

HISTORICAL BACKGROUND OF THE POPULATION BIOLOGY OF THE SWIMMING CRAB *Arenaeus cribrarius* (Crustacea: Portunidae) IN THE UBATUBA COAST, SOUTHEAST BRAZIL

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ABSTRACT

This study presents results obtained 25 years ago on the population structure, sex ratio, and handedness of *Arenaeus cribrarius* in Ubatuba, North coast of São Paulo State, Brazil. Sampling studies were conducted during two different periods (from November 1988 to October 1989, and from May 1991 to April 1993), one of them performed for pooled data, and other exclusively for Fortaleza Bay (monthly samples from November 1988 to October 1989). Males were larger (CW, average \pm SD: 73.38 \pm 15.78 mm) than females (68.45 \pm 12.20 mm). The size between juvenile and adult stages has an overlap, for males (40-70mm CW) e fêmeas (45-75 mm CW). A prevalence of females was registered for pooled data (1:1.42; $P < 0.01$), but it was not recorded in Fortaleza Bay (1:1.25; $P > 0.05$). The sex ratio was close to 1:1 in the smaller size classes, with females dominating in the intermediate classes, and males in larger ones. In Fortaleza Bay, a female biased sex ratio was only noted in transect I (1:3.88; $P < 0.05$) and in the autumn (1:1.67; $P < 0.05$), with 73% of the specimens measured were right-handed.

Keywords: body size; Fortaleza Bay; handedness; population structure; sex ratio.

ANTECEDENTES HISTÓRICOS DA BIOLOGIA POPULACIONAL DO SIRI *Arenaeus cribrarius* (Crustacea: Portunidae) NA COSTA DE UBATUBA, SUDESTE DO BRASIL

RESUMO

Este estudo apresenta resultados obtidos há 25 anos sobre a estrutura populacional, razão sexual e heteroquelia de *Arenaeus cribrarius*, em Ubatuba, Litoral Norte do Estado de São Paulo, Brasil. As amostragens foram realizadas em dois períodos diferentes (novembro/1988 a outubro/1989, e maio/1991 a abril/1993), um delas realizada para os dois períodos agrupados, como também exclusivamente para a Enseada da Fortaleza. Os machos (LC, média \pm DP: 73,38 \pm 15,78 mm) apresentaram maior tamanho do que as fêmeas (68,45 \pm 12,20 mm). O tamanho nos estágios juvenil e adulto se sobrepuseram, para machos (40-70mm LC) e fêmeas (45-75 mm LC). Houve prevalência de fêmeas para os dados agrupados (1:1,42; $P < 0,01$), o que não foi confirmado na Enseada da Fortaleza (1:1,25; $P > 0,05$). A razão sexual foi de 1:1 nas classes iniciais de tamanho, com predomínio das fêmeas nas classes intermediárias, e dos machos naquelas maiores. Na Enseada da Fortaleza a razão sexual foi desbalanceada apenas no transecto I (1:3,88; $P < 0,05$) e no outono (1:1,67; $P < 0,05$), sendo 73% dos espécimes destros.

Palavras-chave: Enseada da Fortaleza; estrutura populacional; heteroquelia; razão sexual; tamanho corpóreo.

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INTRODUCTION

Some crab species are of great economic importance, especially in countries from Europe, Asia, and North America, where they are prized as food items or industrially processed. According to FAO-GLOBEFISH (2007), the worldwide import of brachyurans increased more than 900% during the 22 years from 1983 to 2004. Among the main exploited species, those belonging to the Portunidae are important in Asia (e.g., *Portunus trituberculatus*, *P. pelagicus*, and *Scylla serrata*) (SATHIADHAS and NAJMUDEEN 2004) and North America (e.g., *Callinectes sapidus* and *Arenaeus cribrarius*) (HAEFNER 1985; SECOR *et al.*, 2002). In Brazil, portunid crabs are of some economic importance, but in a smaller scale as compared to the previous mentioned regions. Most of the crabs captured in Brazil are considered as bycatch in fisheries and commonly discarded (SEVERINO-RODRIGUES *et al.*, 2002).

Arenaeus cribrarius (Lamarck, 1818) is a swimming crab widely distributed in the western Atlantic, from Massachusetts, USA to Mar del Plata, Argentina (WILLIAMS, 1984; SCELZO, 2001), although Brazil is the type locality (MELO, 1996). This portunid is typically associated with very fine sand benthic habitats, where it remains frequently buried. It has a generalist diet, consuming mainly other crustaceans and fishes (CARMONA-SUAREZ and CONDE, 2005) and, as such, it is an important component of the food web of sand beaches (MCDERMOTT, 1983; DELANCEY, 1989). Due to its great abundance, this portunid has been mentioned in various studies of diversity, including those conducted by BRAGA *et al.* (2005), and SEVERINO-RODRIGUES *et al.* (2009). Moreover, there are available data on its distribution (ZANGRANDE *et al.*, 2003; GUERRA-CASTRO *et al.*, 2007), morphology (PINHEIRO and FRANSOZO, 1993 a,b; PINHEIRO and TADDEI, 2000; PINHEIRO and HATTORI, 2006), reproductive biology (PINHEIRO and FRANSOZO, 1998, 1999, 2002), and ecological interactions (COSTA *et al.*, 2010).

The main goal of this investigation was to analyze the population structure of *Arenaeus cribrarius* including sex ratio changes in body size,

between seasons and in different marine areas in Ubatuba, Southeastern Brazil. This article is based on data collected about 25 years ago, and as such is a very important historical record of times when the study area was under less anthropogenic influence than the present day. Within 20 years (from 1991 to 2010), for example, the human population increased 66% in Ubatuba, from about 48,000 to almost 80,000 inhabitants (IBGE, 2010). Also, from the 5-years periods from 1998-2002 to 2009-2013, catches of crustaceans showed an average decrease from 294.5 to 215.5 tons, while productive units (number of vessels or fishermen) increased from 253.6 to 282.4 (INSTITUTO DE PESCA, 2014). In addition to the data presented being a historical record for portunids in this region, this data can also be used for further comparisons and possibly future fishery management of this species.

MATERIALS AND METHODS

Animals were collected during two periods: monthly during one year (November 1988 to October 1989) from seven 1-km transects in Fortaleza Bay (Figure 1; transects I to VII) and monthly during two years (May 1991 to April 1993), comprising samples from two beaches (Itamambuca and Grande), also along 1-km transects, in Ubatuba Municipality (Figure. 1; transects VIII and IX), Southeast coast of Brazil. To increase sample size, 158 additional specimens captured in six extra trawls performed in 1989 in Fortaleza Bay were also included. All of the collections were conducted using a shrimp-fishing vessel equipped with two otter-trawls (3.7-m wide mouth, 15-mm mesh net body, and 10-mm mesh cod end), during high tides on full moon days.

After capture, the *Arenaeus cribrarius* specimens were separated from the other organisms, sexed, described according to their maturation stage (juvenile or adult), and the ovigerous condition of the females was also recorded. Due to the absence of abdominal dimorphism among juvenile and adult males, we analyzed the male specimens to verify whether thoracic esternites were adhered to abdomen, what happens only in juveniles (according to PINHEIRO and FRANSOZO, 1993b).

The body size (largest carapace width excluding lateral spine = CW) of each animal was measured (calipers, ± 0.01 mm). Animals with malformations or damage to the exoskeleton were discarded from

the analyses. Body size was compared between males and females through Mann-Whitney test since data were heterocedastic.

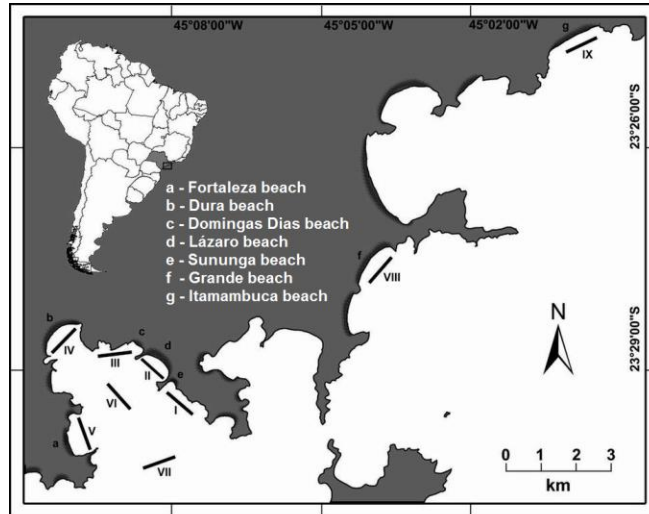


Figure 1. Map of study region showing the location of the seven transects in Fortaleza Bay (I to VII) and transects in front of Grande beach (VIII) and Itamambuca beach (IX) along the Ubatuba coast, southeast Brazil.

All swimming crabs captured, excluding injured ones (hereafter: pooled data), were used to characterize the population structure based on the distribution of the specimens in different CW size classes (5 mm). In Fortaleza Bay, the population was analyzed with regard to the structure and composition of *Arenaeus cribrarius* and also at different transects (I to VII). The distribution of the individuals by size classes was analyzed according to the extreme-size individuals, which were divided by sex and maturation phases (juvenile and adult), and to the overlay of these maturation phases by sex. Males and females of different size classes were separated into normal components using Bhattacharya's method using FiSAT FAO-ICLARM software (GAYANILO and PAULY, 1997). The software provides a separation index (SI), which identifies different modes only when $SI > 2$ ($P < 0.05$) and quantifies the mean (\pm standard deviation) and number of individuals of each cohort.

The sex ratio (male: female) of *Arenaeus cribrarius* was verified according to analyses at the (1) population level, as well as a function of (2) size, (3) seasons, and (4) trawled areas in Fortaleza Bay

(transects). Pooled data was employed for the population level and size analyses (1 and 2), whereas animals obtained in Fortaleza Bay were used to analyze items 3 and 4. The analysis of the sex ratio as a function of size was performed according to the method proposed by WENNER (1972) through the establishment of size classes (CW) and the calculation of the percentage of males in each class (with a minimum of ten individuals per class). The contrast between the sexes was evaluated statistically using chi-square tests, and the male prevalence data per size class was used to construct a scatter diagram to verify the tendency of empirical points and to perform a comparison with the patterns described by WENNER (1972).

The sizes of the chelas (right and left) of all the pooled data were measured (calipers, ± 0.01 mm) to determine 'handedness'. Those animals that were missing one or both chela were excluded from the analyses. The percentages of larger chelae based on the sex and the maturation stage (juvenile and adult) were calculated, and these percentages were then compared (chi-square test).

RESULTS

A total of 2,335 specimens of *Arenaeus cribrarius* were collected during the study. In Fortaleza Bay (November 1988 to October 1989), we sampled 403 specimens of *A. cribrarius* (189 males and 214 females), including 245 individuals from the monthly transects and 158 specimens obtained from six extra trawls. These animals were added to the 1,932 individuals (777 males and 1,155 females), captured monthly from May 1991 to April 1993.

Males had a greater body size (CW, average \pm SD: 73.38 ± 15.78 mm) than females (68.45 ± 12.20

mm) (Mann-Whitney test: $U = 513,482$; $P < 0.001$), reaching the 110-115-mm class, whereas the largest females were found in the 90-95-mm class (Figure 2). An overlap in body size was found between the juvenile and the adult stages of each sex, in the 40-70 mm and 45-75 mm CW classes for the males and the females, respectively. The smallest ovigerous female captured at Fortaleza Bay (at transect I in October 1989) measured 59.8-mm CW. For pooled data, however, the smallest ovigerous female (52.6 mm CW) was captured in January 1993. Cohort analysis revealed evidence for six cohorts in males, and three in females (Figure 2; Table 1).

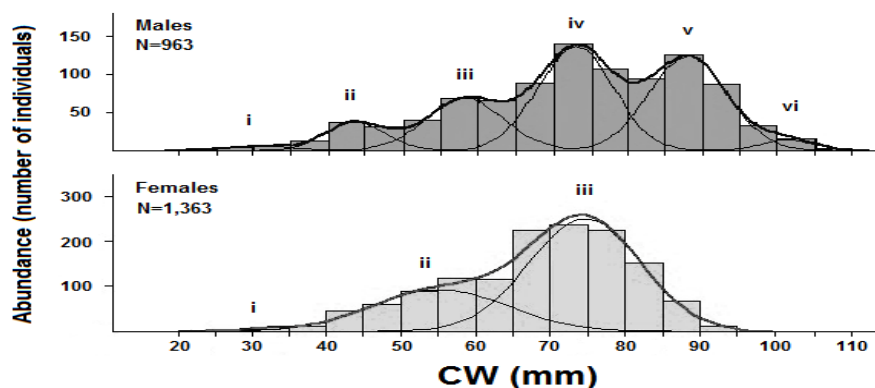


Figure 2. *Arenaeus cribrarius*. Males and females distributed by size classes of carapace width (CW) of all samples collected during the study (pooled data) (November 1988 to October 1989 and May 1991 to April 1993) from Ubatuba coast, southeast Brazil. Curves indicate the representation of the normal cohorts (cohorts = roman numerals).

Table 1. *Arenaeus cribrarius*. Normal components of CW (carapace width, in mm) obtained for all of the individuals captured during the study (pooled data) (November 1988 to October 1989 and May 1991 to April 1993). n, number of individuals; SD, standard deviation; and SI, separation index ($N = 2,326$).

Sex	Age cohorts	CW Normal Components (Mean \pm SD)	n	SI
Males	i	30.86 \pm 4.32	12	-
	ii	43.64 \pm 3.96	75	3.09
	iii	58.30 \pm 5.14	178	3.22
	iv	72.96 \pm 5.02	346	2.88
	v	88.03 \pm 5.26	328	2.93
	vi	101.43 \pm 3.33	24	3.12
Females	i	30.93 \pm 2.55	6	-
	ii	55.14 \pm 9.05	420	4.17
	iii	74.61 \pm 7.48	937	2.36

The smallest specimen collected in Fortaleza Bay was a juvenile male (22.10 mm CW; transect III, January 1989), whereas the largest specimen was an

adult male (103.60 mm CW; transect V, May 1989; Figures 3). Considering all specimens collected (pooled data), the smallest animal was as mentioned

above, but the largest was captured in Fortaleza Bay in an additional trawl conducted in October 1989 (adult male, 112 mm CW).

The sex ratio (male: female) of *Arenaeus cribrarius* in Fortaleza Bay was 1:1.25, but this difference was not significant difference (Table 2). A significant female bias (1:1.42; $\chi^2 = 68.79$; $P < 0.01$) was, however, confirmed when considering the pooled data (N = 2,326, with exception of injured specimens). In Fortaleza Bay, no variation in the sex ratio of this portunid was found in most transects, with females predominating over the males only in transect I (Table 2). Analysis of the seasonal sex ratio

revealed a predominance of females over males only in autumn (Table 3) and varied considerably among the size classes, with values close to 1:1 (smaller size classes) or showing a predominance of females (intermediate classes) or males (largest classes, Figure 4).

73% of *Arenaeus cribrarius* were right-handed, and no differences were found between the sexes ($\chi^2 = 0.65$; $P = 0.42$; Table 4). Similarly, there was not differences on handedness between maturation stages, being kept the pattern of larger number of right-handed individuals both in juveniles as in adults ($\chi^2 = 0.29$; $P = 0.59$; Table 4).

Table 2. *Arenaeus cribrarius*. Sex-ratio and relative frequency as a function of sex in seven transects of Fortaleza Bay, Ubatuba coast, Southeastern Brazil (November 1988 to October 1989; N = 245).

Transects	Males		Females		Sex-ratio	χ^2
	n	%	n	%		
I	8	20.51	31	79.49	1.00 : 3.88	13.56 **
II	1	25.00	3	75.00	1.00 : 3.00	Na
III	50	48.54	53	51.45	1.00 : 1.06	0.09 ns
IV	41	54.67	34	45.33	1.00 : 0.83	0.65 ns
V	7	70.00	3	30.00	1.00 : 0.43	1.60 ns
VI	-	-	4	100.00	0.00 : 4.00	Na
VII	2	20.00	8	80.00	1.00 : 4.00	3.60 ns
Total	109	44.49	136	55.51	1.00 : 1.25	2.98 ns

** = $P < 0.05$; ns = not significant ($P > 0.05$); na = not applicable; χ^2 = chi-square test value.

Table 3. *Arenaeus cribrarius*. Sex-ratio and seasonal relative frequency of males and females obtained in the monthly samplings conducted from November 1988 to October 1989 in Fortaleza Bay, Ubatuba coast, southeast Brazil (N = 245). Where: χ^2 = chi-square test value.

Season	Males		Females		Sex-ratio	χ^2
	n	%	n	%		
Summer	38	42.70	51	57.30	1.00 : 1.34	1.90 ns
Autumn	30	37.50	50	62.50	1.00 : 1.67	5.00 **
Winter	29	56.86	22	43.14	1.00 : 0.76	0.96 ns
Spring	12	48.00	13	52.00	1.00 : 1.08	0.04 ns

** $P < 0.05$; ns = not significant ($P > 0.05$)

Table 4. *Arenaeus cribrarius*. Handedness of individuals as a function of sex, maturity stage, and total individuals captured during the study (pooled data) (November 1988 to October 1989; and May 1991 to April 1993) in Ubatuba coast, Southeastern Brazil (N = 1,750).

Sex/Maturation	Handedness			
	Right		Left	
	n	%	n	%
Males				
Juvenile	74	74.0	26	26.0
Adult	436	71.6	173	28.4
Total	510	71.9	199	28.1
Females				
Juvenile	192	74.1	67	25.9
Adult	575	73.5	207	26.5
Total	767	73.7	274	26.3
Total				
Juvenile	266	74.1	93	25.9
Adult	1,011	72.7	380	27.3
Total	1,277	73.0	473	27.0

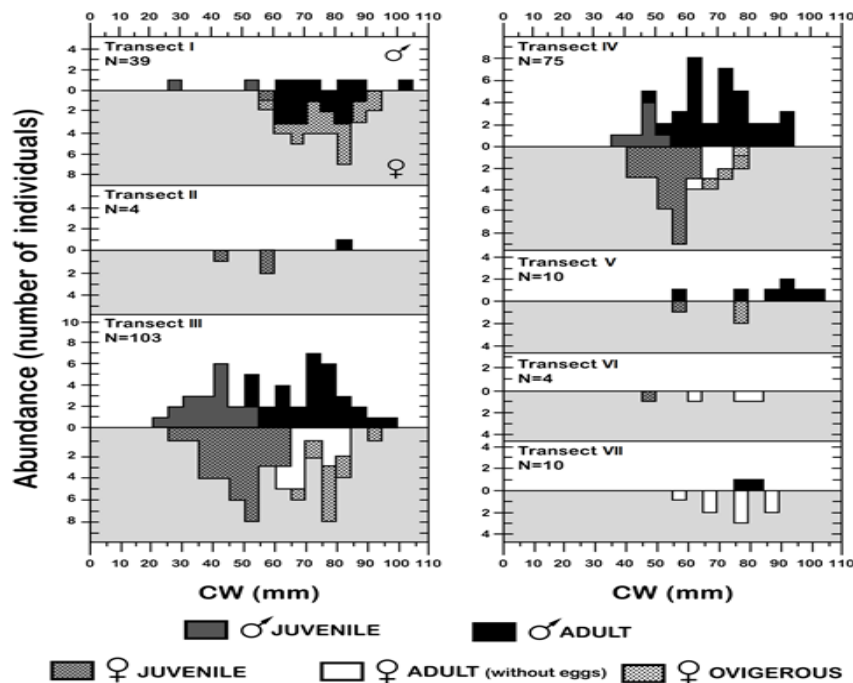


Figure 3. *Arenaeus cribrarius*. Morphotypes distributed by size classes of the carapace width (CW) of the specimens obtained through the monthly samplings in seven transects in Fortaleza Bay (November 1988 to October 1989) (N = 245).

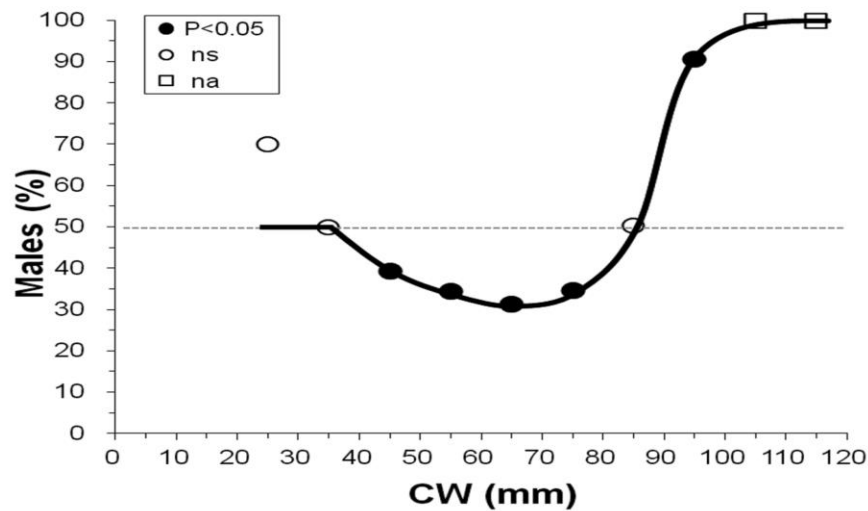


Figure 4. *Arenaeus cribrarius*. Sex ratio based on the percentage of males in size classes of different carapace width (CW) of the total number of animals captured during this study (pooled data) (November 1988 to October 1989 and May 1991 to April 1993; N = 2,326) from Ubatuba coast, Brazil. $P < 0.05$ = the sex-ratio of 1:1 was significantly different, as determined by chi-square test; ns = not significant; na = this test was not applied when the number of individuals in a size class was less than ten.

DISCUSSION

The overlap among the maturation stages in each sex of *Arenaeus cribrarius* suggests that the size of males and females at puberty molt is 40-70 and 45-75-mm CW, respectively, which agrees with the relative growth analysis conducted in the same area by PINHEIRO and FRANSOZO (1993b), who described changes in the growth rate of males (propodus) and females (abdomen) in the previously mentioned intervals. The identification of the maturation stages (juvenile and adult) based on the abdominal adherence of somites in thoracic sternites in *Callinectes* spp. (WILLIAMS, 1974; BAPTISTA-METRI *et al.*, 2005; DE CARVALHO and COUTO, 2011) also applies to *A. cribrarius* and this simple method could be successfully employed to determine the closed fishing laws, mainly when the size at physiological maturity is unavailable.

As observed in portunids, females generally were smaller as compared with males (e.g., ARAÚJO *et al.*, 2011; PARDAL-SOUZA and PINHEIRO, 2013). The larger size attained by males

has been proposed to be related to the differential allocation of energy to somatic growth in this sex, as opposed to the allocation of energy to egg production that occurs in females (HARTNOLL, 1985). This fact was confirmed by the greater number of age cohorts found for males, which was double that found for females. This pattern agrees with that proposed by PINHEIRO and HATTORI (2006), who estimated a greater growth rate in males ($k = 1.8$) compared with females ($k = 1.6$). Males reaching larger sizes promote an important implication on the reproductive behavior of portunid crabs: males fight each other to mate and also carry/protect the females immediately after puberal molt (CHRISTY, 1987). According to PINHEIRO and FRANSOZO (1999), this behavioral pattern also applies to *A. cribrarius*, which implies that the larger size attained by males is an important reproductive strategy that promotes copulation success and female survival.

With regard to the sex ratio patterns as a function of size, *Arenaeus cribrarius* exhibits the 'anomalous' type (WENNER, 1972), as has

previously been reported for other decapod species (e.g., MORI and ZUNINO, 1987; ABELLÓ *et al.*, 1990). Although natural selection favors the generation of offspring at a sex ratio of 1:1 (KOLMAN, 1960), most studies have found differences in this expected proportion. The analysis of pooled data revealed that the overall population of *A. cribrarius* presents a sex ratio in favor of females (1:1.4), in contrast to other portunids, which exhibit the opposite pattern: e.g., 1.8:1 in *Liocarcinus puber* (CHOY, 1988); 2.4:1 in *Portunus pelagicus* (PRASAD and TAMPI, 1954); and 2.5:1 in *Callinectes ornatus* (BRANCO and FRACASSO, 2004) and *C. danae* (PEREIRA *et al.*, 2009). According to WENNER (1972), deviations from an equal sex ratio may be due to endogenous factors related to the natural life history of each species, such as differential longevity, growth, and mortality between sexes and migration. Furthermore, distributional differences, granulometric preferences, and other factors can also affect the sex ratio. Given these explanations, the pattern found for *A. cribrarius* might be explained by the faster growth of males when compared to females, which results in a prevalence of females in intermediary size classes, and a reproductive adaptation that favors larger males to copulate and protect females, as confirmed by PINHEIRO and FRANSOZO (1999).

Environmental parameters are known to play important roles in the distribution of species. CARMONA-SUAREZ and CONDE (2002) and ZANGRANDE *et al.* (2003), found a positive correlation between the occurrence of *Arenaeus cribrarius* and salinities greater than 30, whereas PINHEIRO *et al.* (1996) noted a strong positive correlation between the abundance of this species and sediment grain size, as corroborated by GUERRA-CASTRO *et al.* (2007). In Fortaleza Bay, there was a predominance of adult females only at transect I, where there was also a greatest number of ovigerous females, as well as an association with medium and coarse sand fractions of the sediment (PINHEIRO *et al.*, 1996). According to these authors, this sediment acts like an artificial brood pouch for mature females during the spawning process and serves as a support to mould egg mass. The close association between *A. cribrarius* adult females and

coarse sand, as well as the differential distribution of juveniles and adult males that occurs in association with very fine sand corroborates the previous conclusion of the importance of the sampling area in population analyses, such as distribution of different sexes. Furthermore, transect I was from the deepest area in Fortaleza Bay and it is located close to rocky shores (PINHEIRO *et al.*, 1996), which could provide protection for ovigerous females, and probably more stable environmental conditions (e.g., higher salinity) (HINES *et al.*, 1987).

PINHEIRO and FRANSOZO (2002) registered the mating of *Arenaeus cribrarius* in Ubatuba during the autumn months, when a greater incidence of females in post-molt with full spermathecae (recent copulation) and mature gonads were observed. It is, therefore, expected that females are very active at this time due to the characteristic migration of portunid females (SFORZA *et al.*, 2010; SANT'ANNA *et al.*, 2012) in search of better environmental conditions for spawning (e.g., higher salinity, adequate substratum to lay their eggs, and reduced predation pressure, as mentioned by HINES *et al.*, 1987). These different factors likely explain the larger number of females as compared to males found during autumn in Fortaleza Bay.

As described by several authors, brachyurans are usually right-handed (e.g., MUIÑO *et al.*, 1999; FUMIS *et al.*, 2007), as recorded in this study. However, compared to other previously studied portunids, the percentage of right handed crabs was lower for *A. cribrarius* (71 to 74%). In *Liocarcinus depurator*, for example, the percent range of right-handed individuals was 87-89% (MUIÑO *et al.*, 1999), and that of *Callinectes ornatus* 81-87% (HAEFNER, 1990). At transition from the juvenile to adult stage some crabs exhibited a decrease in the percentage of right-handed animals due to loss of the right chela loss in inter- or intra-specific interactions with the subsequent development of the remaining chela as major (SIMONSON, 1985). *Arenaeus cribrarius*, however, does not show this pattern.

CONCLUSIONS

A historical overview of the population biology of *Arenaeus cribrarius* is relevant for comparisons

with future environmental scenarios, mainly based on growing anthropogenic influences. An overlap between juvenile and adult phases indicates the puberty size molt in males (40-70 mm CW) and females (45-75 mm CW), and confirms maturity sizes. Males reached greater body size than females, due to higher growth rates, promoting double of age cohorts and a bias for males in the larger CW sizes. Females were prevalent during the molt/copulation period and in more hydrodynamic marine areas, which can be explained by their environmental requirements for reproduction, what will also affect population structure.

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