Intra-annual variation in rainfall and it's influence of the adult's *Cyprideis* spp (Ostracoda, Crustacea) on a eutrophic estuary (Guanabara Bay, Rio de Janeiro, Brazil).

L. A. Pessoa[a,b,c]* (ID), P. C. Paiva[d] (ID), R. Paranhos[e] (ID), M. A. V. Freitas[b,c] (ID) and C. A. Echeverría[a,b,c] (ID)

[a]Laboratório de Pesquisas Costeiras e Estuarinas – LABCOEST, Universidade Federal do Rio de Janeiro – UFRJ, Ilha do Fundão, Av. Pedro Calmon, CEP 21941-596, Rio de Janeiro, RJ, Brasil

[b]Instituto Virtual Internacional de Mudanças Globais – IVIG, Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia – COPPE, Universidade Federal do Rio de Janeiro – UFRJ, Ilha do Fundão, Av. Pedro Calmon, CEP 21941-596, Rio de Janeiro, RJ, Brasil

[c]Programa de Planejamento Energético e Ambiental – PPE, Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia – COPPE, Universidade Federal do Rio de Janeiro – UFRJ, Centro de Tecnologia, Ilha do Fundão, Av. Athos da Silveira Ramos, CEP 21941-909, Rio de Janeiro, RJ, Brasil

[d]Laboratório de Polychaeta, Departamento de Zoologia, Instituto de Biologia, Universidade Federal do Rio de Janeiro – UFRJ, Centro de Ciências da Saúde, Ilha do Fundão, Av. Carlos Chagas Filho, CEP 21941-590, Rio de Janeiro, RJ, Brasil

[e]Laboratório de Hidrobiologia, Departamento de Biologia Marinha, Instituto de Biologia, Universidade Federal do Rio de Janeiro – UFRJ, Centro de Ciências da Saúde, Ilha do Fundão, Av. Carlos Chagas Filho, CEP 21941-590, Rio de Janeiro, RJ, Brasil

*e-mail: leandro.amaro.pessoa@gmail.com

Abstract

Spatial and temporal distribution of two species of adult´s ostracods (*Cyprideis* sp. and *Cyprideis salebrosa*) were studied as a function of the rainfall patterns in the Guanabara Bay, Rio de Janeiro, Brazil. Samples were taken in ten stations, along six surveys representing three periods (Dry, Early and Late Rainy) for two years. Stations were nested in four areas (Outer, Central, EPA Guapimirim and Impacted). The bottom water (temperature, salinity, dissolved oxygen and oxygen saturation) were measured in each area to characterize the influence of seasonal variations by rainfall. *Cyprideis* sp. and *Cyprideis salebrosa* showed patterns distribution to seasonality/surveys (p = 0,002 and p <0,001, respectly). The spatial distribution of *Cyprideis* sp was significantly different areas studied (p <0.001) indicated well defined areas and distribution in along of the surveys. However, *C. salebrosa* showed homogeneous distribution in along of the areas within of each survey (p <0.001). Redundancy Analysis (RDA) for the two years evidenced environment preference of the *Cyprideis* sp. for areas with marine conditions (high influence for channel central) and *C. salebrosa* for brackish water (high influence of the rivers). This observation reinforces of the existence of areas created by the seasonality of pluviometric regime, a possible dispersion of the adult's ostracods and possibility the use with bioindicators.

Keywords: bioindicators, macrobenthic, climate change, sediments, soft-bottom and sublittoral.

Variação intra-annual na chuva e a sua influência nos adultos de *Cyprideis* spp (Ostracoda, Crustacea) em um estuário eutrofizado (Guanabara Bay, Rio de Janeiro, Brasil).

Resumo

A distribuição espacial e temporal de duas espécies de ostracodes adultos (*Cyprideis* sp. e *Cyprideis salebrosa*) foi estudada em função do padrão pluviométrico na Baía de Guanabara, Rio de Janeiro, Brasil. As amostras foram coletadas em dez estações ao longo de seis campanhas, representando três períodos (Seco, Pré e Pós Chuvoso) por dois anos. As estações foram agrupadas em quatro áreas (Externo, Central, EPA Guapimirim e Impactado). A água do fundo (temperatura, salinidade, oxigênio dissolvido e saturação de oxigênio) foi medida em cada área para caracterizar a influência das variações sazonais pela chuva. *Cyprideis* sp. e *Cyprideis salebrosa* mostrou distribuição de padrões para sazonalidade/campanhas (p = 0,002 e p <0,001, respctivamente). A distribuição espacial de *Cyprideis* sp. foi significativamente diferente das áreas estudadas (p <0,001) indicou áreas bem definidas e distribuição ao longo das campanhas. No entanto, *C. salebrosa* mostrou distribuição homogênea ao longo das áreas dentro de cada campanha

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(p <0,001). A Análise de Redundância (RDA) para os dois anos evidenciou a preferência ambiental dos *Cyprideis* sp. para áreas com condições marinhas (alta influência para o canal central) e *C. salebrosa* para águas salobras (alta influência dos rios). Essa observação reforça a existência de áreas criadas pela sazonalidade do regime pluviométrico, uma possível dispersão dos adultos de ostracodes e a possibilidade do uso como bioindicadores.

Palavras-chave: bioindicadores, macrobenthos, mudança climática, sedimentos, fundo não-consolidado, infralitoral.

1. Introduction

In tropical estuaries, benthic biological processes are usually strongly influenced by the characteristics of the water mass above the communities, as well as the granulometric bottom structure (Day et al., 1989; Little, 2000; Gray and Elliot, 2009). Communities parameters reflect these conditions through variations in species composition and relative dominance, due to species-specific physiological tolerance to several factors, allied to particular dispersion pattern strategies (Day et al., 1989; Gray and Elliot, 2009; Echeverría et al., 2010; Neves et al., 2013; Pereira et al., 2013; Magalhães et al., 2014). The latter are modulated, in turn, by physical and chemical factors during adult's dispersion and settlement events (Alongi, 1989; Day et al., 1989; Valiela, 1995; Echeverría et al., 2010; Pereira et al., 2013).

Climatic patterns in tropical coastal and estuarine areas are mainly characterized by the alternance of historically well defined rainy and dry periods (Amador, 1997; INMET, 2008; Knauss, 2005; Marengo et al., 2009; Amador, 2012). Freshwater runoff from rivers is one of the main natural variation factors in tropical and subtropical estuaries, implying, in certain cases, in a wide seasonality of environmental parameters (Alongi, 1989; Day et al., 1989; Mayr et al., 1989; Paranhos and Mayr, 1993; Paranhos et al., 1993; Passadore et al., 2007). Circulation in a tropical estuarine system is characterized by the presence of two main mutually-interacting water masses (Pritchard, 1955; Pritchard, 1967; Knauss, 2005; Prandle, 2009). As the tide rises, colder, saltier, and consequently denser seawater penetrates below the warmer, fresher, less dense, estuarine water. The level of mixing is used to define the model of local circulation (Pritchard, 1955; Pritchard, 1967; Knauss, 2005; Prandle, 2009). Thus, the extent of seawater influence throughout the estuary is river-runoff dependent, especially in a microtidal environment, as Guanabara Bay, Rio de Janeiro, Brazil (Mayr et al., 1989; Amador, 1997; Kjerfve et al., 1997; Amador, 2012). When the river-runoff is reduced, as in the dry season (lower rainfall), seawater influence extends throughout the entire estuarine body (Mayr et al., 1989; Paranhos and Mayr, 1993; Paranhos et al., 1993; Amador, 1997; Kjerfve et al., 1997; Amador, 2012). On the contrary, in the wet season (higher rainfall), the higher river-runoff influences the entrance of marine water, thus limiting the extension of the salt wedge (Mayr et al., 1989; Paranhos and Mayr, 1993; Paranhos et al., 1993; Kjerfve et al., 1997). This balance between marine input, regulated by river-runoff, and tide amplitude, results in a characteristic seasonal variation in Guanabara Bay, which presents an extremely wide watershed (Mayr et al., 1989; Amador, 1997; Kjerfve et al., 1997; Amador, 2012).

An increase in runoff in tropical bays enhances the input of sediment, organic matter, heavy metals, organochlorates, and other anthropically originated residuals, thereby increasing the bottom bacterial activity (Paranhos et al., 1998; Crapez et al., 2000; Carreira et al., 2001; Paranhos et al., 2001; Baptista Neto et al., 2005). Several rivers are polluted around the Guanabara Bay, manly because of populous regions which discharge high amounts of organic matter. Approximately 55 rivers discharge in the Guanabara Bay, some of them are highly polluted (Amador, 1997; Kjerfve et al., 1997; Paranhos et al., 1998; Crapez et al., 2000; Carreira et al., 2001; Paranhos et al., 2001; Baptista Neto et al., 2005; Brito et al., 2006; Amador, 2012).

During the process of carbonic chains (organic matter, petroleum residuals and others) are degraded, inducing the consumption of dissolved oxygen, both from the sediment and the water column, resulting in an increase in substrata acidity and a reduction in dissolved oxygen (Paranhos et al., 1998; Little, 2000; Paranhos et al., 2001; Mendonça Filho et al., 2003; Gray and Elliot, 2009). These disturbances generate changes in the benthic community structure. These ecological conditions are observed in ecosystems that are recovering from a disturbance followed richness and diversity decrease, appearance of opportunistic species, and others (Rakocinski et al., 1997; Brown et al., 2000; Rosenberg, 2001; Bergin et al., 2006; Gray and Elliot, 2009; Echeverría et al., 2010; Pereira et al., 2013).

Ostracods are small crustaceans with a bivalved carapace that when accumulated in the sediment may be relatively transparent, translucent or opaque. Their size ranges from 0.2 to 2.0 mm (Brandão et al., 2018). They are important in the environmental assessment because they are particularly immobile in the sediment, not being able to distance itself actively from local impacts (Mezquita et al., 1999; Vilela et al., 2013). Thus, the analysis of the composition, distribution and diversity of the ostracod fauna allows its use as indicators of environmental impact and system recovery (Schratzberger et al., 2003; Vilela et al., 2013; Keats and Osher, 2007). They colonize a wide range of aquatic environments (Frenzel and Boomer, 2005), most of the species are benthic and many occur in calm water environments where the clay or fine bottom sand is rich in organic matter (Van Morkhoven, 1962; Armonies and Hellwig, 1986; Brown et al., 2000). However, the granulometric variable as lower natural change over time, and bottom water variable is altered at each cycle tidal, runoff, wind, and others (Day et al., 1989; Gray and

Elliot, 2009). The most frequent habitat of several recent ostracods is the water-sediment interface or immediately below, being thus vulnerable to the direct influence of the parameters of both the bottom water and the sediment (Carbonel, 1988).

Ostracods are also used as bioindicators of salinity, temperature, dissolved oxygen, organic matter and metal concentration and others (Ruiz et al., 1997; Modig and Ólafsson, 1998; Curry, 1999; Vilela et al., 2003; Ruiz et al., 2004; Frenzel and Boomer, 2005; Nagorskaya and Heyser, 2005; Bergin et al., 2006; Ruiz et al., 2006). *Cyprideis* spp. has been tested as indicators of environmental parameters, and their physiology is sufficiently understood to allow their use in monitoring programs (Curry, 1999; Debenay et al., 2003; Frenzel and Boomer, 2005; Vilela et al., 2003).

Knowledge about the spatial and temporal distribution of species *Cyprideis* spp. may provide subsidies to evaluate assessment and monitoring environmental alterations related to sediments, such as dredging, sediment discharge and others. These environmental conditions exert an influence on benthic communities, by creating a mosaic with different dynamics, according to their relative position within the bay (Ghiselli Junior et al., 2003; Vilela et al., 2003; Ghiselli Junior, 2006; Echeverría et al., 2010; Pereira et al., 2013). The *Cyprideis* spp in the Guanabara Bay are abundants live in and above the sediments and possibly respond to seasonal variations (Sola and Paiva, 2001; Ghiselli Junior et al., 2003; Vilela et al., 2003; Ghiselli Junior, 2006).

The main objectives are to characterize the spatial distribution of the two dominant recent adult's ostracods species (*Cyprideis salebrosa* and *Cyprideis* sp.) from the soft-bottom sublittoral and to study the relationship of these species with bottom water parameters and rainfall in an estuarine system the Guanabara Bay along two years.

2. Materials and Methods

2.1. Study area

Guanabara Bay, located in the State of Rio de Janeiro between 22°40` and 23°00` South and 43°00` and 43°20` West, comprises 377 km², excluding the islands (Figure 1, Amador, 1997). According to circulation-model criteria, the bay is classified as a predominantly saline-water estuarine system with semi-diurnal tides (Amador, 1997). Several authors (Mayr et al., 1989; Paranhos and Mayr, 1993; Paranhos et al., 1993; Valentin et al., 1999) observed that the prevailing seasonal pattern of abiotic parameters consists of a reduction in temperature and increase in salinity from May to September (Dry season), and the reverse from October to April (Rainy season). The grain-size pattern varies spatially, with a predominance of silt and clay and high organic content in the inner bay, with gradual changes towards the entrance, where there is a concentration of coarse sand and low organic matter content (Quaresma et al., 2000).
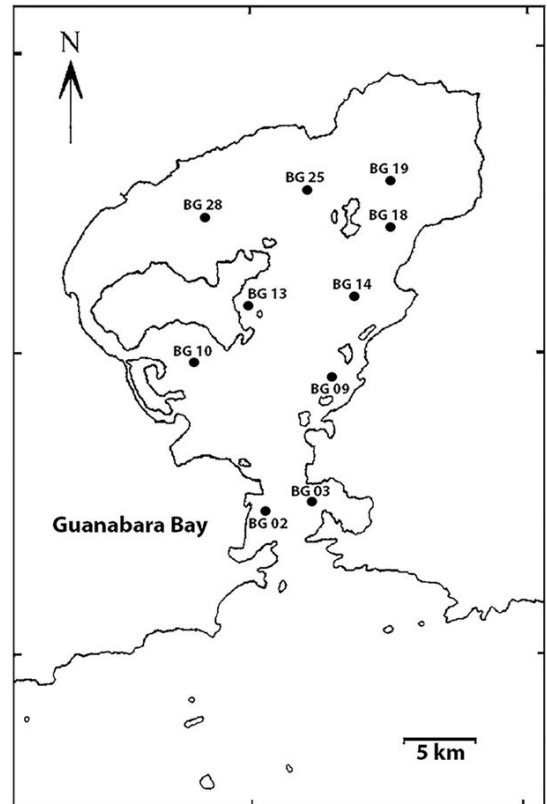

Figure 1. Study area and stations selected for sampling in the Guanabara Bay.

2.2. Sampling

Samples were taken during a two-year period from 2005 to 2007, in six periods planned according to historical rainfall records (1961-1990 Climatologic Normal), and using data supplied by the National Institute of Meteorology (INMET – Figure 2). In Rio de Janeiro, there is a marked seasonality in rainfall, characterized by a rainy season in the summer and a dry in the winter (Figure 2). Thus, periods were defined comprehending three periods over two years: (D) Dry, (ER) Early Rainy and (LR) Late Rainy seasons, in order to assess the effect of cumulative rainfall on benthic communities (Figure 2). Ten sampling stations were defined and nested in areas according to similar environmental conditions along the estuarine system (Mayr et al., 1989; Paranhos et al., 1993). Thus, the four areas are: Outer (BG 02 and BG 03); Central (BG 09, BG 13 and BG 14); EPA Guapimirim (Enviromental Protected Area Guapimirim / BG 18 and BG 19) and Impacted (BG 10, BG 25 and BG 28 – Figure 1). These areas were chosen according to their previously described environmental characteristics along the estuarine systems, such as: Depth, granulometry, circulation and water physical-chemical (Meniconi et al., 2012a; Mayr et al., 1989; Paranhos et al., 1993; Amador, 1997; Valentin et al., 1999; Amador, 2012).

Benthic samples were taken using a Gravity corer (0.0078 m² for sample). Ten samples were taken at each
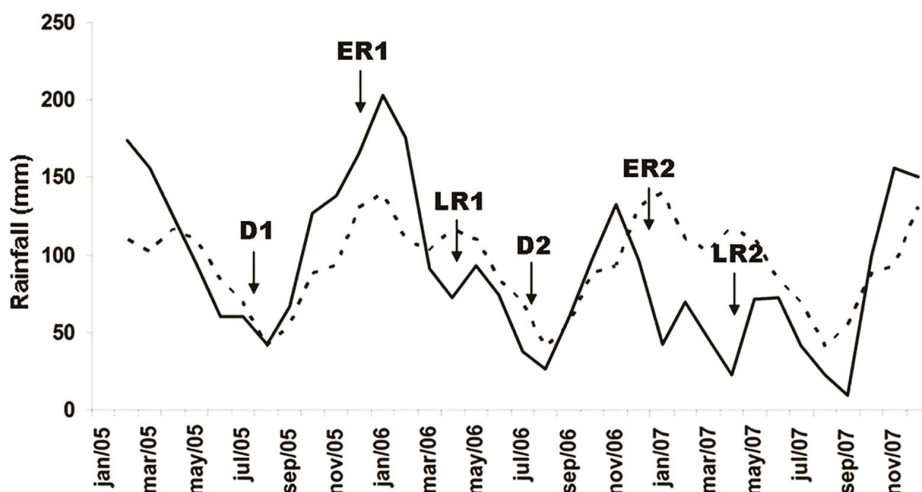
Figure 2. Climatological normal (1961-1990) in Rio de Janeiro region (dashed line) and the mean monthly accumulated rainfall (continuous line) during the study period (2005, 2006 and 2007). The samplings occurred in dry (D1: July 2005; D2: July 2006), early rainy (ER1: December 2005; December 2006) and late rainy (LR1: April 2006; LR2: April 2007) seasons. Data modified from INMET (2008). Source: inmet.gov.br/html/observacoes.php

station for six surveys (total numbers of samples, n = 600), geo-referenced throughout the bay and distributed from the entrance to the inner part of the bay (Figure 1). Stations were selected in according to batimetric (between four and seven meters depth). Such a narrow bathymetric range was chosen to facilitate the comparison of biological communities throughout a gradient of physical variables not linked to depth. The inner (EPA Guapimirim and Impacted stations) and Central (with exception of BG 09) stations were composed of fine sediments (silt-clay) (Quaresma et al., 2000), where the sampler performance was effective. At Outer stations BG 02 and BG 03 (sand), as well as BG 09 (very fine sand-clay), sampling was undertaken by skin-diving, due to the low efficiency of the Gravity corer in sandy sediments. Nonetheless, direct comparison of data was possible, as the corer used in skin-diving sampling was the same as that used in the Gravity corer.

The bottom water samples were collected twice a month at all stations, the temperature was measured with a graduate thermometer. Salinity and dissolved oxygen were determined, respectively, by chlorinity and Winkler methods. Water chemistry variables were determined in triplicate using standard oceanographic methods (Grassholf et al., 1999; Parsons et al., 1984). Temperature and salinity were measured during sampling using a Multi Probe System YSI 556 (YSI Incorporated, USA). Salinity was also determined by titration of chlorine against standard seawater (Ocean Scientific International Ltd. - OSIL). Dissolved oxygen was determined by Winkler titration. Twice weekly samples of background water were retrieved at the stations of original collection. All georeferenced data, together with the results from other projects, are available in the database of the Guanabara Bay Environmental Assessment Program (Meniconi et al., 2012b).

The samples were washed in 500 µm mesh-size sieves, and the material retained fixed in 70% alcohol. The material was sorted and identified in the laboratory using stereoscopic microscope. Since 500 µm mesh was used, the criteria for defining macrobenthic population patterns (recent adult's ostracods), here observed, represent the late stages in development or last instars of the ostracods adults (Howe et al., 1961; Kesling, 1961). Even though most ostracods meiofaunal-sized (including the estuarine ones), the focus of the present study are two species of *Cyprideis* with adult size larger than 500 µm. in Guanabara Bay, it is common to located specimens with a sufficient size to fit into the macrobenthic category (Sola and Paiva, 2001; Ghiselli Junior et al., 2003; Vilela et al., 2003; Ghiselli Junior, 2006).

2.3. Data analysis

Bottom water analysis was undertaken after gathering abiotic data (temperature, salinity, dissolved oxygen and oxygen saturation) from the stations within each of the areas of the bay, namely in this paper as: Outer, Central, EPA Guapimirim and Impacted. Temporal analysis of bottom water was in accordance with seasonal rainfall dynamics, as observed on past years, according climatologic normal (Inter-annual variation - Figure 2) and following the same sampling design as the macrobenthos. Bottom-water data were grouped in time, taking into consideration the four months immediately preceding each macrobenthic sampling season: (D) Dry; (ER) Early Rainy and (LR) Late Rainy season.

Ostracod densities were log transformed (log (x+1)), in order to improve variance homogeneity before data analysis. A Partly-Nested ANOVA (analogous to a split-plot design) was undertaken, with the fixed variables Areas and

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Surveys crossed, and the variable 'Stations' nested within Areas and crossed with Surveys (Quinn and Keough, 2003).

Redundancy Analysis (RDA) was used for the interpretation of the interactions of environmental variables (the code is represented for letter (Survey – I, II, III, IV, V and VI) and number (Station), for example V19 is the variable Survey five and Station nineteen) with the two species (*Cyprideis* sp. and *Cyprideis salebrosa*) in all surveys (Borcard et al., 2011). BG 02 and BG 03 stations were excluded, in order to reduce the analysis noise since no *Cyprideis* individuals of both species were found.

The analyzes (Nested ANOVA and Redundancy Analysis) were perfomed using R statistical environment (R Development Core Team, 2008).

3. Results

A seasonal pattern was apparent in bottom water variables, within the typical, characteristic circulation pattern of tropical and subtropical estuaries. The highest salinity, dissolved oxygen and oxygen saturation were always in the outer bay, during dry periods, and with relatively low temporal variation (Figure 3). The lowest salinity was always observed in the inner areas during early rainy season (ER1 and ER2), whereas higher temperatures and lower levels of both dissolved oxygen and oxygen saturation occurred in late rainy season (LR1 and LR2) (Figure 3). A clear spatial gradient was apparent on bottom

water characteristics with salinity constantly decreasing and seasonal variation increasing towards the entrance (Outer) to the inner bay (Impacted), where the lower and temporally variable salinities are indicators of the seasonal inflow of river water inside the bay itself (Figure 3).

Cyprideis was absent in stations BG 02 and BG 03, located near the entrance of the bay. These stations differed from the remaining, regarding to sediment composition (mainly sand – Quaresma et al., 2000). In all other stations (BG 09, BG 10, BG 13, BG 14, BG 18, BG 19, BG 25 and BG 28), *Cyprideis* species were observed in at least one season because of the presence of fine sediments with high organic matter concentration (Quaresma et al., 2000 - Figure 4).

Population densities of the two species were higher in LR1 (Late Rainy season - April/2006). with both species occurring at all the stations, with the exception of BG 02 and BG 03 (Figure 4). The highest mean densities in this study were observed at stations BG 09 for *Cyprideis* sp. (7,359 ind.m^{-2}), and BG 19 for *C. salebrosa* (1,064 ind.m^{-2}), both in LR1 (Figure 4). The lowest mean density for *Cyprideis* sp. was 38 ind.m^{-2} in BG 25 and for *C. salebrosa* 70 ind.m^{-2} in BG 09, also in LR1. Both species occurred together in all the seasons in stations BG 09, BG 13 and BG 14 only (Figure 4).

The distribution of *Cyprideis* sp. and *Cyprideis salebrosa* showed relationship to the seasonality/surveys (p = 0,002 and p <0,001, respectively). *Cyprideis* sp was significant in the
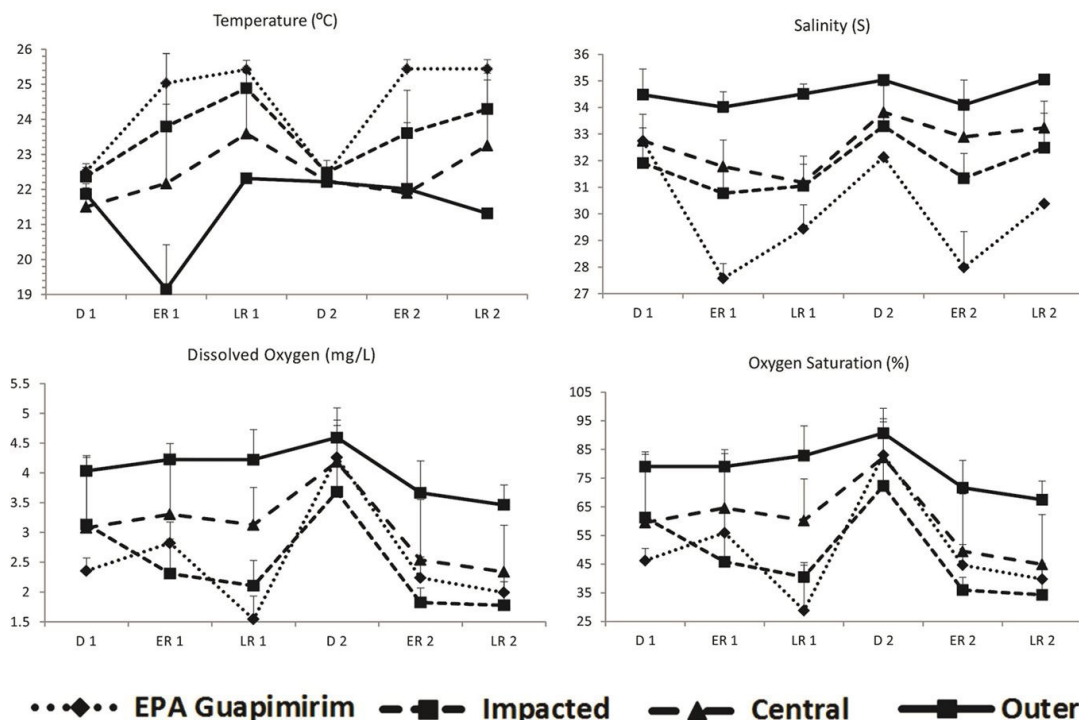

Figure 3. Abiotic bottom water data from all the seasons (D – Dry season, ER – Early Rainy season and LR – Late Rainy season) in the four sectors of the Guanabara Bay (EPA Guapimirim - BG 18 and BG 19; Impacted - BG 10, BG 25 and BG 28; Central - BG 09, BG 13 and BG 14; Outer - BG 02 and BG 03).

spatial distribution areas (p <0.001) indicated well defined areas and distribution in along of the surveys. However, *C. salebrosa* showed homogeneous distribution among the areas within of each survey (p <0.001). The density of *Cyprideis* sp. presented spatial variation only among Stations and among Surveys, there were no interactions between Areas and Surveys or Stations and Surveys, indicating a homogenous pattern between different areas of the bay (Table 1).

Nevertheless, as regards *C. salebrosa*, significant seasonal variation among Surveys was observed being this variation different among Areas but not among Stations. This indicates that sampling stations within each area (Area) of the bay were homogeneous as regards *C. salebrosa*

densities and that there is a seasonal variation among the different regions of the bay (Table 2).

This variation was due to the decrease in density at the early wet season (summer) in the inner areas of the bay, being the decrease stronger in the Impacted area and less intense in the EPA Guapimirim.

The redundancy Analysis for the two years (2005-2007/Figure 5) showed that both species (*Cyprideis salebrosa* and *Cyprideis* sp.) show different environmental preferences of the *Cyprideis* sp. Is directly related to both higher salinity and dissolved oxygen, which are prevalent in the Central sector. Conversely, *Cyprideis salebrosa* showed a higher dominance in the inner stations (BG 18, BG 19, BG 25 e BG 28) of the Guanabara Bay, which
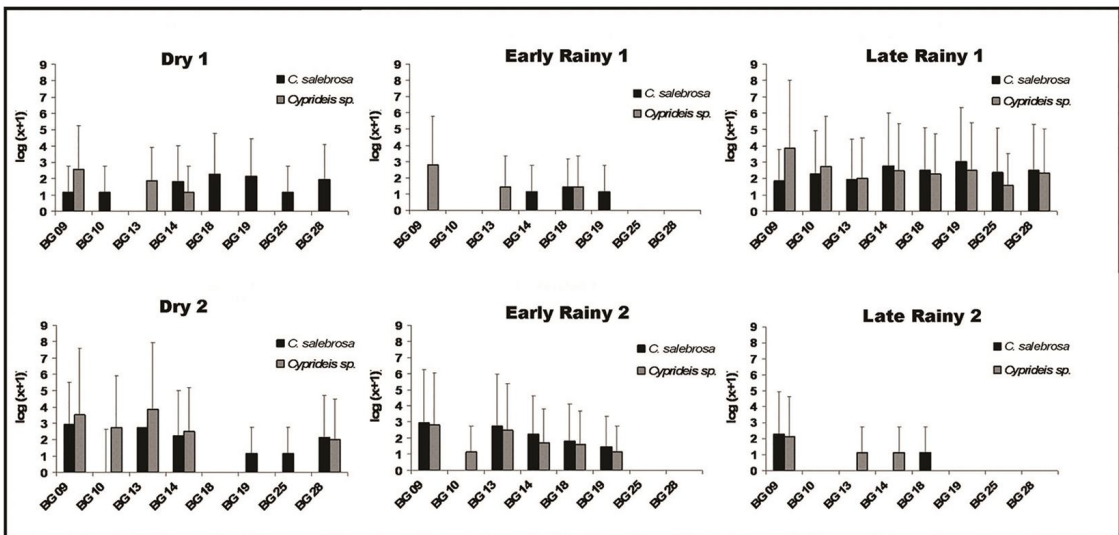

Figure 4. Mean density normalized (log (x + 1)) and standard deviation of *Cyprideis* sp. and *Cyprideis salebrosa* in each station along the seasons (n=600).

Table 1. Results of the Partly-Nested Analysis of Variance in *Cyprideis* sp. density (p <0.05 significant values in bold-type).

SOURCE	S.S.	D.F.	M.S.	F-RATIO	P
Survey	21.180	5	4.236	5.153	**0.002**
Group	22.278	2	11.389	3.846	0.097
Survey x Group	7.541	10	0.754	0.917	0.533
Station (Group)	14.803	5	2.961	4.802	**<0.001**
Survey x Station (Group)	20.556	25	0.822	1.333	0.132
Error	266.349	432	0.617		

Table 2. Results of the Partly Nested Analysis of Variance in *C. salebrosa* density. (p <0.05 significant values in bold type).

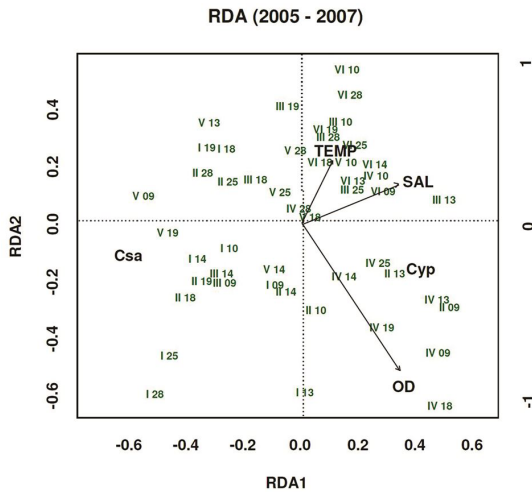| SOURCE	S.S.	D.F.	M.S.	F-RATIO	P
Survey	14.808	5	2.962	13.106	**<0.001**
Group	2.220	2	1.110	2.106	0.217
Survey x Group	15.134	10	1.513	6.694	**<0.001**
Station (Group)	2.633	5	0.527	1.360	0.238
Survey x Station (Group)	5.643	25	0.226	0.583	0.938
Error	167.267	432	0.387		

Figure 5. Redundancy Analysis (RDA) in all seasons (2005-2007). Species: Csa (*Cyprideis salebrosa*) and Cyp (*Cyprideis* sp.) and abiotic bottom water: SAL (salinity), TEMP (temperature) and OD (dissolved oxygen).

are associated to lower salinity and frequent events of anoxia/hypoxia.

These atypical rainfalls because the second year was a low pluviosity promoted a change in the biotic structure and allowed a wider distribution of *Cyprideis* sp. (marine conditions) for the Central, EPA Guapimirim and Impacted sector owing to the more widespread adequate environmental conditions for this species.

4. Discussion

In the inner part of the bay, the seasonal patterns of bottom water salinity and temperature variation clearly demonstrated the seasonal influence of river-input, mainly during the wet season. The highest salinities, associated to lower temperatures and relatively high concentration of dissolved oxygen, occurred during the dry season. This was inversely observed during the wet season of this following year (Figures 2 and 3). This pattern could be observed mainly in the areas Impacted and EPA Guapimirim. In the Central area, the pattern implied a mixture of external (marine) waters with internal estuarine waters, as well as poorly defined seasonal variation were observed. In the Outer area, the typical marine pattern was constant (Figures 2 and 3).

The high occurrence of *C. salebrosa* mainly in stations located near EPA Guapimirim (BG 14, BG 18 and BG 19), where the river runoff is expressive during rainy periods, implies that this species is tolerant to variations in salinity, as well as several abiotic factors modulated by river runoff, such as temperature, dissolved oxygen, nutrients, organic matter, fine sediment, and anthropic and industrial pollution, a result of washout from the metropolitan areas (Meniconi et al., 2012a, b; Figures 4 and 5).

Cyprideis sp. occurred mainly in stations BG 13 and BG 14 (Figures 4 and 5), classified herein as Central,

due to their location and hydrological characteristics (Figures 1 and 3). Nevertheless, the densities of both species were also high in station BG 09 (Figure 4), which differed from the remainder by the significant fraction of fine sand and clay in the bottom (Quaresma et al., 2000). During flood tides, there is the strong influence of nearness to the central channel to be considered, whereas during the ebb, there is an increase in riverine organic matter (Rosenberg, 2001). As an example, during LR1 (April 2006), high densities of both species were recorded in all stations, probably due to the increase in organic matter deposition and river-originated nutrients, caused by the preceding rainy months (Meteorology National Institute – INMET / Figure 2). However, when compared to LR2 (April 2007), when a repetition of the same population pattern would be expected, significant differences were found. A possible explanation could be the unusually low rainfall observed during the preceding months, thus altering the physical and chemical characteristics of the bay, when compared to the seasonal pattern observed during the first year of the study (Meniconi et al., 2012a, b).

Through temporal analysis, *Cyprideis* sp. presented a similar seasonal variation throughout the entire area. This species preferentially occurs in areas under marine influence (Benson, 1959; Benson, 1961; Anadón et al., 2002; Boomer and Eisenhauer, 2002). Could be still further modulated by the widespread influence of the salt wedge, enhanced by the presence of the extensive central channel until end of the bay (Mezquita et al., 1999; Debenay et al., 2003; Nagorskaya and Heyser, 2005, Figures 3, 4, 5 and Table 1).

However, our analyses suggest that the abundance of *C. salebrosa* varies seasonally in along the bay (Figures 3, 4, 5 and Table 2). Probably the outcome of the variable influence of river-runoff in the inner areas, the mixture with marine waters in the Central, and the influence of seawater in tidal events (Carbonel, 1988; Curry 1999; Passadore et al., 2007). Lower densities in the internal areas could be associated to high anthropic impacts, caused by domestic and industrial sewage discharge, associated to restricted circulation in the Impacted area (Mayr et al., 1989; Paranhos et al., 1998; Modig and Ólafsson, 1998; Carreira et al., 2001; Paranhos et al., 2001; Machado et al., 2002; Mendonça Filho et al., 2003). On the other hand, in EPA Guapimirim, an Environmental Protection Area, impacts can be considered less intense, in spite of the constant runoff of several nearby rivers and the high concentrations of organic matter (Carreira et al., 2001). Patterns in the Central area were more complex, as this comprised stations under the influence of changing water conditions, with pronounced marine influence modulated by tidal cycles and winds, leading to intense variations in salt wedge extent (Paranhos et al., 1993; Paranhos and Mayr, 1993).

Ghiselli Junior et al. (2003) and Ghiselli Junior (2006) studied meiofaunal ostracods in Guanabara Bay and noted that dry periods are characterized by low ostracod densities associated to a possible decrease in size. This is in accordance to observations of macrobenthic ostracods,

since, although densities increased throughout the rainy season, these were comparatively lower in the beginning of the dry period of the second year. Vilela et al. (2003) studied ostracods in the Guanabara Bay and reported high densities of *C. salebrosa* and *Cyprideis* sp. in more than 90% of the studied meiofaunal samples and proposed a possible tolerance of these species to pollution levels in the bay. Sola and Paiva (2001). Analyzed sublittoral macrobenthic densities along the year and observed no clear pattern of temporal variation for *Cyprideis* in the external area of the bay, even under conditions of exceptionally high waves (storm-surges). Van Der Ven et al. (2006) recorded unidentified ostracods in samples sieved through a 1 mm mesh, which is larger than the usual one (500 µm) for macrobenthos. The marked seasonality, linked to the pluviometric period, suggests the existence of areas or zones inside the Guanabara Bay (Mayr et al., 1989; Paranhos et al., 1993; Paranhos and Mayr, 1993; Wandeness et al., 1997). This condition can be identified through the diverse bottom water dynamics, thus in accordance with established models of circulation observed in other tropical and subtropical estuaries (Amador, 1997; Kjerfve et al., 1997; Miranda et al., 2005). Density patterns of both studied species were different pluviometric periods. Seasonal variation in *Cyprideis* sp. was coherent throughout their entire spatial distribution. However, in *C. salebrosa*, it was possible to identify three different patterns of seasonal distribution, each linked to their relative location inside the bay. These differences can be attributed to the higher tolerance of *Cyprideis* sp. to marine environments, in comparison to *C. salebrosa*, which prefer brackish water, typical of inner estuarine areas (Anádon et al., 2002; Boomer and Eisenhauer, 2002; Ghiselli Junior et al., 2003; Vilela et al., 2003; Ruiz et al., 2005; Ghiselli Junior, 2006).

The results suggests a species-specific dynamic seasonal colonization/defaunation pattern on a spatial gradient along the bay (Echeverría et al., 2010; Pereira et al., 2013). Species recolonize seasonally available areas from areas were favorable conditions are more stable along the year and retreats back in a seasonal climate-induced pattern (Day et al., 1989; Gray and Elliot, 2009). Climatic changes may compromise these recolonization patterns and lead to a diminished recolonization capacity, if conditions remain unfavorable for longer periods (Frenzel and Boomer, 2005). These patterns also affects the exportation of propagules and recruits to other suitable points along the coastline (Gray and Elliot, 2009). These observed patterns may not be exclusive of ostracods and conclusions can probably be extended to other species with similar life cycles. The knowledge of the benthic communities dynamics in impacted coastal and estuarine ecosystems, associated to abiotics parameters is very important in the assessment or interpretation of natural or anthropic changes in coastal and estuarine ecosystems. It support the hypothesis of the seasonal dynamics in adult's *Cyprideis* populations seems to be a prerequisite for using this area in environmental monitoring studies, in which specific seasonal characteristics can lead to use as bioindicators on coastal and estuarine ecosystem.

In summary, the findings of the present study demonstrated that the seasonality of the rainfall regime clearly defines the dry and rainy periods and influence the macrobenthos. Different species show different distribution patterns, as observed for the distribution of *Cyprideis salebrosa* is different season throughout the bay, which is caused by the influence of the watershed contribution of the internal areas and the mixture with the tidal flow of the central channel. However, *Cyprideis* sp. distribution is seasonally and spatial homogen. Differences in densities and relationships to abiotic variables suggests that *Cyprideis* sp. presents a higher preference to marine conditions, while *Cyprideis salebrosa* prefers brackish environments, typical of estuaries (Figure 5, Table 1 and 2). This observation suggests the existence of distinct regimes within the Guanabara Bay caused by the seasonality of the pluviometric regime which influence the abiotic variables of the bottom water and sediment. Therefore, the knowledge of the seasonal dynamics of adult's *Cyprideis* spp. populations is fundamental for environmental monitoring, since the specific seasonal characteristics of the group can lead to misinterpretations when used as bioindicators.

Acknowledgements

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