Patterns of Species Richness and Species Density of Sublittoral Soft-bottom Polychaetes in a Grossly Polluted Urban Bay: Guanabara Bay, Rio de Janeiro, Brazil

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ABSTRACT


The Guanabara Bay measures 384 Km² and a large portion of the largely untreated domestic sewage from at least 7.81 million people eventually ends up in its waters. About 12000 industries are located on its drainage basin. The ongoing pressure upon the Bay requires an updated knowledge of its ecosystems structure and function. Patterns of species richness and species densities for the polychaete taxocenosis in the Bay were assessed through a sampling design consisting of 38 stations performed during the dry (September, 2000) and the rainy seasons (May, 2001). Surface and bottom water characteristics were recorded for each sampling site. Sediment was obtained in triplicate with a 0,1m³ Van-Veen grab and analyzed by its sedimentological features such as: grain size, organic matter content, carbonates, and redox potential. Independent of the season studied, the sediment becomes more anoxic while the organic matter content greatly increases towards the inner parts of the Bay. The BIOENV-test revealed that the organic matter content, sorting coefficient, dissolved oxygen concentration, and redox potential characterized a number of sample stations sharing similar hydrodynamic environments. The samples yielded 72 species of polychaetes totaling 9021 individuals. The species richness proved to diminish dramatically towards the inner parts of the Bay. The higher species richness in the outer parts of the Bay could be related to better environmental conditions and its more hydrodynamic environment. Three species of polychaetes accounted for 79,93% of the total species density. Densities were generally much higher nearby the wastewater flow.

ADDITIONAL INDEX WORDS: Domestic sewage, coastal management, environmental impact.

INTRODUCTION

The Guanabara Bay is the most distinguished Brazilian bay. Its drainage basin is located in the Rio de Janeiro state between latitudes 22º24’S and 22º57’S; and the meridians 042º33’W and 074º19’W. In spite of its historical, economic, cultural, and scientific importance, the bay is among one of the greatest impacted coastal environments in the country. Just before European colonization the scenario was totally different. The Atlantic Forest covered around 73,91% of the surface of Guanabara Bay's drainage basin. Mangroves extended for 257 km² of bay margins. There were about 118 beaches. The sandbanks, marine terraces and dunes reached almost 132 km of bay margins. There were about 118 beaches. The sandbanks, marine terraces and dunes reached almost 132 km of bay surface.

Five centuries later, more than 11 million people inhabit its margins and surroundings areas. The degradation process assumed a drastic scale in the last decades caused by urban-industrial development. Nowadays, the bay shows an eminently urban profile. The sewage treatment stations process only 15% of the total effluents. As a consequence, the domestic rejects of approximately 7,8 million people ends up in its waters. The organic domestic pollution is considered to be the worst environmental problem of the bay. There are about 6000 industries around it and another 6000 in its drainage basin. Two petroleum refineries, a big fish improvement industry, and a landfill can be found around the bay. The central channel must be constantly dredged because of the intense ship traffic. The increasing contribution of the solid suspension material caused the loss of around 10% of Guanabara Bay water mirror. The ongoing pressure upon the bay requires an updated knowledge of its ecosystems structure and function.

One of the main objectives of the bioenvironmenral programs is to access changes induced by anthropogenic effects (POCKLINGTON and WELLS, 1992). The reason why the soft-bottom marine macrofauna is preferably used to assess environmental impacts could be explained by its low capacity of escape from unfavorable conditions as many species are sessile or sedentary. This species covers a wide range of nutritive and reproductive habits being easily affected by contamination and other disturbs (GRAY, 2002).

Polychaetes are among the most representative animals in soft-bottom environments. In detriment of its locomotion habit, sedentary or little mobile, these organisms are vastly used in the interpretation of the spatial-temporal patterns induced by anthropogenic or natural influences. However, a brief examination of scientific literature reveals a gap in the soft-bottom macrofauna patterns of the Guanabara Bay. In order to evaluate the influence of the environmental factors on sublittoral soft-bottom polychaetes, patterns of species richness and species densities were analyzed.

METHODS

Two oceanographic cruises were undertaken, one just after the dry period (September of 2000) and another just after the rainy period (May of 2001) of the austral hemisphere. The sample net was composed of 38 random sample sites (Figure 1). The bay was divided into three sectors following the oceanographic and hydrological features determined by the Japan International Cooperation Agency - JICA (1994), AMADOR (1997) and KJERFVE et al. (1997). The stations that composed these sectors were: inner sector: 1 to 11; intermediate sector: 12 to 26; and outer sector: 27 to 38. These works pointed out that the hydrodynamic sheltered areas were mainly found at the inner sector although some of them can be found at intermediate and outer sectors.
Surface and bottom water quality variables such as temperature, pH, salinity, and dissolved oxygen concentration were measured at all stations. It was used an Van Dorn bottle to collect water samples and a Secchi disc to access the water transparency.

Three replicate benthic grab samples were collected from each sample site with a 0.1m Van-Veen grab. Small sediment subsamples were collected from the grab for organic content and granulometric analysis. Sediment grain size was analyzed using the methodology proposed by Sugio (1973). Six size classes were used in this study: silt-clay (< 63m), very fine sand (63 to 125 m), fine sand (125 to 250 m), medium sand (250 to 500 m), coarse sand (500 to 750 m), and very coarse sand (750 to 1,000 m). Organic content of the dry sediment was estimated as the loss of weight after ashing. Carbonate rates were calculated by weighing a fraction of the sediment before and after it was attacked with chloridic acid (SUGUIO, 1973). The redox potential profile of freshly collected sediment samples was measured in situ with a simple platinum electrode, model 6 A05/AG, Analyser.

Samples were washed on a 1 mm screen and organisms were transferred to labeled plastic bags containing 10% buffered formalin. The polychaetes were classified to the lowest possible taxonomic level. Species richness was considered as the total number of species presented in each sample site. This parameter considered species as the organisms identified to binomial composition and the genus defined with “sp.” designation. The samples yielded 72 species of polychaetes totaling 9021 individuals. The species richness proved to diminish dramatically towards the protected areas of the bay (Figure 3). There isn’t an expressive temporal variation of species richness between dry and rainy season. While the dry season accounted for 93% (67) of the species richness, the rainy season held 87.5% (63) of the species encountered in the bay. On the other hand, there is a high spatial variation as the outer part of the bay have approximately 7 times more species than the inner sector. The Pearson’s linear correlation showed a positive correlation of the greatest richness with depth, high oxygen concentrations, oxidized sediment, fine and medium sand and redox potential (Table 1).

Following the environmental gradients, species richness proved to diminish towards the hydrodynamic protected areas of the bay. Stations located in the outer sector of the bay presented species richness values much higher than the inner sector that revealed about 31% of azoic stations, all of them located in low hydrodynamic sites, as follows: stations 2 to 8, 10 to 12, 31, and 32 in the dry season; and stations 1 to 6, 10 to 13 and 16 in the rainy season.

Opposite from the species richness patterns, an important difference was observed between the patterns of the species density among the two studied seasons. The total average density obtained in both seasons was 30,070 ind/m³, but in the dry season the density reached 11,660 ind/m³ and in the rainy season was 18,410 ind/m³.

Three species alone accounted for 79.93% of the total densities. These species were Pocillochaetus australis Nonato, 1963, Spiochaetopterus nonatoi Bhaud & Petti, 2001 and Prionospio heterobranchia Moore, 1907. The highest values of species densities were observed in the intermediate sector located at stations 22 and 24 in both studied periods, but even higher in the rainy season (Figure 4). These sites are nearby the wastewater flow of one of the biggest and most polluted urban river channels of Guanabara Bay (Mangue Channel, station 22) and the other is close to a big fish improvements industry installed at the Niterói city margins (station 24). Only one species was representative in this situation. P. australis reached the highest values of densities of all the other sites just at these stations (22 and 24), in both seasons. The density of this species Bay as it was shown by the cluster analysis in both seasons studied (Figure 2). The organic matter content, silt-clay content, sorting coefficient, redox potential and oxygen level concentration were the main factors that can explain environmental similarities among stations.

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Figure 1. Guanabara Bay. Study area showing the 38 sample stations.

RESULTS

There is an increasing gradient of organic matter content and anoxic condition of the sediment towards the inner parts of the

Figure 2. Cluster analysis of the environmental parameters between the (a) dry period and (b) the rainy period. y-axis: euclidean distance.
followed the patterns for all the bay, with high numbers of organisms found in the rainy season. While in the dry season were collected 1,983 ind/m² (station 22) and 1,937 ind/m² (station 24) of P. australis, in the rainy season the density of this species reached 4,427 ind/m² (station 22) and 3,120 ind/m² (station 24). The same pattern was noted for S. nonatoi that dominated at middle to inner parts of the bay where finer and anoxic sediments were found in the rainy season. It was observed a substitution of Prionospio heterobranchia high densities by S. nonatoi densities between the two seasons. At rainy season S. nonatoi presented densities 220% higher than in the dry season. In the meantime, Prionospio heterobranchia that reached the highest density in four stations (9, 20, 25 and 33) in the dry season did not reach this level in any of the stations in the rainy season.

The lowest densities occurred in sites of the bay with restricted current circulation. In some of these stations null values were observed in species densities. On the other hand, in the three more exposed stations (36, 37 and 38) of the outer sector, low species densities were found but different species predominated in each of these stations. Those stations seem to be more dynamic than the other areas.

The stations located nearby the wastewater urban flow presented low species richness and species density limited to a few species.

Table 1. Pearson’s linear correlation between the species richness and environmental variables in the dry and rainy season. Remarks values 5% significant.

<table>
<thead>
<tr>
<th>Environmental variables</th>
<th>Dry Season</th>
<th>Rainy Season</th>
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</thead>
<tbody>
<tr>
<td>Depth</td>
<td>0.65</td>
<td>0.42</td>
</tr>
<tr>
<td>O₂</td>
<td>0.70</td>
<td>0.45</td>
</tr>
<tr>
<td>Redox Potential</td>
<td>0.60</td>
<td>0.57</td>
</tr>
<tr>
<td>Salinity</td>
<td>0.18</td>
<td>0.06</td>
</tr>
<tr>
<td>Temperature</td>
<td>-0.61</td>
<td>-0.24</td>
</tr>
<tr>
<td>Sorting coefficient</td>
<td>-0.61</td>
<td>-0.61</td>
</tr>
<tr>
<td>Very coarse sand</td>
<td>0.17</td>
<td>0.01</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.48</td>
<td>0.25</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.53</td>
<td>0.54</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.57</td>
<td>0.65</td>
</tr>
<tr>
<td>Very fine sand</td>
<td>0.26</td>
<td>0.15</td>
</tr>
<tr>
<td>Silt-clay</td>
<td>-0.72</td>
<td>-0.67</td>
</tr>
</tbody>
</table>

Organic matter content, sorting coefficient, oxygen level concentration and redox potential were the main environmental variables responsible for grouping species distribution among stations. These results were revealed by the BIOENV-test (R=0.409 - dry season; R=0.442 rainy season).

The sediment composition and the polychaete community structure of some inner sites were similar to exposed ones. Those stations receive influence of the central channel, bringing less polluted waters and sand to the inner parts of the bay. The granulometric heterogeneity associated with less impacted conditions of the central channel variables rendered favorable to the proliferation of some polychaetes species inside a sector with the worst environmental marks of the bay.

DISCUSSIONS

The decreasing gradient of species richness towards the inner parts and sheltered areas of the bay could be explained by its low survival in a disturbed environment caused by the flattened ecological niche in these areas where anoxic and high organic sediments predominates. The negative correlation species richness with low oxygen concentration, shallow water and fine fractions of the sediments was observed before (SAIZ-SALINAS, 2000; NEWELL et al., 2001). The concentration of rare species in the transition area from exposed hydrodynamic sites to more protected ones was found in different estuaries around the world (WHILATCH, 1977; GRAY, 2002). The community succession patterns usually displace from primitive stages presenting low species richness with pronounced dominance to advanced stages where the species richness is high, with many rare species and reduced dominance. Human induced impacts generally conduct to an opposite tendency (MAY, 1981). COGNETTI (1978) accentuated that the pollution simplifies the species distribution, spatially and temporally, with a progressive decreasing of the species number, except those capable of surviving in unfavorable conditions. In fact, the great majority of the rare species collected in the present study mainly occurred in the outer sector and around the central channel, a transition area toward the intermediate sector of the bay. This situation became more evident in the rainy season, when the number of rare species was slightly lower compared with the dry season. Some species were more common in the direction of the inner parts of the bay, like Prionospio heterobranchia (dry season) and Spiochaetopterus nonatoi (rainy season), indicating an intensification of the environmental disturbing at this region of the estuary, favoring a small number of species, generally with eurytopic features (JACKSON, 1974).

Sporadic hypoxic and anoxic events followed by the macrofauna depletion are a common phenomena observed in the soft-bottom benthic community that inhabits the waters below the halocline. However, benthic mass mortality could happen after anoxic events in tropical coastal areas too (POWILLEIT and KUBE, 1999). GRAY et al. (2002) accentuated that hydrographic conditions are very important in the determination of where anoxic events probably could occur. Organic material accumulation and water deoxygenation have a strong impact upon the fauna, where low concentration levels can exclude the community (CLARK, 1997). Therefore, different oxygen concentrations distributed in the bay have an important consequence in the polychaete spatial composition.

PEARSON and ROSENBERG (1978) reported azoic areas where the sediment became reduced and the water column presented low dissolved oxygen concentration. In fact, many azoic stations were found in places affected by an intense silting up, low dissolved oxygen concentration and less tide circulation. All the azoic stations showed an extreme reduced value of the redox potential, corroborating this tendency. The conditions met by the soft-bottom macroinfauna in this situation are critical due to the lethal characteristics of the sulfidric acid and ammonia causing mass mortality (POWILLEIT and KUBE, 1999; GRAY et al., 2002).

GRAY et al. (2002) concluded that a single factor does not exist in community modification. BARRETO and CUNHA (1977)
observed organic debris and mud from vegetal and animal sources in many parts of the Guanabara Bay, with industrial sewage inputs localized on its drainage basin. This high organic load of poor quality and difficult assimilation by the macrofauna just contributes to the sediment reduction process and the increase of the dissolved oxygen consuming at the water column close to the bottom (GRAY et al., 2002). In poor tide circulation sites, this kind of situation became more evident, leading to a longer water renewing period, increasing hypoxic and anoxic time events. Consequently, the lack of oxygen in the water column and the anoxic and high organic sediment composed by silt-clay associated with high sedimentation rates reported in the literature, could explain the great number of azoic stations in the Guanabara Bay.

One of the usual ways that the contaminants reach the coastal areas is through untreated sewage discharge. High input levels of organic materials deriving from domestic sewage demands a raised quantity of oxygen, and at the same time releases nutrients along and contribute with methane and sulfidric gas, resulting from bacterial decomposition of the organic compounds (KENNISH, 1991). The samples collected at these stations showed clearly that Poecilochaetus australis got benefit from high organic input. In general, when the pollution favors one or two populations there will be an induction for aggregation, which is usually related to the decreasing of the species richness (ROSENBERG, 1977). Poecilochaetus australis was described with specimens collected in a harbor in the southwest part of Brazil in a black mud sand sediment containing 30% metallic minerals with iron and titanium (NONATO, 1963). High densities of P. australis were collected in another Brazilian bay, Santos Channel, which is the biggest commercial port and one of the most impacted coastal bays in Brazil. These observations advise that P. australis inhabit strait ecological niches and are infrequently inhabited by other species. P. australis is represented exclusively by juvenile forms and are probably post-metamorphosed (NONATO, 1963).

The functional structure of this species and its food habits could also lead to an important adaptive advantage because P. australis can make use of depositivore and suspensivore habits depending on the current flux and by environmental nutritional availability in the water column or in the sediment (FAUCHALD and JUMARS, 1979). The food supply is one of the most important limit factors of many species and communities (GASTON, 1987), and P. australis gave a clear evidence of the benefit of the continuous input of organic material into the marine environment. All of these features can be found in many opportunistic species (GRASSE, 1974; GIANGRANDE, 1997) and is confirmed by the development of opportunistic benthic species promoted by organic enrichment (PEARSON and ROSENBERG, 1978).

The level of hydrodynamic action was another factor that influenced the observed polychaete species composition. Physical marine environmental studies demonstrated that high-energy areas are typically composed of sand and low organic matter contents; and low energy sites are dominated by mud with less bottom currents (SNELGROVE and BUTMAN, 1994; THORNTON, 1995). A direct modification caused by hydrodynamic effects in the Guanabara Bay was observed by SOLA and PAIVA (2001) at the Urca beach, localized in one of the highest hydrodynamic areas of the bay. The authors found modifications in the macroinfauna species composition while the stability of the sediment composition after storms was almost the same. The low species density found at the more hydrodynamic stations of the outer sector could be associated with the occurrence of a big storm. It will be necessary future studies to assess information about what is the exact moment of maximum polychaete species densities after storms.

Probert (1984) concluded that the spatial heterogeneity have an important temporal component associated with sediment proprieties changes, where the knowledge of these.....

CONCLUSIONS

There exists a clear tendency of the species richness decreasing towards the inner parts of the bay. A great number of azoic stations were found at sites localized close to the coast with low hydrodynamic action presenting elevated contributions of silt-clay and organic matter. Stations localized in the outer sector and around the central channel composed of a more heterogeneity and oxidized sediment with high oxygen concentrations in the water column are mainly controlled by hydrodynamic energy. This area showed a higher species richness value when compared with those stations of the intermediate and inner sector close to the continent.

Some stations situated in small bays of the intermediate and outer sectors repeat environmental and biological conditions of a great part of the inner sector, in the same way that in the inner sector there exists stations that reproduce similar situations of some regions of the intermediate and outer sectors. Reduced sediment, low dissolved oxygen concentration in the water column and high levels of silt and clay were the main environmental variables that influenced the survival of the sublittoral soft-bottom polychaetes. The concentration of rare species in the transition zone between the outer and intermediate sector showed clearly an ecotono determined by the intensification of sedimentation rate and by the lack of dissolved oxygen concentration towards the inner parts of the bay.

The stations nearby untreated sewage runoff located in front of the Mangue Channel (station 22) and Jurujuba Harbor (station 24) were in an elevated level of deterioration. At these
stations could be noted a species richness decreasing and a raising species density of some species, mainly *Poecilochaetus australis* and *Spiochaetopterus nonatoi*.

The Guanabara Bay could be divided into three main regions; i) exposed areas presenting heterogeneous and oxidized sediment, high oxygen concentration levels, great species richness and low species density; ii) fine sand areas with some stations nearby urban sewage effluents showing species richness decreasing and highest density of *Poecilochaetus australis* and *Spiochaetopterus nonatoi*; iii) protected and inner areas with low dissolved oxygen concentration, poor selected, fine and reduced sediment, presenting low species density and species richness or even azoic station in its majority.

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LITERATURE CITED


