Differential habitat use by demographic groups of the redfinger rubble crab *Eriphia gonagra* (Fabricius, 1781)

Andrade, LS.[a]**, Goés, JM.*[b]*, Fransozo, V.*[c]*, Alves, DFR.*[a]*, Teixeira, GM.*[d]*, and Fransozo, A.*[a]

[a]Núcleo de Estudos em Biologia, Ecologia e Cultivo de Crustáceos – NEBECC, Departamento de Zoologia, Instituto de Biociências, Universidade Estadual Paulista – UNESP, Campus de Botucatu, Distrito de Rubião Junior, s/n, CEP 18618-000, Botucatu, SP, Brazil

[b]Laboratório de Zoologia, Universidade Federal do Piauí – UFPI, Campus Ministro Reis Velloso, Av. São Sebastião, 2819, Parnaíba, PI, Brazil

[c]Departamento de Ciências Naturais, Universidade Estadual do Sudoeste da Bahia – UESB, Estrada do Bem Querer, Km 04, CEP 45031-900, Vitória da Conquista, BA, Brazil

[d]Departamento de Biologia Animal e Vegetal, Universidade Estadual de Londrina – UEL, Rodovia Celso Garcia Cid, PR 445 Km 380, Londrina, PR, Brazil

* e-mail: andradels.nebecc@gmail.com

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Abstract

The structurally diverse rocky shores along the northern coast of the state of São Paulo, Brazil, support a varied fauna and provide refuges for many organisms. Some of these environments allow for extensive microhabitats, among them the sand reefs formed by the polychaete *Phragmatopoma lapidosa*, which occupy much of this area. The beauty of the landscape attracts large numbers of tourists, who contribute to the damage to the sand reef colonies, causing an imbalance in the patterns of population distribution and of this ecosystem. We describe the structure and population biology of the redfinger rubble crab *Eriphia gonagra*, and investigated the differential occupation of the habitat by each demographic category of this species. Crabs were sampled monthly for two consecutive years on the rocky coast of Grande Beach, Ubatuba, São Paulo, during spring low tides. Sampling was carried out over an area of approximately 1200 m^2, during two hours on the rock surface and another two hours on the sand reefs. A total of 1407 crabs were collected; 776 on the sand reef (SR) and 631 on the rocky shore (RO). The majority of juvenile crabs inhabited the SR, while adult crabs were equally distributed in both microhabitats. This study showed that the SR is a natural nursery ground for the establishment of the early juvenile stages of *E. gonagra,* which use the reefs as a refuge and food resource. Many other organisms (mollusks, echinoderms, polychaetes etc.) settle on the reefs, and these areas may be among the most important in maintaining benthic diversity in the region.

Keywords: coastal structures, crab nursery, ecological zonation, Xanthoidea, ontogenetic habitat shift.

Ocupação diferencial do habitat por grupos demográficos do caranguejo de dedos vermelhos Eriphia gonagra (Fabricius, 1781)

Resumo

Os costões rochosos do litoral norte paulista, devido à sua constituição diversificada, sustentam uma grande diversidade de espécies animais e vegetais, além de proporcionar uma série de abrigos para proteção de muitos organismos. Em alguns destes costões ocorre a formação de microhabitats, entre eles os recifes de areia formadas pelo poliqueta *Phragmatopoma lapidosa*, que ocupam grande parte desta área. A paisagem diferenciada do local atrai um grande número de turistas, o que contribui para a deterioração das colônias que constituem esse recife, causando um desequilíbrio nos padrões de distribuição das populações desse ecossistema. Este trabalho visou levantar informações sobre a estrutura e dinâmica populacional de *Eriphia gonagra*, além de investigar uma ocupação diferencial do habitat por diferentes grupos etários deste caranguejo. Os caranguejos foram amostrados mensalmente, durante dois anos consecutivos, no costão rochoso da Praia Grande, Ubatuba, São Paulo, Brasil, em períodos de marés baixas de sizígia. A coleta ativa dos indivíduos foi efetuada em uma área de aproximadamente 1200 m^2 por um período de duas horas na superfície rochosa e outras duas horas nos recifes de areia. Foi capturado um total de 1407 indivíduos, sendo 776 no recife de areia (SR) e 631 na superfície rochosa (RO). A maior parte dos jovens habita o recife, enquanto adultos encontram-se igualmente distribuídos nas duas áreas amostradas. Este estudo mostra que os recifes de areia podem ser considerados berçários de suma importância para o estabelecimento dos estágios juvenis de *E. gonagra*, que utilizam tais locais para proteção e alimentação. Muitos outros organismos (moluscos, equinodermos, poliquetas etc) se estabelecem sobre os recifes, sendo que essas áreas podem estar entre as mais importantes na manutenção da diversidade bêntica na região.

Palavras-chave: estrutura costeira, berçário de caranguejos, zonação ecológica, Xanthoidea, mudança de habitat na ontogênese.

1. Introduction

The benthic macrofauna comprises a diversity of aquatic animals that live closely associated with the bottom; they represent a fundamental link in the food chains of their respective ecosystems. They also act in processes that influence nutrient and contaminant cycling, such as bioaccumulation, trophic transfer, migration, biodegradation, and bioturbation (Reynoldson, 1987). Part of the benthic fauna live in intertidal zones and depend on this habitat to complete their life cycles; examples include the brachyurans *Pachygrapsus transversus* (Gibbes, 1850), *Hexapanopeus schmitti* Rathbun, 1930, and *Menippe nodifrons* Stimpson, 1859 (Flores and Negreiros-Fransozo, 1998; Mantelatto and Souza-Carey, 1998; Braga et al., 2005), and other invertebrates such as the isopod *Ligia pallasii* Brandt, 1833, shrimps and anemones, the anomuran *Calcinus tibicen* (Herbst, 1791), the mollusk *Stramonita haemastoma* (Linnaeus, 1758) among others, respectively studied by Carefoot (1973), Knowlton and Keller (1985), Fransozo and Mantelatto (1998) and Watanabe and Young (2006).

The rocky shore of Grande Beach (Ubatuba, state of São Paulo, Brazil) is composed of many large rocky outcrops and sand reefs, and this landscape attracts large numbers of tourists (Burone and Pires-Vanin, 2006). The sand reefs are a result of an accumulation of the polychaete worm *Phragmatopoma lapidosa* (Kinberg, 1867), and offer small structural refuges for infaunal organisms (Wilson, 1979). The rock surfaces also have concavities and crevices that can be used as shelter by larger animals than occupy the spaces available in *P. lapidosa* reefs.

Many decapod species and other marine invertebrates colonise marine habitats with spatially diverse structural features. Usually, juvenile individuals settle in a certain area, and subsequently migrate to other sites where food is more abundant and other essential factors for their growth and reproduction are more available. Occupation of specific sites as nursery grounds for the establishment and development of early post-larval stages is very common in brachyuran species; juvenile and adult crabs often occupy different habitats as they develop, because of their different needs for certain resources (Berrill, 1982; Fukui, 1988; Morgan and Christy, 1995; Flores and Negreiros Fransozo, 1998; Giménez et al., 2004).

The sand reefs produced by sabellariid polychaetes support several communities of decapod crustaceans (Coull and Bell, 1983). Almaça (1990) studied the crab community structure and interactions of these colonies, and noted the importance of the trophic relationship between polychaetes and crabs; the former are an important food resource for many species of the marine benthic and demersal fauna (Petti et al., 1996). Gore et al. (1978) found that 65% of the crustaceans associated with the sand reefs of *Phragmatopoma caudata* (Kröyer, 1856) in Florida (USA) utilise the sabellariids themselves as their main food resource. This kind of differential utilisation of food-habitat may be the key to the successful coexistence of diverse species in the same habitat. In addition, the sand banks of *P. caudata* constitute an important substratum for crustacean decapods, where megalopae of several species are intensively recruited, while juveniles and small adults share the substratum, searching for food and shelter from wave action (Bosa and Masunari, 2002).

Hall et al. (1991) stated that physical perturbations in benthic habitats influence the structure of marine communities, and in shallow coastal environments, the macrobenthic community is subject to a variety of changes. Soltan et al. (2001) observed that populations of the upper sublittoral on rocky shores and sand reefs are more affected than other shallow benthic populations, because they are more exposed to urban and industrial debris carried on the sea surface. According to Lopes et al. (1994), the northern coast of the state of São Paulo is particularly vulnerable to petroleum contamination, because of the intensive tanker traffic in the area. On rocky shores, the oil can remain adhered to the substratum, directly affecting the living organisms, especially larvae, preventing them from settling (Lopes et al. 1997). Experiments by Lopes et al. (1997) on rocky shores at São Sebastião in São Paulo demonstrated mortality of many individuals of *Eriphia gonagra* (Fabricius, 1781), among other invertebrates.

In addition to the vulnerability to petroleum contamination and the direct impacts of visitors, other human activities can have indirect effects on the intertidal flora and fauna. For example, shifts in the size structure of a population towards smaller and younger individuals may result in a disproportionate decrease in the reproductive ability of the population, because reproductive potential increases with size (Levitan, 1991). For species with long-lived pelagic larval stages, declines in reproductive output can affect both local and regional recruitment. Human activities can also result in cascading effects such as alteration of community processes through disruption of the ecological balance of competitors, predators, and/or food supply (Duran and Castilla, 1989), or through alterations in habitat conditions such as declines in the abundance of ecosystem engineers (Brown and Taylor, 1999; Schiel and Taylor, 1999). Studies on rocky-shore populations have provided useful data for future investigations concerning water quality (Fairweather, 1990) and human impact on coastal systems (Smith et al., 2008; Sanchez-Cabeza and Druffel, 2009).

The redfinger rubble crab *E. gonagra* inhabits the intertidal zone of rocky shores, where it occurs in crevices and galleries formed by rock deposits, and also associated with sand reefs. According to Melo (1996), the distribution of *E. gonagra* is restricted to the western Atlantic, from North Carolina, USA, to Santa Catarina, Brazil. The goal of this study was to analyse the differential habitat occupation by different demographic groups of *E. gonagra,* in order to contribute to species preservation by increasing knowledge of its habitat use, from post-settlement to the adult and mature stages.

2. Material and Methods

2.1. Field collections

Crabs were sampled monthly, during spring low tides, from January 1996 through December 1997, on the rocky shore at Grande Beach (23°28'02" S; 45°03'35" W), Ubatuba, São Paulo. Sampling was carried out by the same two collectors throughout the study period over the entire length of the rocky shore, including the sand reef and rocky portions, covering a total area of 1200 m^2. Two sampling hours were dedicated to the rocky portion (RO) and another 2 hours to the sand reefs (SR) constructed by polychaetes (*P. lapidosa*).

2.2. Laboratory procedure

All crabs were packed in individual plastic bags to prevent agonistic behavior among specimens and consequent loss of appendages. In the laboratory, these were classified and grouped in demographic categories. Sex of specimens was determined from abdominal morphology (wide in females) and number of pleopods (2 pairs in males and 4 pairs in females). The adherence of the abdomen to the thoracic sternite and the gonad development stage were checked to distinguish adult from juvenile crabs (Guimarães and Negreiros-Fransozo, 2005). The number and size (maximum carapace width) of juvenile males (JM), adult males (AM), juvenile females (JF), adult non-ovigerous females (AF), and ovigerous females (OF) were recorded, and the crabs were grouped in 12 size classes of 4 mm each, based on carapace width. A consignment of individuals collected in this study is integrated into a scientific collection of Study Group of Crustacean Biology, Bioscience Institute, of the Universidade Estadual Paulista Júlio Mesquita Filho.

2.3. Statistical analyses

The number of individuals was standardise per catch per unit effort (CPUE), *i.e.*, crabs collected for 100 m^2 (2 collectors x 2 hours) in each month, as calculated by other researchers working on coastal monitoring (e.g. Kennelly, 1992; Seminoff et al., 2003; Adjers et al., 2006). All these data were tested for normality and homoscedasticity by the Shapiro-Wilk and Levene tests. The total abundance and the number of specimens of each demographic group were compared between the sampling areas (RO and SR) by Student's *t* test. The sex-ratio in each area, and also for the total number of individuals was compared by means of a binomial test (Fisher 1930, Wilson and Hardy, 2002). The size of crabs was compared between RO and RS by the Mann-Whitney non-parametric test. All statistical analyses were performed according to Zar (1996), at the 5% significance level.

3. Results

A total of 1407 specimens were collected; 776 on the sand reef (SR) and 631 on the rocky portion (RO). The sex-ratio did not differ from the expected, except in 1997 at SR, when the number of females was higher (*t* test, $p < 0.01$) (Table 1). The Mendelian ratio was observed in all size classes of males and females (Figure 1), except the 7th (from 26 to 30 mm), in which females predominated (p=0.026).

Comparison of the abundance of each demographic group in each biotope revealed a strong predominance of juvenile crabs in SR (Table 2), whereas non-ovigerous adult females, ovigerous females, and adult males were distributed similarly between the two biotopes, in both sampling years. The mean size of the specimens collected in SR was 21.37 ± 8.3 mm CW (mean ± standard deviation), and in RO was 25.15 ± 8.7 mm; these means differed statistically (*t* test; $T = 8.3$; $p = 0.00$). The mean size of each demographic group is shown in Table 3. Taking into account the total number of males and females from each biotope (RO and SR), no significant differences between the sexes were observed. On the other hand, when the size of individuals was compared within the same demographic group, the largest individuals occurred in RO. The sizes of immature individuals obtained in SR and RO did not differ statistically.

Comparing the frequency of females by size class in each habitat showed that in SR, no females were captured in the

Table 1. *Eriphia gonagra*. Sex ratio and number of individuals on the sand reef (SR) and rocky surface (RO) from January 1996 to December 1997.

Reef	Year	Females			Males		Total	Sex ratio	P
		AF	OF	TJ	AM	TJ		M:F	
Sand	1996	135	42	116	175	100	568	1.0:1.1	0.44_{ns}
	1997	76	40	7	83	2	208	1.0:1.4	0.01*
Rock	1996	83	41	11	103	6	244	1.0:1.2	0.10_{ns}
	1997	101	53	36	154	43	387	1.0:1.0	0.70_{ns}

*P<0.01; AF: Adult females. OF: Ovigerous females. AM: Adult males. TJ: Total Juveniles.

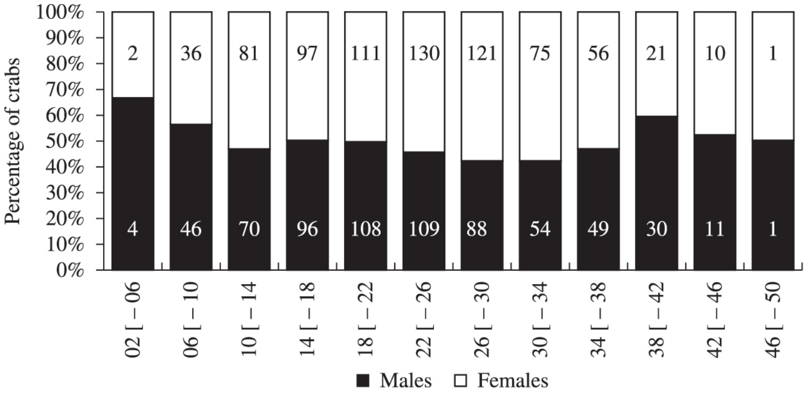

Figure 1. Percentages of males and females of *Eriphia gonagra*. Percentages of males and females per size class during the study period.

Table 2. *Eriphia gonagra*. Mean numbers of individuals and standard deviations (sd) of demographic groups on the sand reef (SR) and rocky surface (RO).

Local	Year	AF	OF	AM	TJ
Sand reef	1996	11.3 ± 5.3	3.5 ± 2.2	14.6 ± 6	18 ± 7.7
	1997	6.3 ± 2.6	3.3 ± 2.1	6.9 ± 2.6	0.8 ± 1
	Total	8.8 ± 4.8	3.4 ± 2.1	10.8 ± 6	9.4 ± 10.3
Rock reef	1996	6.9 ± 3.6	3.4 ± 2.2	8.6 ± 2.3	1.4 ± 1.1
	1997	8.4 ± 4.3	4.4 ± 1.8	12.8 ± 5.6	6.6 ± 5.9
	Total	7.7 ± 3.9	3.9 ± 2	10.7 ± 4.7	4 ± 4.9
STATISTIC					
Sand *vs*. Rock	1996	T= 2.35*	T= 0.09	T= 3.23*	T= 7.41*
	1997	T= 1.45	T= 0.20	T= 3.31*	T= 3.35*
	Total	T= 0.89	T= 1.15	T= 0.03	T= 2.30*

T: value of *t*-test for independent samples. AF: Adult females. OF: Ovigerous females. AM: Adult males. TJ: Total juveniles; *p<0.01.

Table 3. *Eriphia gonagra* Fabricius, 1781. Minimum, maximum, mean size and standard deviation (sd) of carapace width (mm) in each demographic group from the sand reef and rock surface.

AGE GROUP	CARAPACE WIDTH (mm)						
	Sand reef			Rock surface			Sand *vs* Rock (Z)
	Min	Max	Mean ± SD	Min	Max	Mean ± SD	
JF	6.8	19.7	12.56 ± 2.8	4.7	17,9	12.29 ± 3.6	–0.01
JM	4.3	16.6	11.21 ± 2.9	5.8	15,9	11.48 ± 2.7	–0.58
OF	18.6	44.1	28.11 ± 5.8	17.7	43.0	30.08 ± 5.7	–2.34*
AF	10.8	42.3	24.05 ± 5.9	13.3	46.1	26.84 ± 7.0	–3.83*
AM	13.7	49.6	25.24 ± 7.1	13.9	45.1	27.09 ± 7.4	–2.99*

Z: value of Mann-Whitney test. JF: juvenile females. JM: juvenile males. OF: Ovigerous females. AF: Adult females. AM: Adult males; *p<0.01.

first and final size classes. In this biotope, juvenile females reached 19.7 mm CW. In RO, the largest immature female found was 17.9 mm, and the largest mature female was 46.1 mm CW. Males (Figure 2), which were present from the first size classes in both locations, reached larger sizes in SR as both juveniles (16.6 mm) and adults (49.6 mm).

For each year (Figure 3), 1996 showed more juveniles in SR, whereas adult crabs predominated in 1997. In 1996, more adult crabs than juveniles were caught in RO; in 1997, more juveniles were caught. The number of individuals/100 m^2 (CPUE) per month revealed that non-ovigerous females were most abundant, in both biotopes, from January through July, and less abundant in late winter and early spring. Ovigerous females were more abundant in the latter period, although they were present year-round in both places, with estimated densities of 1.17 ± 0.5 and 1.0 ± 0.5/100 m^2 for SR and RO, respectively. Adult males were abundant during the entire study period. Juveniles were abundant year-round in SR, while in RO their numbers declined in autumn and early spring. The recruitment percentage in

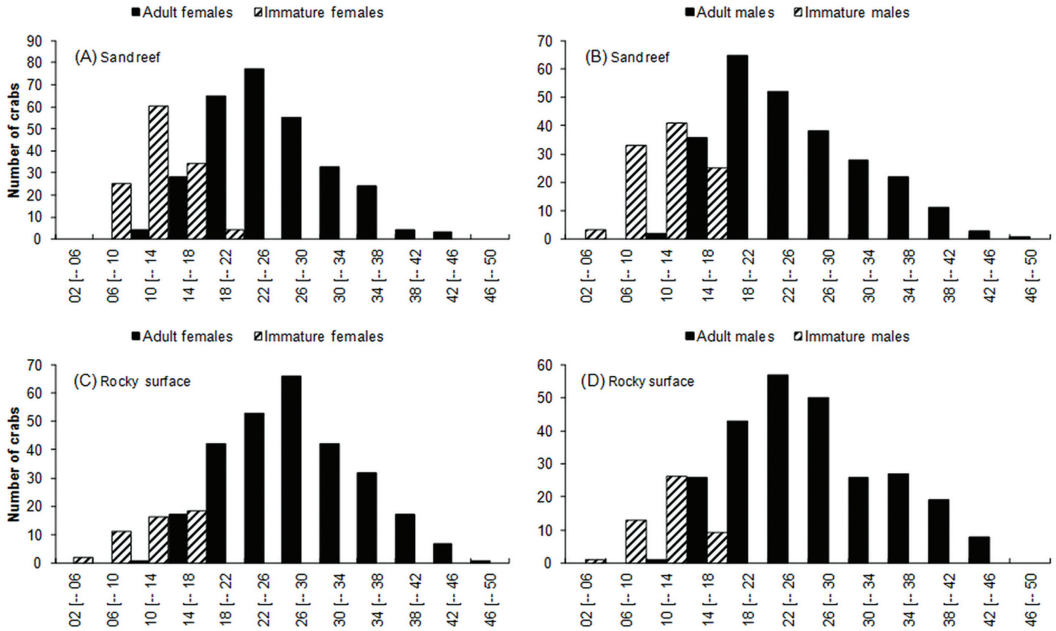

Figure 2. Absolute size-frequency distribution of *Eriphia gonagra*. Absolute size-frequency distribution of females (A, C) and males (B, D) on the sand reef-SR (A,B) and rocky surface-RO (C, D).

the RO was inversely proportional to the number of adult mature females; whereas in SR, the percentages of recruits and adult mature females were similar (Figure 4).

4. Discussion

The size-frequency distribution of crabs was higher in SR than in RO, which could indicate that this habitat is more suitable for colonisation and establishment of the species, because of the greater availability of food (Burone and Pires-Vanin, 2006). According to Eckelbarger (1976), banks of *Phragmatopoma lapidosa* provide a relatively stable and suitable environment for the establishment of these populations, because after a disturbance caused by natural abrasion, human action or wave impact, the colonies develop rapidly and can re-establish themselves within a few days. The numerous crevices in the RO can protect *E. gonagra* against predation by fish and other, larger crabs, since they are widely used as a shelter. Also, the colouration of *E. gonagra* is very similar to the environment (algae-covered rocks), providing mimetism in these conditions.

In both RO and SR, the sex-ratios were close to the Mendelian ratio (p>0.05), as also observed by Góes and Fransozo (2000) for the same specie, as well captured in Ubatuba. However, this pattern is not found for other Eriphioidea crab, that share the same habitat. Oshiro (1999) found that the sex-ratio of the rock crab *Menippe nodifrons* was consistently in favour of females, despite some seasonal variations. Studies of *Epialtus brasiliensis* Dana, 1852 and *Acanthonyx scutiformis* Dana, 1851, both from rocky shores in the Ubatuba region (respectively studied by Negreiros-Fransozo, Fransozo and Reigada, 1994; and Teixeira et al., 2009), reported differing sex-ratios. However, in the present study, females predominated in only one size class, whereas males were most abundant in the intermediate size classes. This can be explained because sexually mature males are more active and are more exposed by their behavior when searching for females for mating and also during mating (Wirtz and Diesel, 1983). This feature might considerably increase the susceptibility of *E. gonagra* to predation.

According to Giesel (1972), the sex-ratio can modulate the population size, affecting the reproductive potential. Díaz and Conde (1989) suggested that this regulatory condition can be seen in species with differential growth rates and/or life expectancy for each sex. Similarly, Wenner (1972) mentioned that differential mortality between the sexes, as well as other factors, can lead to a difference in the cost of brood production in each sex, such as the differential growth rates or size differences between sexes during the period of brood care, altering the sex ratio (Darnell, 1962).

The differences in habitat use by demographic groups of *E. gonagra* were evidenced by the higher abundances at SR. The large number and variety of shelters inside the colonies of *P. lapidosa* make this microhabitat a good place for juveniles to complete their development and growth, because the effect of predation is markedly reduced (Heck and Hambrook, 1991; Flores and Negreiros-Fransozo, 1998). The advantage of shelter was also suggested by Spivak et al. (1994) to account for the extremely high density of juveniles of *Cyrtograpsus angulatus* (Dana, 1851) found in colonies of *Ficopomatus enigmaticus* (Fauvel, 1923). Bosa and Masunari (2002) recorded a

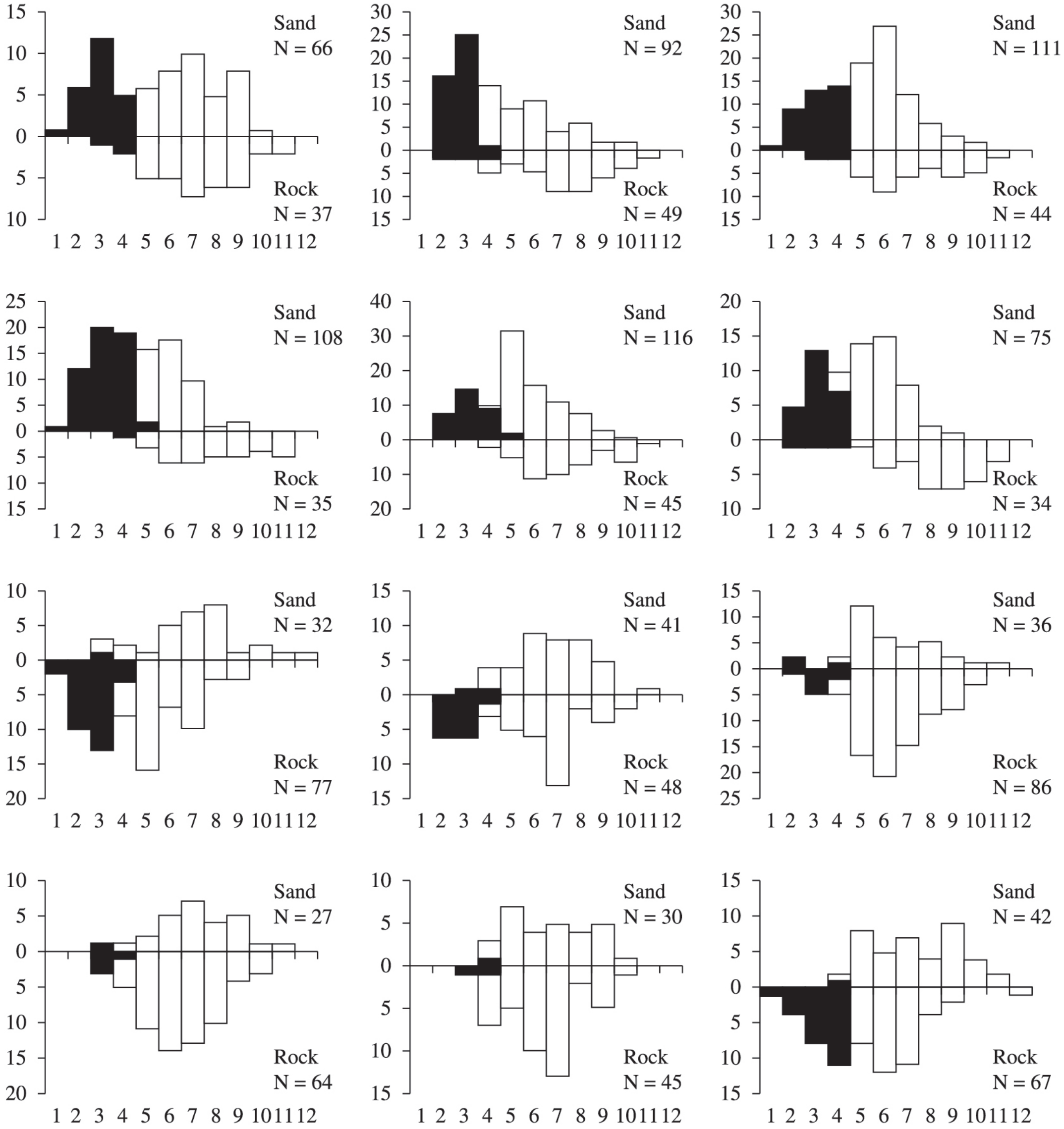

Figure 3. Size-frequency distribution of *Eriphia gonagra*. Bimonthly size-frequency distribution on the sand reef (SR) and rocky surface (RO). (N=number of crabs; dark bars: juvenile crabs; white bars: adult crabs).

high percentage of juveniles of *Petrolisthes armatus* and *Panopeus americanus* associated with *P. caudata* at Caiobá Beach (Matinhos, state of Paraná, Brazil), compared with populations from rocky shores, which was related to the existence of appropriate microhabitats for the settlement of megalopae on sabellariid banks. Similarly, Logan Koch (1982) observed preferential recruitment of several species in locations with greater topographic complexity at the millimetre scale.

Although adult individuals were more abundant in RO, their numbers did not differ significantly from SR. When in very high abundance in SR, some adult and mature crabs probably migrate to RO for mating. This hypothesis seems plausible because mating occurs only after the puberty molt, when crabs are large enough and probably do not fit inside the small holes in the colonies. Factors such as this require habitat alteration in the transition from juvenile to adult. Similarly, Flores et al. (2002), studying the congeneric *Eriphia verrucosa* (Forskall, 1755) on a rocky coast of Portugal, noted that although it was the second most abundant species as adults, no juvenile crabs were found in the same place, which led the authors to suggest that juvenile and adult crabs select different substrates.

The size-frequency distribution of the demographic groups differed somewhat with reference to the two habitats and during the two years of the study. Juveniles were more numerous in SR than RO. The largest adult specimens tended to occupy the RO portion. This indicates that the SR portion is appropriate and important for juvenile recruitment, in which individuals find some needed resource

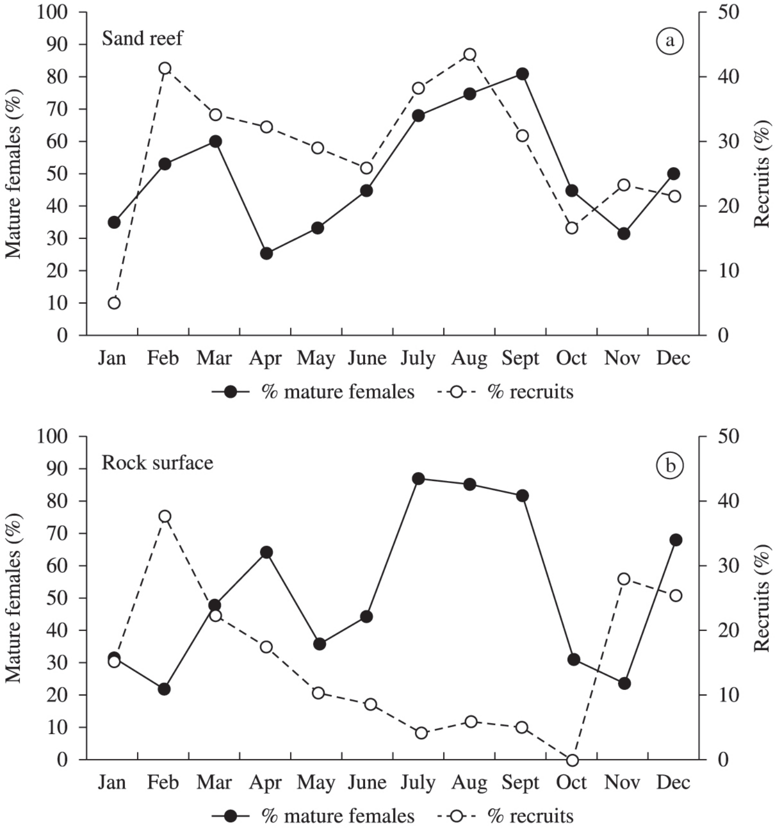

Figure 4. Recruits and mature females of *Eriphia gonagra*. Variation in the percentage of recruits and mature females on the sand reef-SR (a) and rocky surface-RO (b).

in abundance for this life-cycle phase; consequently, the availability of such microhabitats can be determinant for population density.

Johnson (1970) considered larval recruitment as one of the main factors responsible for the diversity of benthic communities. Recruitment success is dependent on both the morphology of the substratum and the existence of refuge sites (Shulman, 1984), which are widely found in *P. lapidosa* banks in SR. According to Anger (2006), several physical and chemical signals can effectively stimulate or prevent the establishment of brachyuran larvae, such as structural features of the bottom, salinity, light, water currents, water vibrations and odor, substratum, predators, foods, commensals, and adults of the same species.

Analysis of the seasonal distribution of *E. gonagra* revealed that the majority of juveniles colonise the sand reefs year-round, indicating continuous recruitment of the species and reinforcing the hypothesis of differential habitat preference according to crab size. The settlement of these juveniles on the sand reefs suggests the existence of a successful growth strategy, which may support the hypothesis of the stability of the population on the rocky shore, because juvenile crabs are fragile and vulnerable to predation, and the SR microhabitat contributes to this critical period of their life-cycle.

Many anomurans and brachyurans that inhabit the intertidal zone of the rocky shore and estuarine waters in temperate and tropical regions spawn over a prolonged period or continuously throughout the year (Sastry, 1983). Ovigerous females of *E. gonagra* were found year-round and with some peaks in their numbers, which indicates continuous reproduction and continuous recruitment, as is common for species in tropical and subtropical climates (Góes, 1995).

The present observations indicate that juveniles of *E. gonagra* remain in SR until they complete their juvenile development, and that some adults after the onset of sexual maturity, including many ovigerous females, are also found in this microhabitat. This could assure the production of offspring, although the largest crabs did not occur there, and also provide protection for small ovigerous females in their first spawning.

In the population of the grapsid crab *P. transversus* studied by Flores and Negreiros-Fransozo (1998) at the same location as the present study, some changes of habitat occurred with a considerable mortality rate, due to greater vulnerability and exposure to adverse environmental conditions. Adaptations to decrease the risk of predation during the changes in habitat could include more complex mechanisms, such as a colour change to provide a new mimetic pattern (Hines, 1982). This does not apply in the case of *E. gonagra,* which did not suffer a high mortality rate during the habitat change, and retains the same colour pattern throughout life.

As recommended by Oliva and Castilla (1986), studies of intertidal faunas should determine the magnitude of the populations, not only for target species subject to human exploitation, but also for other species that modulate the community equilibrium as a whole.

The SR areas are of great importance for the establishment and early growth of *E. gonagra*, because the species uses this microhabitat as a nursery ground. Additionally, during its life cycle, *E. gonagra* exploits at least two microhabitats, indicating effective adaptation to and stability in the intertidal rocky environment.

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