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Seasonal and Spatial Distribution of Sublittoral Soft-Bottom Mollusks Assemblages at Guanabara Bay, Rio de Janeiro, Brazil

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ABSTRACT

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Guanabara bay is an eutrophic and polluted estuary in southeast Brazil. To establish possible patterns of mollusks distribution in GB, a sampling design of 38 stations was performed in the dry season of 2000 and the wet season of 2001. At each station a 0.1 m^2 van-Veen grab sample was taken in triplicate. Sediment samples were analysed for grain size distribution, organic matter, carbonate content and redox potential. The macrozoobenthos were sieved out with 1.0 mm mesh size and sorted to determine the abundance of mollusks. The abundance and distribution of mollusks were related to the sediment features. Three sectors were distinguised in GB, differing in hydrological and sediment characteristics. The sediment was mostly sandy and muddy and showed an increasing organic matter content gradient from the outer to the inner sector of the bay. The inner sediment was essentially reductor while the outer bottom presented a quite oxidant potential. A total of 7590 ind.m^{-2} was encountered (57% gastropods and 43% bivalves). The wet season held the lowest density (2.650 ind.m^{-2}) probably due to bottom hypoxic conditions established in this period. The mean density per sector ranged from 1.410 ind. m^{-2} in the inner sector to 3.550 ind.m^{-2} in the outer sector. The most dominant species were *Anachis obesa*, *Nucula semiornata* and *Olivella minuta*. Organic enrichment, low oxygen concentrations and altered redox conditions allied to the prevailing pattern of circulation seems to have ruled the spatial and seasonal distribution of mollusks in GB.

ADITIONAL INDEX WORDS: *Estuaries, community, macrozoobenthos, pollution, euthrophication.*

INTRODUCTION

Benthic faunal distribution varies considerably in time and space due in great part to the patchiness of species occurrences and overall heterogeneity of the benthic habitat. This heterogeneity has also been attributed to climatic irregularity and man-induced perturbation (MISTRI *et al*., 2000).

Estuaries are subjected to wide seasonal and inter-annual fluctuations in water chemistry, circulation and sedimentation, particularly in response to weather-related variations in freshwater inflow (NICHOLS *et al*., 1986). Superimposed on these natural variations, are changes in response to human activities, especially in relation to waste disposal (NICHOLS *et al*., 1985). Consequently, estuaries are increasingly exposed to a depletion of dissolved oxygen from bottom water layers (KEMP *et al.*, 1992). Seasonally anoxic or hypoxic (O_2 < 2 mg.l^{-1}) bottom waters have been reported from a variety of estuarine ecosystems (KEMP *et al*., 1992) and it is probably occurring in most major estuaries in Brazil.

Hypoxia is spreading and growing more persistent globally because of anthropogenic eutrophication. SAGASTI *et al*. (2001) and Wu (2002) pointed out that among benthic animals, hypoxia can cause mass mortality, changes in behavior and reductions in growth. Hypoxia can also lead to decreased biomass and diversity, affecting species abundance and composition in estuarine benthic assemblages (SAGASTI *et al*., 2000; Wu, 2002).

Guanabara bay (GB), located at 23^0 50' S, 43^0 08' W (figure 1), is a 384 Km^2 eutrophic and heavily polluted coastal bay in southeast Brazil (KJERFVE *et al*., 1997). Due to the rapid degradation of this ecosystem, today, the bay represents an important focus of environmental interest but little information is available about the local benthos. Its drainage water basin receives polluted effluents from 24 sub basins with about 6000 industries and an increasing population of 10 million inhabitants (BRAGA *et al*., 1993). About 75% of the organic wastes originate from urban untreated sewage and 25% from industries. Heavy metals and toxic chemical compounds also abound in GB (CARVALHO *et al*., 1992; KEHRIG *et al*., 2002). Additional contamination results from accidental spills of industrial chemicals and oil. As a result, a common feature of this estuary is the episodic hypoxia caused by a general eutrophication trend (VALENTIN *et al*., 1999; KEHRIG *et al*., 2002).

The ongoing socio-economic pressure upon GB require a counterpart of updated knowledge of its ecosystem structure and function. This study aims to establish spatial and seasonal patterns of mollusk distribution in GB and to discuss whether these associative patterns could be related to environmental variables.

METHODS

A sampling design consisting of 38 stations (figure 1) was performed in two seasons, the austral winter of 2000 (dry season) and in the austral summer of 2001 (wet season). At each station a 0.1 m^2 van-Veen grab sample was taken in triplicate. Sediment samples in each station were analyzed for grain size distribution, organic matter, carbonate content and redox potential. The methods of mechanical dry sieving and decantation described by SUGUIO (1973) were used to determine the grain size fractions. To determine the percentage of total organic matter by loss of mass on ignition, sediments samples were oven-dried at 105 °C for 12 h and ashed at 500 °C for 2 h. Biodetritic carbonate ($CaCO_3$) was obtained by HCl 10% attack.

Biological samples were sieved out through a 1.0 mm mesh size and the benthos sorted under stereomicroscope. The mollusk fauna was characterized by density, frequency of occurrence and specific dominance. According to the frequency of occurrence (F) species were classified as constant (F>50%), common (10%£ F ³ 50%) and rare (F<10%).

The null hypothesis that there is no seasonal variation among the sediment variables was tested by one-way analysis of

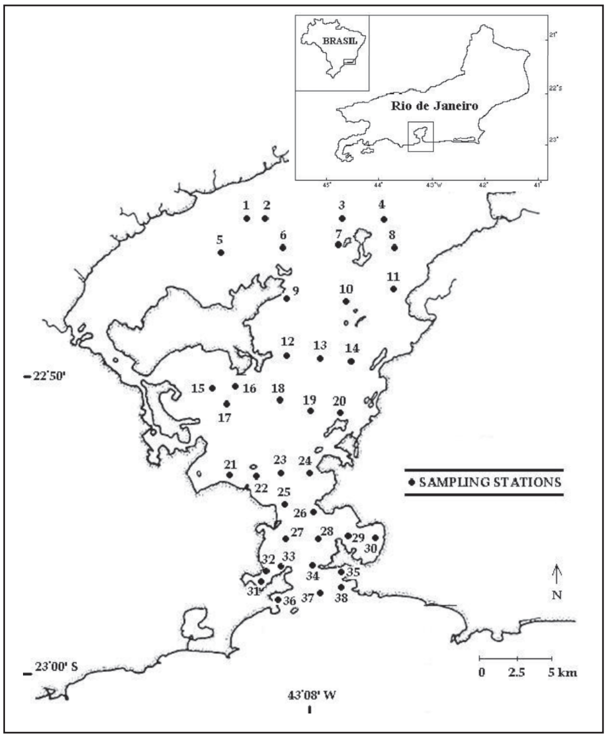

Figure 1. Geographical position of Guanabra Bay in Rio de Janeiro State, southestern Brazil, and sampling stations.

similarity (ANOSIM) permutation test using the Euclidian distance, applying Primer software. An exploratory data analysis (Principle Component Analysis- PCA) was performed to the arcsine transformed normalized data of the abiotic variables. In order to establish possible patterns of spatial distribution, the sampling stations were grouped into an inner sector (stations 1 to 14); an intermediary sector (stations 15 to 26); and an outer sector (stations 27 to 38). The abundance and distribution of mollusks within the sectors were related to the sediment and environmental features. The null hypothesis that there is no significant difference between the mollusks abundance and between the sediment variables (wet season) within the sectors of the bay was tested through Kruskal-Wallis ANOVA by rank analysis.

RESULTS

Mollusks

A total of 48 live species of mollusks were encountered in GB, including 27 bivalves and 21 gastropods. The dry and wet seasons are quite similar in terms of taxonomic composition, 36 and 33 mollusks species, respectively. Empty shells were found for 23 species of bivalves, 15 species of gastropods and 1 species of scaphopod, summing up to 6.500 individuals (89% bivalves and 10% gastropods).

A total density of 7.590 ind.m^{-2} was found for GB during the studied period. The gastropods accounted for 57% and the bivalves for 43% of the total density. The dry season held the highest density (4.940 ind.m^{-2}), represented by two dominant species: *Anachis obesa* (50%) and *Nucula semiornata* (14.6%). Both species were also dominant in the wet season, representing 25.7% and 23.4% of dominance, respectively. The total density in the wet season was 2.650 ind.m^{-2}.

The mean density per sector of GB ranged from 1.410 ind.m^{-2} in the inner sector (57% gastropods), 2.630 ind.m^{-2} in the intermediary sector (71% gastropods) to 3.550 ind.m^{-2} in the outer sector (54% bivalves). The highest density was found in the intermediary sector during the dry season (2.310 ind.m^{-2}), and the lowest in the intermediary sector in the wet season (320 ind.m^{-2}).

In the dry season, *Anachis obesa* was dominant in the inner (69.51%) and intermediary (70.1%) sectors, whilst *Olivella minuta* was dominant in the outer sector (17.1%). *A. obesa* was dominant in all sectors during the wet season, ranging from 23.6% in the outer sector to 30.5% in the inner sector.

According to the frequency of occurrence, 17% of the total species were classified as common (75% bivalves) and 83% as rare species (53% bivalves). There was no constant species registered for the studied period. The common species were *A. obesa* (36.8%), *Nucula semiornata* (23.6%), *O.(Olivina)* cf. *puelcha, Corbula cymella* (15.8% each), *Pitar fulminatus, Ervilia concentrica, Corbula caribaea* (14.5% each) and *Ctena pectinella* (13.2%). Amongst the rare species *Natica* sp., *O. minuta* (9.2% each), *O.* aff. *floralia* (6.6%), *Anadara notabilis, Pitar albidus, Periploma ovata and O.* aff. *defiorei* (5.3% each) were the species which presented frequency above 5%; all of the other rare species occurred with less than 4% of frequency.

In the dry season, *A. obesa*, *O. (Olivina)* cf. *puelcha* and *N. semiornata* were the most frequent species, with 50%, 26% and 21%, respectively. The commonest species in the wet season were *N. semiornata* and *A. obesa* (26% and 24%, respectively), followed by *C. caribaea* and *C. cymella* (18% each).

In relation to the frequency of mollusks within the bay's sectors, *A. obesa* and *N. semiornata* were the commonest species in the inner sector during the dry season (25% and 21.4%, respectively) and in the intermediary sector during the wet season (25% each). *A. obesa* was the only constant species in the intermediary sector during the dry season (92%), followed by two common species: *C. pectinella* and *O. (Olivina)* cf. *puelcha* (25% each). In the outer sector, *O. (Olivina)* cf. *puelcha* (50%), *O. minuta, A. obesa* (42% each), *N. semiornata*, *E. concentrica* and *C. cymella* (33% each) were the most frequent mollusks in the dry season. *E. concentrica* (42%), *N. semiornata* and *P. fulminatus* (33% each) were the commonest species in the wet season within the outer sector, while *A. obesa* and *Natica* sp. (17% each) were the most frequent species in the same sector in the wet season. In the inner sector, *A. obesa*, *C. cymella* (33% each), C. *caribaea* and *N. semiornata* (25% each) were common in the wet season.

Environmental Features

According to ANOSIM test, there is no seasonal variation among the sediment variables (Global r= -0.009; p= 71,2%). The sediment was mostly sandy and muddy and showed an

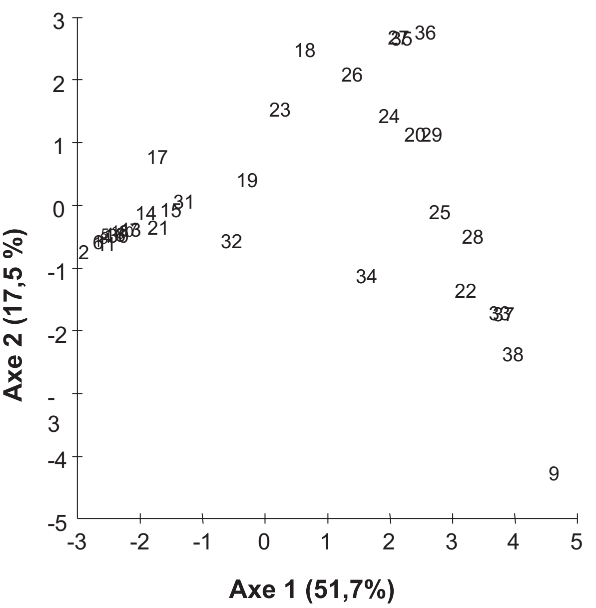

Figure 2: Fatorial axes 1 and 2 of the Principal Component Analysis (PCA) runned on abiotic variables of the dry (a) and wet (b) seasons.

Table 1. *Mean and standard deviation (SD) of the main abiotic variables within the sectors of the GB in the wet season. MGS= mean grain size; OM= organic matter (%); O_2= dissolved oxygen (ml.l^{-1}); Eh= redox potential (mV); S= salinity; T= temperature (^{0}C).*

	INNER		INTERMEDIARY		OUTER	
	Mean	SD	Mean	SD	Mean	SD
MGS	4,76	1,4	3,92	1,19	2,78	1,78
OM	11,81	5,59	6,7	4,56	5,36	6,53
O_2	0,41	0,61	2,02	1,31	3,27	1,28
Eh	-3,8	0,79	-2,87	1,16	-0,86	2,27
S	30,19	4,19	34,23	1,89	35,2	1,62
T	25,37	1,02	24,69	1,35	22,91	2,46

increasing organic matter content gradient from the outer (around 2% in most stations) to the inner sector of the bay (ranging from 14-22%). The carbonate content was low in most stations of the bay (*c.a.* 0%), except in stations 7, 33 (mean of 40% each) and 34 (mean of 90%). The sediment of the inner sector was essentially reductor, ranging from 4 to 3 mV, whilst that of the outer sector presented a quite oxidant potential (-1 to 2 mV). The dissolved oxygen concentrations were lower in the inner stations, varying from 0 to 1.75 ml.l^{-1}, and highest in the outer sector, reaching 4.75 ml.l^{-1} in station 36. Table 1 shows the mean values of the main abiotic variables for the wet season within the bay's sectors.

The Principle Components Analysis (PCA) performed on abiotic variables account for 69% of the variance in the dry season, and 68% in the wet season, corroborating the pattern described above (figure 2). Significant differences between the sediment variables within the bay's sectors obtained in the wet season was observed applying Kruskal-Wallis ANOVA by rank analysis and it is shown in table 2.

The null hypothesis that there is no difference between the mollusk abundance within the sectors of the bay was rejected according to Kruskal-Wallis ANOVA (H= 23.95 p< 0.1 for gastropod mollusks and H= 15.26 p< 0.1 for bivalve mollusks). In relation to gastropod abundance, the intermediary sector in the dry season was highly different from the intermediary and the inner sectors in the wet season. There was a significant difference of bivalve abundance between the outer sector in the wet season and the inner sector in both seasons.

Table 2. *Results of Kruskal-Wallis (K) on sediment variables between the inner (IN), intermediary (INT) and outer (OUT) sectors. K= Kruskall Wallis value; p= probability; MGS= mean grain size (phi); SC= sorting coefficient; PB=peble (%); VCS= very coarse sand (%); CS= coarse sand (%); MS= median sand (%); FS= fine sand (%); VFS= very fine sand (%); OM= organic matter (%); $CaCO_3$=carbonate content (%). Lines indicate significant differences between the GB's sectors.*

	IN INTER OUT	***K***	***p***
MGS		26.396	<0.01 < 0.001
SC		9.815	<0.05 <0.05
PB		10.609	<0.05 <0.05
VCS		20.669	<0.01 <0.001
CS		26.679	<0.01 <0.001
MS		32.812	<0.01 <0.001
FS		33.558	<0.001 <0.001
VFS		31.216	<0.001 <0.001
Silt		37.718	<0.001 <0.001
Clay		25.747	<0.01 <0.001
OM		27.098	<0.01 <0.001
$CaCO_3$		19.040	<0.01 <0.001

DISCUSSIONS

GB is a typical estuarine system subjected to a fast process of degradation due to a continuous input of domestic sewage and periodical inflow of freshwater by a large drainage basin into its shalow waters (FEEMA, 1990). This environment is characterized by a well defined wet (December-April) and dry (June-August) season (KJERVFE *et al*., 1997).

Water quality in GB differs from place to place, according to circulation patterns and pollution *foci* (LAVRADO *et al*., 2000). Some gradients can be observed in many of the hydrobiological and sediment features, revealing the existance of three different sectors, with quite pronounced differences in most properties considered. However, other factors probably also play an important role in partitioning GB.

The high hydrodynamic forcing and sea water exchange at the bay's mouth reflect in sandy bottoms in the outer sector mainly associated with gravel and very coarse sand. The intermediary sector seems to be the most stable environment in terms of water and sediment quality. The channel, which follows the major axis of the bay, where depths reach an average of 20 m, allows an inflow of coastal waters through the bottom layer while freshwater under strong pollution effects flows through the surface layer (MAYR *et al*.,1989). Therefore, the intermediary bottom is mainly sandy mud and muddy. Between the intermediary and inner sectors the central channel widens to 900 m and it subsequently loses its characteristics further into the bay as it becomes progressively shallower (KJERVFE *et al*., 1997). As a result, the inner sector of GB is covered by extensive mud deposits as a result of the active transport of fluvial clastic materials to the bay, accelerated by anthropogenic activities in the drainage basin and restricted water movement (KJERFVE *et. al*., 1997).

Hypoxia or anoxia exhibits a seasonal variability globally, developing in summer and weakening or disappearing in winter in most regions of the world (SAGASTI *et al*., 2002). In summer (wet season), waters are weakly mixed due to the presence of strong stratification (haloclines and thermoclines) caused by meteorological conditions and excessive tributaries inflow to the bay (KARIM, 2002; WU, 2002), especially in the tropics. The sediments are then alternately exposed to oxydizing and reducing conditions. The inner bottom of GB, dominated by excessive anthropogenic input of nutrients and organic matter and a poor water circulation, revealed hypoxic-anoxic conditions (0.0 to 2.0 mlO_2.l^{-1}) and in the intermediary sector, predominantly hypoxic, sediment of stations 16, 17 and 21 were anoxic in the wet season, corroborating the pattern above.

Low oxygen, organic enrichment and altered redox conditions of the sediment were the major environmental factors determining the mollusk composition and its community structure in GB. As demonstrated by PEARSON and ROSENBERG (1978) to other habitats, there is a strong spatial gradient in redox potential profiles. At the highly organic enriched inner sector, sediments are totally anoxic with very impoverished benthic fauna or no fauna at all (stations 1-8), whereas the outer sector of GB comprises a richer and more diversified fauna, where a positive redox potencial was prevailing. The azoic sediment in the inner sector is expected once it is in proximity to the point sources of pollution (NICHOLS *et al*., 1986; ALONGI, 1990).

The mollusk communities in the inner region exposed to low dissolved oxygen events and contaminated sediments were characterized by lower density and greater dominance by few species, especially *A. obesa* and *N. semiornata*. This patterns was also observed by DAUER (1993), adding that contaminated sediments present a diversity of stresses for benthic communities and result in lower biomass, lower species richness and shifts in community composition to a dominance by shallow-dwellers, opportunistic species. Most of other tropical pollution studies similarly indicate a dominance of small opportunistic species and a lowering of species diverity closer to the sewage loadings (ALONGI, 1990). The impoverished community thriving in the inner sector suggest that those habitats are physically regulated and that can only be colonized by a few opportunistic species that are adpted for survival in such harsh environments (MISTRI *et al*., 2000).

The total density of gastropods was higher (14%) when compared to the bivalves found. BATALHA *et al*. (1998) found 38% more gastropods than bivalves, whereas PITOMBO *et al*. (1999) found significantly greater bivalves than gastropods and MIYAJI (1995) encountered an equivalent relationship between bivalves and gastropods, suggesting no general pattern regarding this ratio.

Comparing the present results to the few previous mollusk studies conducted in GB (OLIVEIRA, 1950; REBELO *et al*., 1985 and BATALHA *et al*., 1998), there is an indication of significant long-term changes in species composition and large seasonal and interannual differences in species densities and frequencies are apparent. Apart from the distinct species ecology, this is a possible result from the increasingly anthropogenic disturbances of the GB estuarine environment during the past decades. NICHOLS *et al*. (1985) points out that although species composition of benthic communities can remain reasonably stable, variations in species abundance can be extreme, with interannual variations often exceeding or dwarfing seasonal fluctuations.

In the pioneer published study of the flora and fauna of GB, OLIVEIRA (1950) found a total of 56 mollusk species, of which only 3 species and 2 genra were also encountered in the present study. REBELO *et al.* (1985) also mentioned the occurrence of *A. obesa*, *C. caribaea* and *Nucula crenulata* (sin. *N. semiornata*) in GB. From the total number of mollusk species (18) registered by BATALHA *et al*. (1998), 61% were coincident in this study, including *N. semiornata*, *E. concentrica*, *C. caribaea* and *O. minuta*. OLIVEIRA (1958) had already commented the effects of industrial and urban pollution on the benthic fauna of GB, attributing to the oils and organic sewage the major cause of the disappearance of some species.

With increasingly population growth and anthropogenic input to coastlines in tropical countries (ALONGI, 1989), current monitoring and proper management is urgently needed for the conservation of these unique ecosystems and its biological communities.

CONCLUSIONS

Based on the results herein presented, it was possible to distinguish three different sectors in GB with distint hydrological and sediment characteristics. The inner sector is constituted by anoxic-hypoxic muddy sediments, high organic load, reducing conditions and subjected to a deficient water renewal. The intermediary sector is essentially sand muddy and characterized by effective water exchange, enabling the run off of pollutants and enhancing bottom oxygen and oxidizing potential, although some anoxic-hypoxic events were also a feature of this sector. The outer sector is dominated by normoxic coarser sediments with low organic matter and high oxygen concentrations due to constant exchange with ocean waters.

Mollusks distribution in GB varied significantly in space and time and was probably ruled by the organic enrichment effects of hypoxia and altered redox conditions coupled with prevailent patterns of circulation. Within the sectors of GB an increasing gradient in mollusks diversity and occurrence was observed, ranging from the azoic and impoverished stations in the inner sector to a well-structured community in terms of species composition and abundance inhabiting the outer sector. Seasonal variation was characterized by short-term (time scale of months) pulses in mollusks abundance and frequency, decreasing in the wet season (austral summer), when hypoxia conditions were prevailing in bottom sediements.

This study revealed that mollusks in GB presented altered composition and distribution when compared to previous mollusk investigations in the same estuary. These modifications are attributed to the increasingly instability of its sediment and water. This suggests that GB is not resilient enough to recover its former ecological value under the effects of strong human influence. As long as this cronic anthropogenic disturbance persists the structure of the benthic macrofaunal community in GB is expected to be modified dramatically in time and space.

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