted always in the mornings aboard a shrimp fishing boat equipped with two double-rig nets. The net was dragged for 2 km for 30 min, covering 18000 m^2.

The swimming crabs were identified according to Melo (1996) (= *Portunus spinimanus*) and sexed based on the abdominal morphology (triangular in males and round in females) and pleopods number (two pairs in males and four pairs in females). The carapace length (CL) was measured with a 0.1 mm precision caliper, excluding the lateral spines. The maturity status based on external morphology was defined according to Haefner (1990). Juveniles and adults were differentiated by the abdomen shape and adherence to the thoracic esternites (Santos et al., 1995). Four demographic groups were used in the analyses: juvenile males and females (J), adult males (AM), adult females (AF), and ovigerous females (OF).

Data Analyses: Data were previously tested for normality and homoscedasticity using the Shapiro-Wilk and Levene tests, respectively. The CL of adult males and females was compared using the Mann-Whitney test for two independent samples of non-parametric data. The Kolmogorov-Smirnov test was used to compare the size frequency distribution of males and females. The size at which 50% of population reach morphological sexual maturity was estimated through the relative frequency of adults

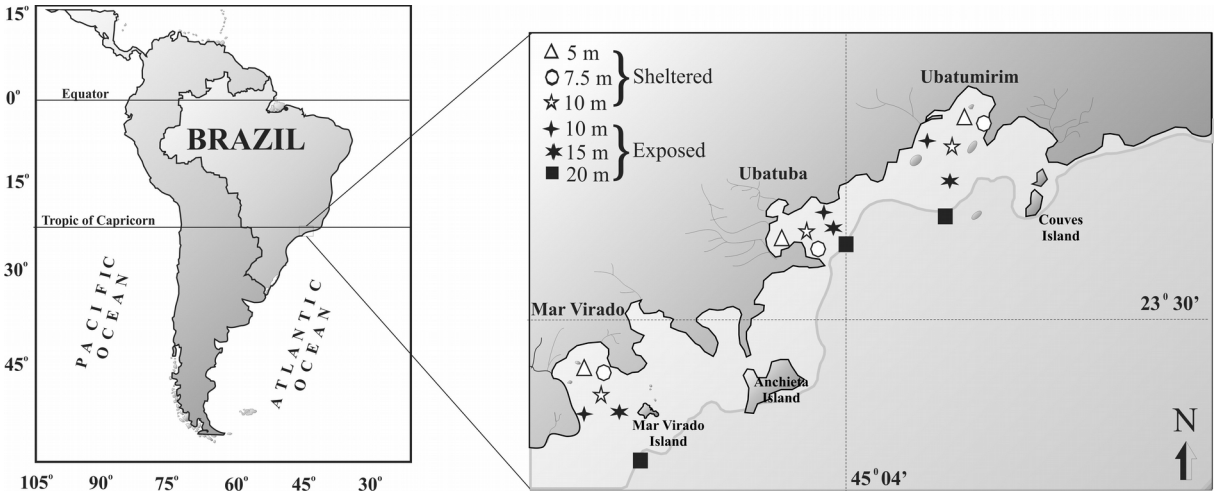

Figure 1. Map of the Ubatuba region (northeastern coast of São Paulo State), Brazil, showing the three bays and their respective sampling stations (adapted from Fransozo *et al*. 2013).

(%) in each size class, adjusted to a sigmoid curve based on the following logistic equation:

$$y = \frac{1}{1+e^{r(CL-CL_{50})}}$$

where *y* is the estimated proportion of adults and *r* is the steepness of the logistic curve. The equation was adjusted by the least squares method (Vazzoler, 1996). Possible deviations from the expected 1:1 sex ratio in each size class were verified by the binomial test (Wilson & Hardy, 2002). All analyses were performed at a 5% significance level (Zar, 2010). Peakfit v. 4.12 (Sea Solve Software Inc., 1999–2003) was used to find the modal peaks of the size-class frequency distributions.

Results

A total of 1,911 individuals of *A. spinimanus* were captured, comprising 502 juveniles (males and females), 350 adult males, 475 adult non-ovigerous females, and 584 ovigerous females. The mean size of adults was significantly different, and males were larger (70.3 ± 18.2 mm) than females (67.5 ± 10.3 mm) ($U = 155575.5$; $p < 0.01$).

The average CL of each demographic group, along with standard deviation and range, are shown in Table I. The size-class frequency distribution was polymodal with three peaks in males, and bimodal in females (Fig. 2). The frequency of individuals in each size class differed significantly between males and females ($p < 0.05$; Fig. 2). The highest abundance of juvenile occurred in the fourth size class (32 -|40 mm CL). Adult males and females were more abundant in the ninth (72 –|80 mm CL) and eighth size-class (64 –| 72 mm CL), respectively.

Table I. *Achelous spinimanus* (Latreille, 1819). Number of individuals (N), size ranges, means and standard deviations (SD) of carapace width for each demographic group.

Demographic group	N	Min - Max (mm)	Mean ± SD (mm)
Juveniles	502	8.4 - 48.1	33.5 ± 18.3
Adult male	350	41.1 - 99.3	70.3 ± 18.2
Adult female	475	40.9 - 94.0	66.2 ± 18.2
Ovigerous female	584	45.0 - 100.2	68.7 ± 18.2

We estimated that 50% of males in the population are sexually mature at 44.7 mm CL, and females at 44.5 mm CL (Figure 3). The size of the smallest ovigerous female was 45.0 mm.

The sex ratio (M:F) was 1:2 ($p < 0.05$). A female-biased sex ratio was seen in intermediate size-classes (Table II).

Discussion

Our study revealed that *A. spinimanus* males are larger than females, which is a common pattern in Brachyura and especially, in Portunidae (Santos *et al*. 1995, Costa & Negreiros-Fransozo, 1998, Branco *et al*. 2002, Branco & Fracasso, 2004, Ripolli *et al*. 2007, Pardal-Souza & Pinheiro, 2012, Pinheiro & Pardal-Souza, 2016). This size difference is probably related to a copulatory behavior in which males protect pre- and post-molt females, through the mate–guarding, to ensure the reproductive success, and in this situation larger males would have higher reproductive success (Hartnoll, 1969, Pinheiro &

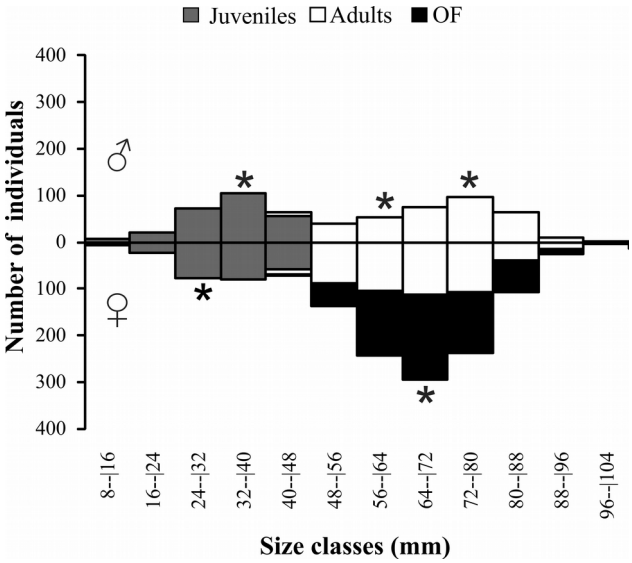

Figure 2. *Achelous spinimanus* (Latreille, 1819). Frequency distribution of individuals in size classes at the sampled bays.

Fransozo, 1999, Pardal-Souza & Pinheiro, 2012, Pinheiro & Pardal-Souza, 2016). Due to this differential size, males often have a longer somatic growth and higher increment in size at each molt (Mantelatto & Fransozo, 1999). Females direct more energy toward reproduction since the oocyte production requires more energy than the spermatozoa production (Hartnoll, 1985). Moreover, females often stop or reduce the somatic growth during the egg incubation (Hartnoll, 1985).

However, other studies did not find significant differences between the mean sizes of males and females of *A. spinimanus* (Andrade *et al.* 2017) and *A. spinicarpus* (Silva *et al*. 2017b). According to the authors, this is a common feature of high density populations, where, as a consequence, males are not affected by intraspecific competition for females. Ogawa & D´Incao (2010) found that females of *A. spinicarpus* are larger than males, which is an unusual feature of the genus *Achelous* De Haan, 1833. This finding was explained by the hypothesis that larger females have a larger brood since there is a proportional relationship between female size and fecundity (Hines, 1962). Based on this premise, more energy would be allocated to a larger offspring production rather than to offspring viability.

The size frequency distribution revealed that the *A. spinimanus* population in Ubatuba is very dynamic and characterized by a polymodal and bimodal distribution in males and females, respectively. This could indicate either the presence of two or more age groups, or that these differences in frequency are related to a differential migration, mortality, and/or natality rates (Diaz & Conde, 1989, Silva *et al*. 2017b).

In a population of *A. spinimanus* from a higher latitude (Armação do Itapocoroy, State of Santa Catarina; 26°46'S 48°36'W), males and females reach morphological sexual maturity at 76 mm and 68 mm, respectively (Branco *et al*. 2002), thus at larger sizes than in our study. This could be related to the lower temperatures in that region and to metabolic differences in that latitudinal range. Lower temperatures in higher latitudes lead to a slower growth, increasing the time to reach sexual maturity, whereas higher temperatures induce growth and lead to an early gonadal development (Vernberg 1962, Annala *et al.* 1980, Castilho *et al*. 2007, Terossi *et al*. 2010).

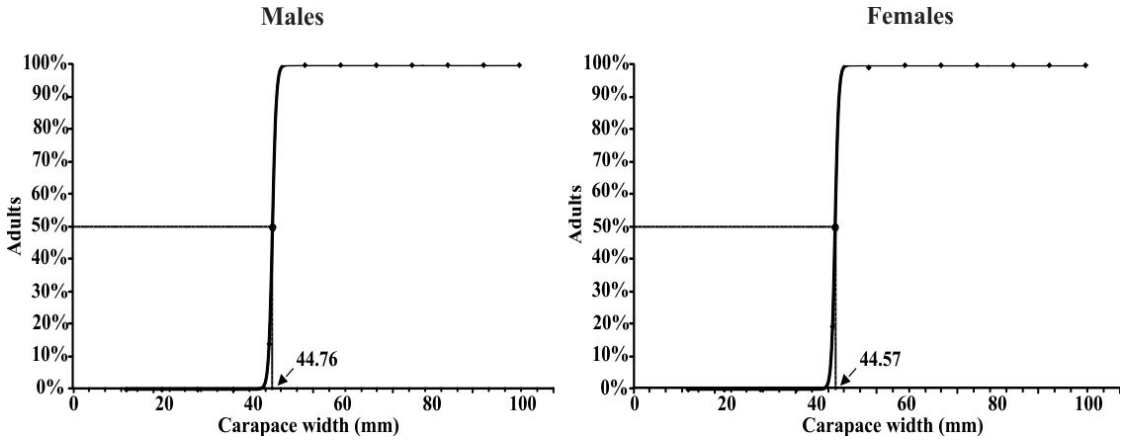

Figure 3. *Achelous spinimanus* (Latreille, 1819). Percentage of adult individuals (males and females) with the tendency line fitted to the logistic function for individuals collected. The arrow indicates the estimated size at morphological sexual maturity.

Table II. *Achelous spinimanus* (Latreille, 1819). Distribution of individuals in size classes and demographic group. * = statistical difference ($p < 0.05$).

	Juveniles			Adults			Total of crabs		
Size class (mm)	♂	♀	**Binomial test/p**	♂	♀	**Binomial test/p**	♂	♀	**Binomial test/p**
8--|16	6	6	0.5/0.78	0	0	-	6	6	0.5/0.78
16--|24	21	23	0.5/0.79	0	0	-	21	23	0.5/0.79
24--|32	72	77	0.5/0.69	0	0	-	72	77	0.5/0.69
32-|40	104	79	0.5/0.08	0	0	-	104	79	0.5/0.08
40--|48	55	58	0.5/0.57	9	14	0.4/0.24	64	72	0.5/0.57
48--|56	0	1	0.9/0.50	40	137	0.2/0.00*	40	138	0.2/0.00*
56--|64	0	0	-	54	243	0.2/0.00*	54	243	0.2/0.00*
64--|72	0	0	-	76	294	0.2/0.00*	76	294	0.2/0.00*
72--|80	0	0	-	96	238	0.7/0.00*	96	238	0.7/0.00*
80--|88	0	0	-	63	106	0.3/0.00*	63	106	0.3/0.00*
88--|96	0	0	-	11	25	0.3/0.02*	11	25	0.3/0.02*
96--|104	0	0	-	1	2	0.5/0.60	1	2	0.5/0.60
Total	258	244	0.4/0.43	350	1059	0.2/0.00*	608	1303	0.3/0.00*

In Macaé, State of Rio de Janeiro(22°47'S; 41°45'W), *A. spinimanus* reaches morphological sexual maturity at a smaller size than in our study (males: 39.9 mm; females: 42.9 mm). In that population, studied in July 2010–June 2011, males reached morphological sexual maturity earlier than females, which is unusual in Portunidae crustacens (Andrade *et al*. 2017). This early maturity might be related to the increasing fishing activity in Macaé. Species of commercial interest, such as *A. spinimanus*, are probably having their populations impacted by this activity. As a consequence, the species suffers a selective pressure, resulting in an altered ontogenetic development. The mortality rate tends to be higher in adults and, the sooner individuals reach maturity, the higher is the species reproductive gain (Andrade *et al*. 2017). The fishing pressure leads to an additional cost to the population: reaching maturity at smaller sizes, the fecundity is reduced, decreasing the reproductive effort (Keunecke *et al*. 2012).

The 1:1 sex rate proposed by Fisher (1930) is based on the equality of energetic cost to produce either sex. The higher proportion of adult females seems to be a common pattern in *A. spinimanus* populations (Santos *et al*. 1995, Branco *et al*. 2002, Ripoli *et al*. 2007, Andrade *et al*. 2017). In populations from deeper zones (26–80 m) in the southern coast of São Paulo, males are more abundant than females (De Carli *et al*. 2016). This could be related to peculiarities of the environment: individuals may undergo trophic and reproductive displacements as part of their life cycles, leading to a separation of stocks according to sex (Santos & Negreiros-Fransozo, 1999, Ripoli *et al*. 2007, Silva *et al*. 2017b).

Based on our results, the suitability of Ubatuba for the establishment and growth of *A. spinimanus* was evident during the studied period. Moreover, this study can serve as a baseline for comparisons with the current conditions of the Ubatuba region, where the increasing urban expansion and fishing activity might be altering the life history features of *A. spinimanus* and other species.

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