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Research Article

Influence of environmental variables on the distribution of intertidal porcellanid crabs in Sepetiba Bay, Rio de Janeiro, Brazil

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ABSTRACT. This study aims to assess the distribution patterns of porcellanid crabs in the intertidal zone of Sepetiba Bay, Rio de Janeiro, Brazil, identifying the abiotic determinants. Samples were collected seasonally (dry and rainy seasons) from January 2005 to August 2007, during low tides in external, intermediate and internal sectors. The crabs were hand caught in consolidated substrates with sampling effort of two people in three different flood zones (lower, medium and higher) for 30 min. Water temperature, salinity, accumulated rainfall, the physical and chemical variables of sediment were analyzed concerning interaction in the distribution patterns of the species. A total of 3,389 crabs, belonging to five genera and eight species, were obtained. With the exception of *Petrolisthes armatus*, found throughout the intertidal range, all species inhabited the intertidal bottom of Sepetiba Bay exclusively. Favorable environmental conditions of the Sepetiba Bay enabled the success of colonization of several porcellanid species which are a refuge and feeding environment of the Marambaia Island and continental (Junqueira and Ibicuí) of the outer zone. The number of species recorded in this study supporting the hypothesis that features of substratum and the availability of food and refuges are factors limiting the establishment of this family in Sepetiba Bay.

Keywords: porcellanids, crustaceans, intertidal zone, organic matter, sediments, Sepetiba Bay, Brazil.

Influencia de las variables ambientales sobre la distribución de cangrejos porcelánidos de la zona intermareal de la Bahía de Sepetiba, Rio de Janeiro, Brasil

RESUMEN. Este estudio tiene como objetivo evaluar los patrones de distribución de cangrejos porcelánidos y sus determinantes abióticos en la zona intermareal de la Bahía de Sepetiba, Río de Janeiro, Brasil. El muestreo se realizó estacionalmente (temporadas secas y lluviosas) entre enero de 2005 y agosto de 2007, durante las mareas bajas en sectores externos, intermedios e internos. Los cangrejos fueron capturados manualmente en sustratos consolidados con dos colectores en tres diferentes zonas de inundación (inferior, medio y superior) por 30 min. Se analizó la temperatura del agua, salinidad, precipitación acumulada y parámetros físicos y químicos de los sedimentos para estudiar la interacción en los patrones de distribución de las especies. Durante el período se analizaron 3.389 ejemplares pertenecientes a cinco géneros y ocho especies de crustáceos de porcelánidos. Con excepción de *P. armatus*, que se encontró en toda la zona intermareal, las demás especies habitaron exclusivamente el intermareal inferior de la Bahía de Sepetiba. Diversas especies de porcelánidos encuentran refugio y alimentación en el medio ambiente de la isla Marambaia y en la parte continental (Junqueira and Ibicuí) perteneciente a la zona externa de la Bahía de Sepetiba. El número de especies registradas en este estudio apoya las hipótesis que las características del sustrato, disponibilidad de alimentos y refugios son factores que limitan el establecimiento de esta familia en esta bahía.

Palabras clave: porcelánidos, crustáceos, zona intermareal, materia orgánica, sedimentos, Bahía de Sepetiba, Brasil.

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INTRODUCTION

Zoobenthos form an extremely rich and diverse set of animals belonging to various zoological groups (Soares-Gomes *et al.*, 2002). Among these are the mesobenthic crustaceans living in interstitial spaces of sedimentary grains and small cracks of rocks, as is the case of porcellanid crabs.

The representatives of the family Porcellanidae are crustaceans very common and abundant on rocky habitats in the intertidal zone, sheltering under rocks among algae and establishing commensally relationships with some another species of the hard bottoms, such as sea anemones, and starfishes. However, these porcellanid crabs are rarely found at depths of over 150 m (Silva *et al.*, 1989).

The success of this group colonization can be attributed not only to the high ecological potential, but to dispersion, primarily attributed to the larva. Such success explains the cosmopolitan distribution of this family, composed by 17 genera and about 230 species (Rodriguez, 1980). According to Melo (1999), 23 species of porcellanid crabs in seven genera are found in Brazilian waters, of these, 13 are known from the coast of the state of Rio de Janeiro.

Porcellanid crabs represent an important part of the decapods fauna living in intertidal and shallow-water zones. However, for this group life in the intertidal zone demands adaptations related to desiccation, temperature and salinity tolerance, and the capability to withstand environmental variations (Jensen & Armstrong, 1991; Stillman & Somero, 1996; Yaikin *et al*., 2002).

Most ecological studies aim to explain patterns of spatial-temporal distribution as a function of environmental variables. According to Giere (1993), the main abiotic factors influencing the distribution of mesobenthic fauna are: structure of sediment, grain size, temperature, dissolved oxygen, pH, and salinity. In order to fill this gap, this study proposes to assess the distribution patterns of porcellanid species in the intertidal zone of Sepetiba Bay, identifying their main abiotic variables.

MATERIALS AND METHODS

This study was conducted in Sepetiba Bay, located in the southeastern coast of Brazil, in the south littoral of the State of Rio de Janeiro (22°54'S-23°05'S, 43°34'W-44°10'W). Sampling sites were selected according to the sediment granulometry, hydrodynamics and environmental pollution, as distributed among the following sectors: external; intermediate; and internal.

The Sepetiba Bay is delimited on the west by the Bay of Isla Grande, north of the Serra do Mar; to the east by the tidal plain of the Barra de Guaratiba and south along the Sandbank of Marambaia. The continental margin is characterized as a zone of a few beats, featuring a mostly silt substrate, with formations of silt, clay, and few areas of sand and gravel (Araujo *et al*., 1997; SEMADS, 2001). The tide enters the bay through a single channel and finds a strong depth gradient, causing a significant phase difference between the mouth and the background, which reflects in higher speeds of the tidal current (DHN, 2006).

This bay is located in one of the largest industrial centers in the state of Rio de Janeiro, which is a favorable region for environmental pollution from liquid effluents. These effluents cause contamination by heavy metals originating from industries and organic pollution incurred from domestic effluents (SEMADS, 2001; Amado-Filho *et al*., 2003).

The external sector of the bay is composed by Marambaia Island, Junqueira Beach, and Ibicuí Beach; the intermediate sector is composed by Laje do Lopes, and Itacuruçá Island (Prainha); and the internal sector by Itacuruçá Beach, and Barra de Guaratiba (Fig. 1).

Sample collections were carried out from January 2005 to August 2007, during receding high tides, covering the rainy and dry periods (Table 1). In this bay, the rainy season occurs from November to early April and the dry season from April to October (Barbiére & Kronemberger, 1994).

The crabs were hand caught in consolidated substrates in the intertidal zone (under stones and logs, among algae, shells, oysters, sponges and bryozoans, and in cracks between boulders). A vertical transect was drawn perpendicular to the waterline, determining three areas in the intertidal zone, corresponding to the smaller, intermediate and higher flood regions. The sampling effort consisted of two people in each intertidal zone area, during 30 min.

The specimens caught were taken to the laboratory of the Marine Biology Station (EBM), of the Federal Rural University of Rio de Janeiro (UFRRJ), in labeled containers, where they were identified according to Melo (1999). Subsequently, the samples were conserved in 70% ethanol and deposited in the collection of EBM.

Water temperature and salinity were recorded at each sampling, using, respectively, a digital thermometer and an optical refratometer. The accumulated rainfall data (monthly) were obtained from the National Institute of Meteorology (INMET)-Rainfall Network of Military Firefighters Force of the State of Rio de Janeiro (CBMERJ).

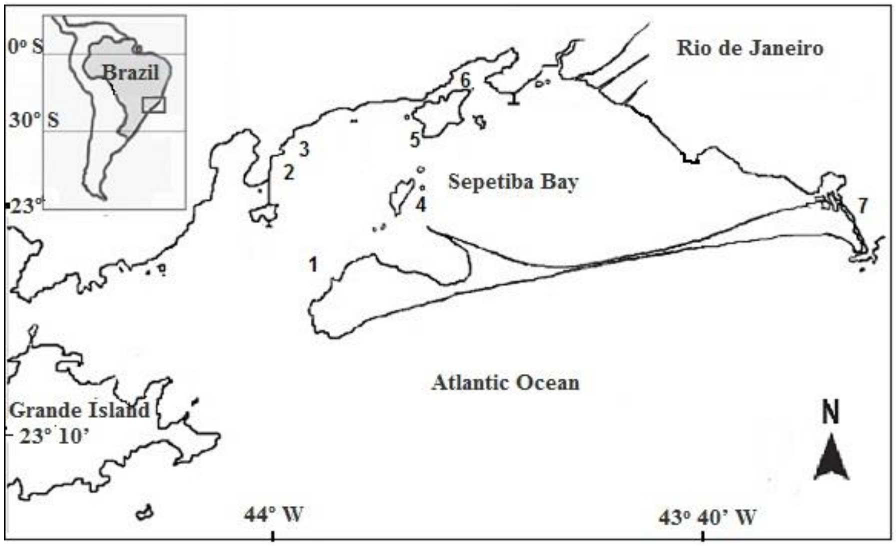

Figure 1. Map of Sepetiba Bay indicating the sampling sites. 1: Marambaia Island, 2: Junqueira, 3: Ibicuí, 4: Lage do Lopes, 5: Prainha, 6: Itacuruçá, 7: Barra de Guaratiba.

Table 1. Sampling chronogram for Sepetiba Bay and the total number of samples collected in the dry and rainy seasons from January 2005 to August 2007.

Sector	Sites	Period/sampling	Dry (N)	Rainy (N)
External	Marambaia	Apr/06 to Feb/07	4	4
	Junqueira	Jul/05 to Mar/07	2	2
	Ibicuí	Jul/06 to Jul/07	6	6
Intermediate	Lage do Lopes	Aug/05 to Mar/07	2	2
	Prainha	Aug/06 to Aug/07	6	6
Internal	Itacuruçá	Jan/05 to Sep/06	2	2
	Barra de Guaratiba	Mar/05 to Mar/07	2	2

For obtaining the sediment at each sampling, we used a polyethylene container, collecting 10 samples of surface sediment in the three areas of the intertidal zone. After the homogenization of the samples, we withdrew a portion of approximately 200 g in order to assess grain size, levels of organic carbon, and total phosphorus.

The granulometric study included the mechanical analysis of sediments according to the Wentworth scale and entire diameter (phi) intervals. A sub-sample of 200 g was placed in a Petri dish and taken to the greenhouse at a temperature of 80°C for 24 h in order to remove all moisture (Suguio, 1973). After drying, 100 g of this sub-sample were weighted in an accuracy scale (Bel Engineering), and subsequently submitted to a ro-tap type shaker (Produtest), for about 15 min, where the entire phi fractions were separated: 2.0, 1.0, 0.5, 0.25, 0.09, and 0.063 mm, respectively; corresponding to gravel, coarse sand, medium sand, fine sand, very fine sand, and silt/clay. For the classification of sediment in each sector we used the SYSGRAN 2.2 software.

In order to quantify two important chemical parameters of the sediment, organic carbon and total phosphorus, the following techniques were employed: the volumetric method by potassium dichromate for content of organic matter (%), and the spectrophotometry technique, adapted for use with resin extracts in sodium chloride, for assessing the total phosphorus content (mg L^{-1}) (EMBRAPA, 1997).

Comparison of temperature, salinity and accumulated rainfall records between sectors of the bay was held using unifactorial variance analysis (ANOVA, $\alpha = 0.05$), complemented by Tukey's test ($\alpha = 0.05$), and the seasonal comparison of these variables within each sector was carried out using Student's *t*-test ($\alpha = 0.05$).

In order to assess the influence of sediment physical parameters and the other environmental parameters (water temperature, salinity, accumulated rainfall), and the interaction of these parameters within the species distribution patterns (except for accidentals), we carried out the canonical correspondence analysis (CCA) using the CANOCO for Windows 4.0 statistical program. The degree of dependency between the distribution of species and chemical variables of the sediment was evaluated using Spearman correlation index ($\alpha = 0.05$).

RESULTS

Water temperature in the bay ranged from 17.1 to 29.0°C, with an average of 24.3 ± 2.8°C. This variable was virtually constant between sectors ($P = 0.4765$). Seasonally, there was an intra-sectorial difference, with higher temperatures in the internal sector during the rainy season ($P = 0.0137$) (Table 2).

Salinity of the bay ranged from 28 to 35, with an average of 33.5 ± 1.4, and we did not find differences between sectors ($P = 0.6392$). The intermediate sector showed different salt concentrations between the dry and rainy seasons ($P = 0.0037$) (Table 2).

Accumulated rainfall ranged from 18 to 345 mm, with an average of 115.8 ± 86.3 mm, and we did not observe sectorial differences ($P = 0.4355$). Despite the high rainfall in the rainy season, mainly in the external sector, no seasonal difference were observed in any of the sectors ($P = 0.4567$) (Table 2).

The sediments sampled were predominantly composed by sand (76.1 ± 13.1%) and gravel (22.5 ± 12.8%), occurring some differences in the granulometric fractions between sectors of the bay. There was a greater degree of grains selection in the intermediate sector (0.722 Φ), dominated by gravel and coarse sand. The more heterogeneous sediments were collected in the internal sector, being formed by a mixture of gravel, coarse sand, medium sand, and silty sand (Fig. 2).

The levels of organic carbon showed an increase in the intermediate sector of the bay (0.64 mg L^{-1}), especially due to the sampling from Lage do Lopes, decreasing in the sampling from Itacuruçá in the internal sector (0.32 mg L^{-1}) and raising again in Guaratiba (Fig. 3a). High phosphorus levels were observed in the internal (5.5 mg L^{-1}) and external (4.0 mg L^{-1}) sectors, especially regarding the samples from Itacuruçá and Marambaia Island, respectively. However the sampling Ibicuí phosphorus content was zero (Fig. 3b).

During the period of study, we caught 3,389 porcellanid specimens, being recorded eight species; among them, four are accidental or absent in all sectors (*Pachycheles monilifer*, *Megalobrachium mortenseni*, *Megalobrachium soriatum* and *Minyocerus angustus*), with low frequencies. *Petrolisthes armatus* was the most abundant, for all sectors sampled, while *Megalobrachium roseum*, *Pisidia brasiliensis* and *Pachycheles laevidactylus* showed the lowest abundances, with a narrow range of distribution, occupying the external and/or intermediate sectors (Table 3).

The CCA showed values of 0.313 and 0.187 for the first two axes, explaining the total variance of 49 and 29%, respectively. The correlation between the abiotic variables and the species was 0.666 for axis 1 and 0.679 for axis 2, reflecting the importance of each variable in the composition of the species. Axis 1 corresponded mainly to gradients of sand and gravel, observing a positive correlation with this first variable and negative with the second. On the other hand, axis 2 was negatively correlated with accumulated rainfall (Table 3). The presence of a small vector for salinity indicated a lower influence of this factor on the distribution of the species (Fig. 4).

Considering the low abundance and/or absence in some sampling points, the distribution patters of porcellanids *P. monilifer*, *M. mortenseni*, *M. angustus* and *M. soriatum* could not be statistically analyzed in this study.

The porcellanid *M. roseum* was positively correlated with the gravel fraction and negatively correlated with sand. *Pisidia brasiliensis* showed positive correlation not only with the fine sediment, but with the accumulated rainfall as well, while *P. laevidactylus* was positively correlated with temperature and sandy sediment (Fig. 4). The species *P. armatus* was excluded from the bidimensional space of the CCA.

Chemical variables of sediment proved to influence the distribution of *M. roseum* and *P. laevidactylus*, and they were positively correlated with organic carbon levels ($P = 0.0042$) and phosphorous ($P = 0.0134$), respectively.

DISCUSSION

Important factors such as temperature, salinity, currents, depth and bottom types showed to be the pricipal responsible for distribution of marine fauna and, particularly, crustaceans (Gore *et al.*, 1978). Since the average salinity did not differ between the sectors of Sepetiba Bay, it could not be considered a limiting factor to the distribution of porcellanid species, according to CCA results. In addition, as well as *P. armatus*, a species characterized as euryhaline (Coelho 1963, 1964; Werding, 1978; Micheletti-Flores & Negreiros-Fransozo, 1999), the other porcellanid species occurring in this bay may have certain tolerance to this environmental variable.

Table 2. Seasonal values (dry and rainy seasons) of abiotic variables recorded in Sepetiba Bay from January 2005 to August 2007. SD: standard deviation.

Sector	Water temperature (ºC)		Salinity		Accumulated rainfall (mm)	
	dry	rainy	dry	rainy	dry	rainy
External Range	19.0-29.0	21.5-28.0	32.0-35.0	28.0-35.0	24.8-345	30.4-270.0
$\overline{X}$ ± SD	23.1 ± 2.9	25.5 ± 2.0	34.0 ± 1.0	33.2 ± 2.0	111.0 ± 85.1	158.9 ± 89.1
Intermediate Range	17.1-27.5	22.0-28.5	33.0-35.0	31.0-34.0	24.8-160.8	30.4-271.0
$\overline{X}$ ± SD	22.2 ± 3.7	25.3 ± 2.4	34.0 ± 1.0	32.3 ± 1.0	74.9 ± 51.0	117.8 ± 98.9
Internal Range	20.0-28.0	24.0-28.0	33.0-35.0	32.0-35.0	22.0-189.0	18.0-200.0
$\overline{X}$ ± SD	24.8 ±3.6	26.0 ± 1.8	34.0 ± 0.8	33.0 ± 1.4	92.0 ± 73.7	133.9 ± 83.0

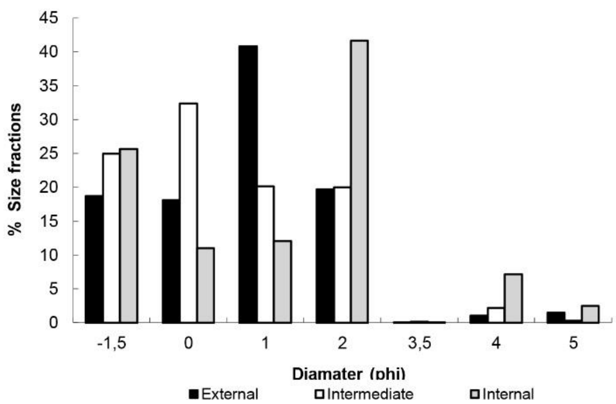

Figure 2. Percentage of size fractions within Phi (Φ) range found in the sectors of Sepetiba Bay (January 2005 to August 2007). -1.5: gravel, 0: very coarse sand, 1: coarse sand, 2: medium sand, 3.5: fine sand, 4: very fine sand, and 5: silt/clay.

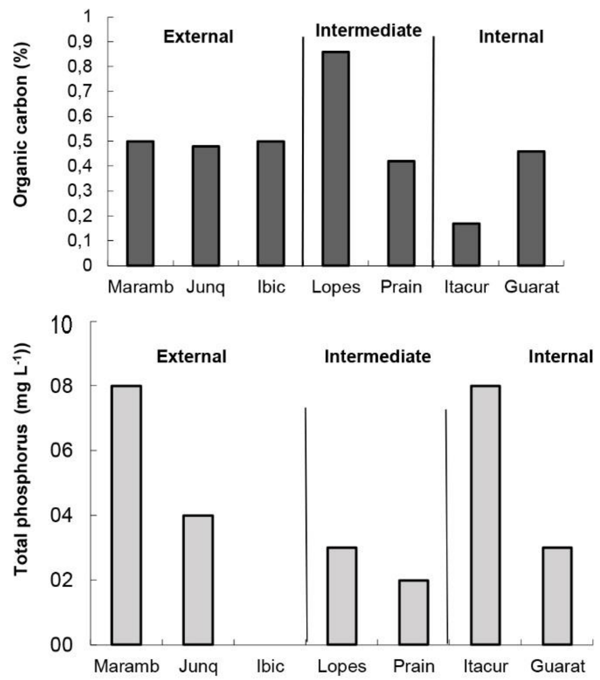

Figure 3. Organic carbon levels. a) Organic carbon variation, b) total phosphorus found in the sectors of Sepetiba Bay from January 2005 to August 2007. Maramb: Marambaia Island, Junq: Junqueira, Ibic: Ibicuí, Lopes: Lage do Lopes, Prain: Prainha, Itacur: Itacuruçá, Guarat: Barra de Guaratiba.

The porcellanids *P. monilifer*, *M. mortenseni*, *M. soriatum* and *M. angustus* with low frequency or absence of occurrence in the intertidal of Sepetiba Bay are considered by Werding *et al.* (2003) sublittoral species, which possibly have narrow habitat requirements. According to Jackson (1974) and Reaka (1980) the most of the inhabitants of the deep waters is less tolerant to environmental conditions and are therefore considered estenotopics species. The fact that these species are accidentally captured in the intertidal region of Sepetiba Bay excluded the possibility that they are correlated with the measured environmental variables.

The size and the nature of sediment are determining factors in the selection of habitats by crustaceans (Teal, 1958; Cobb, 1971). The presence of biotopes with large amount of gravel in the external and intermediate sectors proved to be essential for the occurrence of *M. roseum*, this may be considered eurytopic specie, due to its ability to settle in diverse habitats such as boulders, corals, algae banks on hard substrates, as well as in communities of deep water porifers (Veloso & Melo, 1993; Werding *et al.*, 2003).

On the north coast of São Paulo, the porcellanid *Pisidia brasiliensis* is often found in the subtidal zone, living in association with the bryozoan *Schizoporella unicornis* (Johnston, 1874) and reefs of *Phragmatopoma lapidosa* Kinberg, 1867 (Micheletti-Flores & Negreiros-Fransozo, 1999). Unlike in Sepetiba Bay, the species was positively correlated with the fine sediment, having been collected under boulders seated

Table 3. Porcellanid species collected in Sepetiba Bay from January 2005 to August 2007. Absolute abundance (N) is presented for each sector.

Species	N			Total
	External	Intermediate	Internal	
Petrolisthes armatus Gibbes (1850)	1790	890	192	2872
Megalobrachium roseum Rathbun (1900)	128	14	-	142
Pisidia brasiliensis Haig (1968)	297	30	-	327
Pachycheles laevidactylus Ortmann (1892)	39	-	-	39
Pachycheles monilifer Dana (1852)	4	-	-	4
Megalobrachium mortenseni Haig (1962)	-	2	-	2
Minyocerus angustus Dana (1852)	-	2	-	2
Megalobrachium soriatum Say (1818)	1	-	-	1

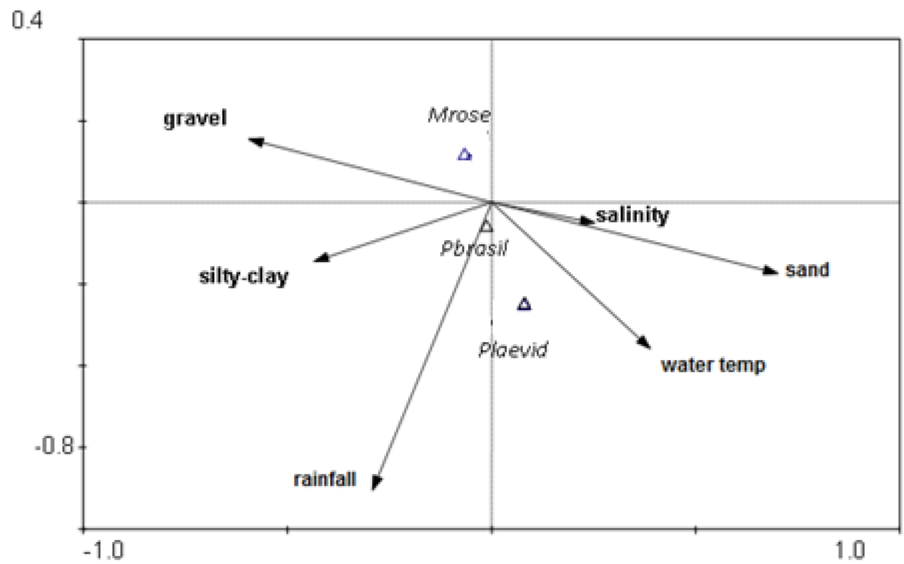

Figure 4. Canonical correspondence analysis (CCA) between porcellanid species collected in Sepetiba Bay, RJ. Mrose: *M. roseum*, Msori: *M. soriatum*, Mmorten: *M. mortenseni*, Mangus: *M. angustus*, Pbrasil: *P. brasiliensis*, Pmonil: *P. monilifer*, Plaevid: *P. laevidactylus*.

upon silty sand in the external sector, which in lower face (in contact with water) have porifers, tubicolous polychaetes and macro algal. Veloso & Melo (1993) also reported the occurrence of *P. brasiliensis* in shallow water, on sandy bottoms and under stones. This species was correlated not only with the fine sediment, but the accumulated rainfall at the entrance of the bay. The correlation of both parameters suggests that *P. brasiliensis* requires large amount of suspended food particles, which can be absorbed by the dense tuft of bristles present on the ventral face of the propodus of the minor chelae. Such additional feeding method has been reported for *Petrolisthes cabrilloi* (Gabaldon, 1979).

In spite of the narrow distribution of *P. laevidactylus*, captured only in the external sector of Sepetiba Bay, its sampling (39 individuals) allowed the correlation with environmental variables obtained in this sector of the bay. Moreover, unlike the accidental species listed for this bay, this is considered by Werding *et al*. (2003) as an intertidal species.

Pachycheles laevidactylus was considered the dominant porcellanid of Sabellariidae reefs on Paranapuã Beach (Micheletti-Flores & Negreiros-Fransozo, 1999). On the coast of the State of Santa Catarina, Brazil, the species was recorded on ropes for mussels' cultivation, being an important contributor to the total biomass of associated decapods (Macedo *et* *al.*, 2012). In contrast, in Sepetiba Bay, this species occurs only in the external sector, an area that showed a predominance of coarse sand and high temperatures during the rainy season.

The constant presence of *P. armatus* in all sectors of Sepetiba Bay reveals the absence of ecological restrictions, which in fact was proven with its disposal in the bidimensional space of the CCA. This suggests its characterization as a cosmopolitan and eurytopic species, which allows its wide distribution in Sepetiba Bay and denotes its high ecological value. In addition, other studies have reported the euryhaline character in the larval (Carvalho *et al.*, 2013) and adult forms (Coelho, 1963, 1964), eurythermic characteristics (Stilman & Somero, 2000), and the use of different strategies by the species. Among those strategies, it is worth mentioning the escape mechanism (Wasson & Lyon, 2005) and the commensally interaction between post-planktonic stages and gastropod *Crucibulum spinosum* (Sowerby, 1824), reducing the risk of desiccation at low tides and minimizing the pressure by predation during high tides (Campos-Gonzáles & Macías-Chávez, 1987).

A positive association between filter-feeding porcellanid (*M. roseum* and *P. laevidactylus*) and chemical variables of sediment demonstrates that both species need waters with high concentration of nutrients, which are distributed in the intermediate sector of the bay, where high concentration of organic carbon was recorded, and the external sector, an area with high levels of phosphorus.

The organic carbon occurs in coastal aquatic ecosystems as part of the biomass, detritic (usually bioclastic) and in dissolved form (Pereira *et al*., 2006). Increased levels of organic carbon in the intermediate sector may be associated with a greater biomass of mollusks and echinoderms, which are the main producers of carbonates of benthic macrofauna (Brusca & Brusca, 2007). While in the internal sector the high percentage of this component organic sedimentary can be explained by the intense continental dredging, standing out the Guandu River as the main material supplier (SEMADS, 2001).

The cycling of phosphorus starts up not only through the weathering of phosphoric minerals of continental rocks, but also by anthropogenic sources such as lixiviation from cultivated soils and effluent emissions, in the form of detergents and industrial waste (Chester & Riley, 1978). Therefore, the high concentration of total phosphorus in Marambaia Island may be related to the development of mariculture, as it in this region cultivation macroalgae occurs, while in the internal sector the high concentration of phosphorus is probably associated to intensification of agricultural activities (SEMADS, 2001).

During the austral winter, cold waters derived from the Falklands currents penetrate through deep channels in the west area of Sepetiba Bay. These waters are warmed inside the bay and become superficial at the mouth of the Guandu River, bypassing the entire bay and returning by the same input channels, generating a superposition of currents (Stevenson *et al.*, 1998). Such changes produce greater quantity of particles in suspension, favoring the active filtration by the specimens (Mantelatto *et al.*, 2004). The influence of the Falklands currents and upwelling phenomena of water masses on the continental shelf (South Atlantic Central Water) shelf have been demonstrated not only of Sepetiba Bay as well as in nearby, the Grande Island Bay (Ikeda *et al*., 1989), further increasing the seasonal availability of nutrients in the study area.

Sediment texture and the amount of organic matter are determining factors in the distribution and maintenance of anomuran populations (Negreiros-Fransozo *et al.*, 1997), and organic matter can be deposited between particles of sediment or on the substrate, as a kind of mantle. Both forms are food resources available to benthic organisms including epifauna, infauna and meiofauna (Fransozo *et al.*, 1998).

The favorable environmental conditions found in Sepetiba Bay, such as sediment texture, organic matter content, water temperature and accumulated rainfall, as well as a sharp spatial heterogeneity in the intertidal zone, enabled successful colonization of at least four species (*P. armatus, P. brasiliensis, M. roseum and P. laevidactyus),* which found an appropriate environment for refuge, food and reproduction, especially in island and continental regions of the external sector of the bay. The other species porcellanid that present lowest frequency accounted for 50% of all species porcellanid collected, may be evidence of marked spatial heterogeneity at the entrance of this bay.

The number of species recorded in this study is about 35% of the total number of species recorded for the Brazilian coast, and 62% of the total richness recorded for the coast of Rio de Janeiro, supporting the hypothesis that features of substratum and the availability of food and refuges are factors limiting the establishment of this family in the region. However, studies that include capturing the subtidal zone and measurement of other environmental variables in this region may contribute to the spread of information about the distribution of Porcellanidae in Sepetiba Bay. Such information is essential once it is a region with numerous human interventions (tourism, fishing, aquaculture practice, ore maritime terminal, a harbor and a large steel company) that can cause the loss of biodiversity recorded in this study.

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