Benthic Foraminiferal Response to Variations in Temperature, Salinity, Dissolved Oxygen and Organic Carbon, in the Guanabara Bay, Rio de Janeiro, Brazil.

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Abstract

Recent benthic foraminiferal distribution patterns in Guanabara Bay are investigated in relation to temperature, salinity, dissolved oxygen and organic carbon content. Patterns of foraminiferal fauna differ between the entrance of the bay and inner parts. The primary result of the present study is that the distribution of *Cassidulina subglobosa* and *Discorbis williamsoni* appear to be governed by lower temperature and higher salinities being found in the entrance of the bay. According to dissolved oxygen content it was observed that *Quinqueloculina seminulum* occurs when values are higher than 2 mg/l, being intolerant to low oxygen bottom water conditions. By the other hand, *Buliminella elegantissima, Bolivina striatula* and *Bulimmina elongata* flourishes under low oxygen waters and in sediment where the organic matter accumulation is high, being found mainly in the central parts of the bay.

Key words: biological indicators, temperature, salinity, dissolved oxygen.

Resumo

Padrões de distribuição de foraminíferos bentônicos recentes são investigados com relação a temperatura, salinidade, oxigênio dissolvido e conteúdo de carbono orgânico. A distribuição de foraminíferos é diferente na entrada da baía se comparada às partes internas. Os primeiros resultados mostram que *Cassidulina subglobosa* e *Discorbis williamsoni* são encontradas em ambientes com baixa temperatura e altas salinidades na entrada da baía. De acordo com o teor de oxigênio dissolvido foi observado que *Quinqueloculina seminulum* ocorre quando os valores são mais altos que 2mg/l, sendo intolerante às condições. Por outro lado, *Buliminella elegantissima, Bolivina striatula* e *Bulimmina elongata* aparecem nas partes centrais da baía, que são locais com baixa oxigenação e sedimentos onde a acumulação de matéria orgânica é alta.

Palavras-chave: indicadores biológicos, temperatura, salinidade, oxigênio dissolvido

1 Introduction

Guanabara Bay is an extremely important ecosystem considering its multiple uses: recreation, sports practice, fishing, navigation, water supply and waste dilution. Despite its beauty, it is a place undergoing serious environmental problems derived from unorganized process of urbanization and industrial concentration. The social and economic importance of the Guanabara Bay and the risk of increase environmental degradation lead to the necessity of understand the complex ecology of communities and correlations to abiotic factors.

Foraminiferal assemblages as biological indicators have been successfully used in ecological interpretations. While the distribution of each species is unique, groups of species (assemblages or communities) can be recognized as inhabiting particular areas such as mangroves, estuaries, bays, inner/outer shelves and deep basins. These natural habitats have particular geomorphologic and hydrographic characteristics, and may be further differentiated by variables such as depth, salinity, temperature, organic content, textural parameters, and oxygen supply. Foraminiferal zonations are frequently shown to be related to natural water-mass boundaries (Denne & Sen Gupta, 1993), river runoff influence, seasonal changes, currents, and biogeochemical processes. This response ranges from typical estuarine scales (e.g., in the determination of a salt-edge penetration) to oceanic proportions (e.g., showing a specific water-mass confluence). Furthermore, it has been demonstrated that foraminiferal biodiversity patterns show traceable responses to temporal environmental changes of higher frequencies, such as tidal movements and seasonal variations in estuaries and bays (Debenay *et al.*, 1998; Eichler, 2001), or lower frequencies such as inter-annual events (Stevenson *et al.,* 1998).

This paper will discuss aspects of the relationship between benthic foraminiferal assemblages and environmental variables (salinity, temperature, dissolved oxygen and organic carbon) collected in 52 samples from superficial sediment of Guanabara Bay in winter and in summer. This study deals with the foraminiferal assemblage response to seasonal variations in this high complex environment.

2 Description of the area

Guanabara Bay is located in the southeast region of Brazil (Rio de Janeiro State). It is located within latitudes 22°57’and 22°41’S and longitudes 43°02’and 43°16’W and has a total area of 381 km^2 and has several islands (Figure 1). It is mostly oriented in a N-S direction, has a total extension of 30 km, and the entrance is 1.8 km wide.

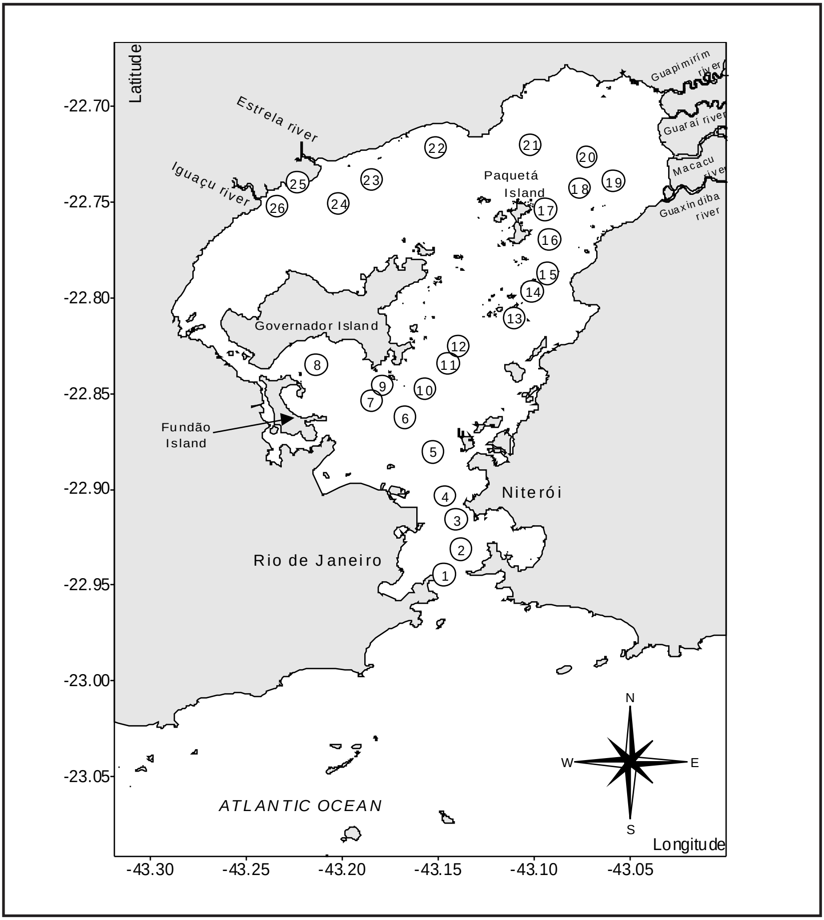

Figure 1 Location of study area and sampled stations.

The climate is tropical humid with temperature around 25°C and practically two seasons: summer, from November to April (rainy season) and winter from May to November (drier season). Tides are semi-diurnal with diurnal inequalities and their maximum height is 1.4 m. Along the main channel, which follows the major axis of the bay depths reach an average of 35m whereas in the northwest end the bay is 1m deep during ebb tide. Guapimirim mangrove swamps, an environmentally protected area is located at the northeast part of Guanabara Bay and the freshwater contribution is derived not only from 35 rivers that flow into the bay, but also from wastes inputs.

The discharge of organic matter, industrial liquid waters, toxic substances and heavy metals from 10.000 industries, 16 oil terminals, 12 shipyard, 2 oil refineries and from the Rio de Janeiro Port Authority enhances the fast process of degradation in Guanabara Bay drainage area. Another problem is related to domestic sewage, where garbage disposal and domestic effluents are discharged in the water threatening the environmental quality. For instance, it changes the patterns of tidal currents, creates areas of sediment deposition and modifies the bathymetry because of consolidation of the bottom material. Therefore, the human impact has caused serious hazards, both in ecological and the socio-economic sense: the water of the bay is inappropriate for bathing, the mangrove area has been reduced by half, fishing activities has been decreased and intense sedimentation has forced an increase of dredging costs for maintaining navigable channels.

Despite its advanced state of degradation, Guanabara Bay plays an important role in the life of the Brazilians who live around its margins. It is also believed that through actions of environmental control, the total recuperation of the quality of the water may be achieved, as it has happened in other parts of the world. Preventive and corrective measures should be taken so that the recuperation and the maintenance of the multiple uses should succeed in the long term. To do so, a first step would be the understanding of the dynamics of the bay environment.

3 Methodology

3.1 Sample collection and laboratory procedures

Twenty-six samples were collected during winter, in august/2000 and 26 during summer February/2001 (Figure 1). Samples were taken with a grab sampler (Van Veen) and the uppermost layer of the sediment (about 5 mm) was scraped off and kept in a mix of 30% alcohol and seawater. Temperature (thermometer Eydan), salinity (refractometer Atago) and dissolved oxygen (Oxygen eletrode Mettler Toledo) from the surface and bottom water were measured at each station. For the analyses of organic carbon, the carbonate was dissolved in 1 M HCl, and 1 g of sediment was dried in a centrifuge tube. These samples were rinsed and dried, and then aliquots were used to determine organic carbon using a LECO CNS analyzer. For foraminiferal work, a solution of Rose Bengal in ethanol was used for staining specimens. After staining, a fixed volume of 50 cm^3 of sediment was washed through a 0.063 mm sieve. When the number of foraminifers in a sample was low (<500), all specimens were counted. With richer samples (containing thousands of specimens), the sample was split to provide a subsample for counting. The quantitative analysis of the data set is based on counts of both living and dead specimens. Species identifications and counting were done under an optical microscope, handled dry, and scanning electron micrographs were taken to help in some problematic identification.

3.2 Data analyses

Environmental data (temperature, salinity, dissolved oxygen, organic carbon and productivity) and faunal data (relative abundance of *Cassidulina subglobosa, Discorbis williamsoni, Quinqueloculina seminulum, Buliminella elegantissim,* and *Bulimina elongata* - indicator foraminiferal species) were used to construct geo referenced contour maps of spatial distribution that enhance data visualization. Maps were constructed using a grid based contour program, Surfer for Windows (Golden Software). Gridding methods produce a regularly array of Z values from irregularly spaced XYZ data. The term “irregularly spaced” means that the points follow no particular pattern over the extent of the map, so there are many holes where data is missing. Gridding fills in these holes by extrapolating or interpolating Z values in those locations where no data exists. To interpolate environmental and faunal data, the Kriging method was used because it is one of the more flexible methods, it is useful for gridding almost any type of data set and it generates the best overall interpretation of most data sets. The foraminiferal assemblage occurrence and the environmental variables mapping show different spatial distribution and provide comparison between patterns found in winter and summer.

4 Results

Both the winter and summer data show lower temperature and higher salinity values in entrance of the bay and higher temperature and lower salinities values in northwestern and northern of the bay (Tables 1 and 2). Temperature data varied in winter from 22 to 25°C on surface and 21 to 23°C in bottom whereas; in the summer it is observed increase of these values ranging from 26 to 31°C in surface and 23 to 29°C in bottom. In winter, salinity data varied from 31 and 34°C both on surface and in bottom, while in summer it is observed decrease of minimum values, ranging from 5 to 32°C on surface and 10 to 32°C in bottom.

Winter	Position	Depth(m)	Sup. temp.(oC)	Bottom temp.(oC)	Sup. salinity	Bottom salinity	pH	Sup. Oxig.(g/ml)	Bottom Oxig. (g/ml)	Org. carb.(%)
1	22 56' 68" - 43 50' 88"	20	21,6	20,5	34,5	35,5	7	7,01	6,09	0,112
2	22 55' 90" - 43 08'29"	26	20,68	20,07	35,18	35,49	7,21	7	6,3	0,018
3	22 54' 97" - 43 08' 43"	20	22,53	20,28	33,32	35,46	7,22	11,7	8,1	0,879
4	22 54' 23" - 43 08' 77"	35	21,96	19,63	34,24	35,8	6,84	7,4	7,1	1,896
5	22 52' 84" - 43 09' 16"	24,7	22,86	19,82	33,13	35,77	6,7	13,4	6,1	0,999
6	22 51' 77" - 43 10' 04"	10	23,5	20,39	33,07	35,58	6,75	14,5	5,6	4,091
7	22 51' 26" - 43 11' 09"	6,8	23,35	21,24	33,65	34,92	5,66	11	1,6	2,042
8	22 50' 88"- 43 11' 77"	3,5	23,17	21,72	30,92	34,39	6,3	8,07	2,51	3,054
9	22 50' 76" - 43 10' 73"	6	23,52	21,38	31,98	34,77	6,68	13	5	0,042
10	22 50' 88" - 43 09' 42"	19	23,81	20,17	32,85	35,69	6,39	13	5	3,004
11	22 50' 07" - 43 08' 69"	13,1	23,87	20,82	33,48	35,36	6,42	10,6	4,2	0,073
12	22 49'52" - 43 08' 37"	12	22,7	21,7	31	34	5,94	12,76	4,99	1,760
13	22 48' 65" - 43 06' 62"	6,7	23,72	21,37	32,85	34,66	6,6	14	3,2	3,653
14	22 47' 82" - 43 06' 05"	5,4	22,94	21,55	32,77	34,38	6,42	14.6	6,7	3,774
15	22 47' 26" - 43 05' 58"	5,4	23,24	21,43	32,65	31,8	6,25	13	2,7	1,008
16	22 46' 96"- 43 05' 71"	7	22,98	21,73	32,27	34,09	6,5	13,52	2,8	4,047
17	22 45' 25" - 43 05' 63"	8	23,01	21,18	32,54	34,86	7,99	11	2,7	4,033
18	22 44' 59" - 43 04' 58"	5	24,6	22,8	30	30	5,85	13,88	1,87	3,839
19	22 44' 36" - 43 03' 52"	4	25,2	23,6	30	30	6,53	7,92	1,16	4,385
20	22 43' 59" - 43 04' 35"	4	24,2	23,6	31	31	6,18	12,12	1,95	4,671
21	22 43' 22" - 43 06' 11"	4	26,8	23,2	32	32	5,46		2,4	5,763
22	22 43' 30" - 43 09' 07"	4	24,4	23,5	31	31	5,6	11,78	0,69	5,010
23	22 44' 31" - 43 11' 08"	6	25,4	23,1	32	32	5,33	14,36	1,55	3,856
24	22 45 '05"- 43 12' 10"	3	21,2	21,2	30	31	5,1	2,03	3,8	4,125
25	22 44' 40" - 43 13' 37"	2	21,8	21,6	31	31	4,75	3,3	2,59	3,263
26	22 45' 15" - 43 14' 03"	1	21,7	21,7	31	31	1,81	3,9	3,9	3,748

Table 1 Position, depth, temperature and salinity (sup and bottom), pH, oxygen and organic carbon in winter.

Summer	Position	Depth(m)	Sup. temp.(oC)	Bottom temp.(oC)	Sup. salinity	Bottom salinity	pH	Sup. Oxig.(g/ml)	BottomOxig. (g/ml)	Org. carb.(%)
1	22 56' 68" - 43 50' 88"	19	26.8	21.4	34.6	35.2	7	6,86	5,5	0,244
2	22 55' 90" - 43 08'29"	26	26	24.7	31.28	34.55	6,98	5,07	4,98	0,243
3	22 54' 97" - 43 08' 43"	20	26.88	24.9	31.65	34.56	6,92	6,06	4,68	4,498
4	22 54' 23" - 43 08' 77"	35	24.83	23.6	31.63	34.32	6,85	5,84	3,82	0,600
5	22 52' 84" - 43 09' 16"	24,7	26.75	23.22	30.98	34.5	6,6	5,12	4,03	2,028
6	22 51' 77" - 43 10' 04"	10	27.27	25.60	31.28	34.25	7,02	5,72	3,71	0,848
7	22 51' 26" - 43 11' 09"	6,8	27.70	25.06	30.55	34.05	6,6	5,8	1,45	4,794
8	22 50' 88"- 43 11' 77"	5	27.9	24.8	31.5	33.4	5,7	10,5	1,83	1,003
9	22 50' 76" - 43 10' 73"	6	28.28	25.10	29.36	33.70	6,72	5,63	2,45	1,691
10	22 50' 88" - 43 09' 42"	19	27.29	21.80	29.57	34.51	7,02	6,8	3,4	3,159
11	22 50' 07" - 43 08' 69"	13,1	27.55	22.81	29.31	33.93	8,06	5,75	2,83	0,516
12	22 49'52" - 43 08' 37"	12	27.3	22.0	30.6	34.0	5,7	6,09	1,46	4,523
13	22 48' 65" - 43 06' 62"	6,7	28.37	24.25	26.87	32.76	7,02	8,93	0,31	4,658
14	22 47' 82" - 43 06' 05"	5,4	28.22	24.21	26.89	32.70	8,88	7,15	0,13	3,844
15	22 47' 26" - 43 05' 58"	5,4	28.61	27.09	26.20	29.92	8,72	9,82	0,09	4,579
16	22 46' 96"- 43 05' 71"	7	29.3	24.2	25.3	32.6	5,7	6,1	0,12	3,594
17	22 45' 25" - 43 05' 63"	8	30.06	23.05	23.90	33.31	8,26	7,85	0,19	4,830
18	22 44' 59" - 43 04' 58"	5,5	31.8	26.6	25	29.0	7,3	11,4	0,3	6,023
19	22 44' 36" - 43 03' 52"	3,5	29.9	28.3	22	28.0	6,9	12,92	1,93	5,198
20	22 43' 59" - 43 04' 35"	4	29.9	29.1	15	29.0	7,38	10,25	0,2	4,288
21	22 43' 22" - 43 06' 11"	5	32.9	27.3	18	29.0	7,08	14,31	0,21	3,790
22	22 43' 30" - 43 09' 07"	4,5	31.4	27.0	29	31.0	6,7	11,91	0,12	4,230
23	22 44' 31" - 43 11' 08"	4,5	30.0	26.1	30	30.0	6,98	12,17	0,2	3,717
24	22 45 '05"- 43 12' 10"	3	29.0	26.5	28.0	32.0	7,1	11,1	0,12	3,974
25	22 44' 40" - 43 13' 37"	1	31.2	29.7	5	14.0	5,5	5,02	8,83	3,845
26	22 45' 15" - 43 14' 03"	0,5	30.1	29.3	5	10.0	2,41	1,74	1,72	3,909

Table 2 Position, depth, temperature and salinity (sup and bottom), pH, oxygen and organic carbon in summer.

Temperature and salinity data showed not only the coastal water input, through the highest concentration in the bottom, but also the freshwater contribution (rivers) through the lowest concentrations on the surface. The spatial distributions determined by temperature and salinity variations confirm the estuarine nature of the studied area.

The tropical rains in summer surpass the intense evaporation due to high temperatures that leads to the dilution of the bay waters during this period of time. As a consequence the lowest values of salinity are found during the summer.

The relative frequency of *C. subglobosa* and *D. williamsoni* (Figures 2 and 3) in the entrance of the bay confirm their preferences to high salinities and lower temperatures (Tables 1 and 2). In winter and in summer it was not observed these two species in the inner parts of the bay, thus suggesting that salinity and temperature provides a competitive edge in habitat segregation.

The seasonal evolution of the parameters studied is presented by the variations of temperature and salinity and the consequences of these variations are illustrated on the dissolved oxygen content changes (Tables 1 and 2). Both in winter and in summer, dissolved oxygen indicates that higher values are found on surface and lower values are found in the bottom. In winter, well-oxygenated bottom waters characterize the entrance of the bay and the central parts. In summer, these values decrease and severe oxygen depletion was found in bottom waters.

Figure 4 shows that during winter where dissolved oxygen in bottom water is higher than 2 mg/l it was possible to observed *Q. seminulum*. By the other hand, in summer, when dissolved oxygen values decrease this species become less frequent, being intolerant to low oxygen bottom water conditions (Kaiho, 1994).

Bolivinids and buliminids which present infaunal morphological characteristics, such as spherical or elongate test shapes are very tolerant to low oxygen concentration of the bottom water. If we compare the distribution of dissolved oxygen in bottom waters with relative frequency of *B. elegantissima* (Figure 5) and *B. elongata* (Figure 6) it can be visualized that during winter in the south of Ilha do Governador presents high abundances of these species. In summer time the severe oxygen depletion in the central part of the bay controls the community structure of foraminiferal assem-

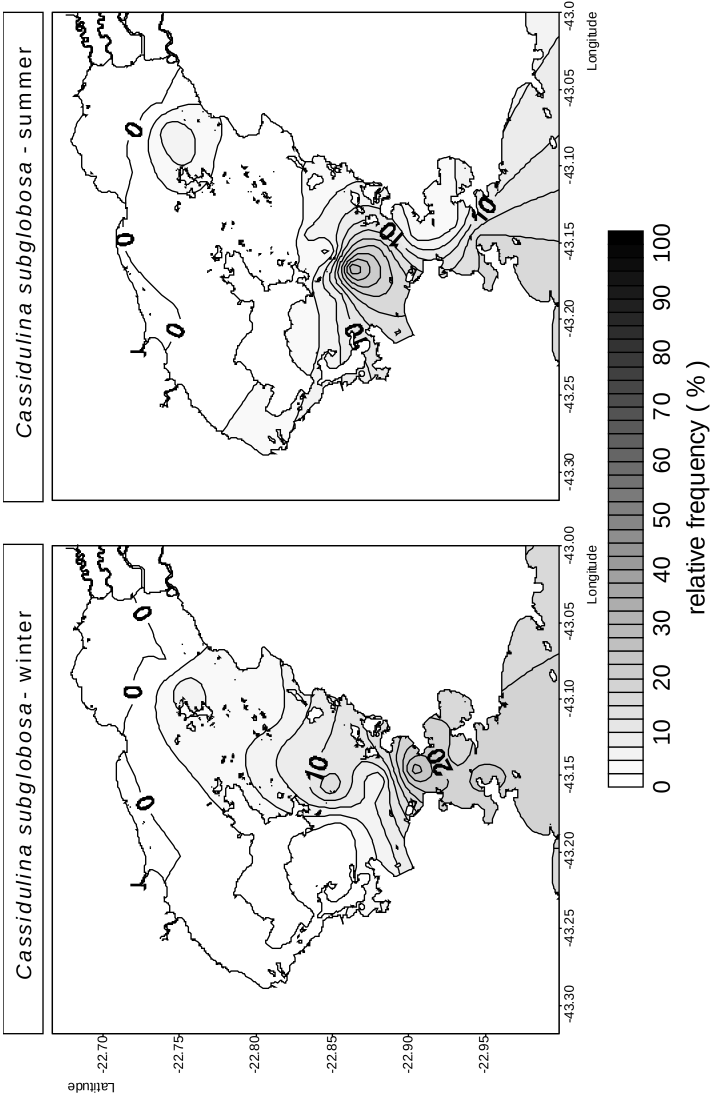

Figure 2 Spatial distribution of relative frequency of *C. subglobosa.*

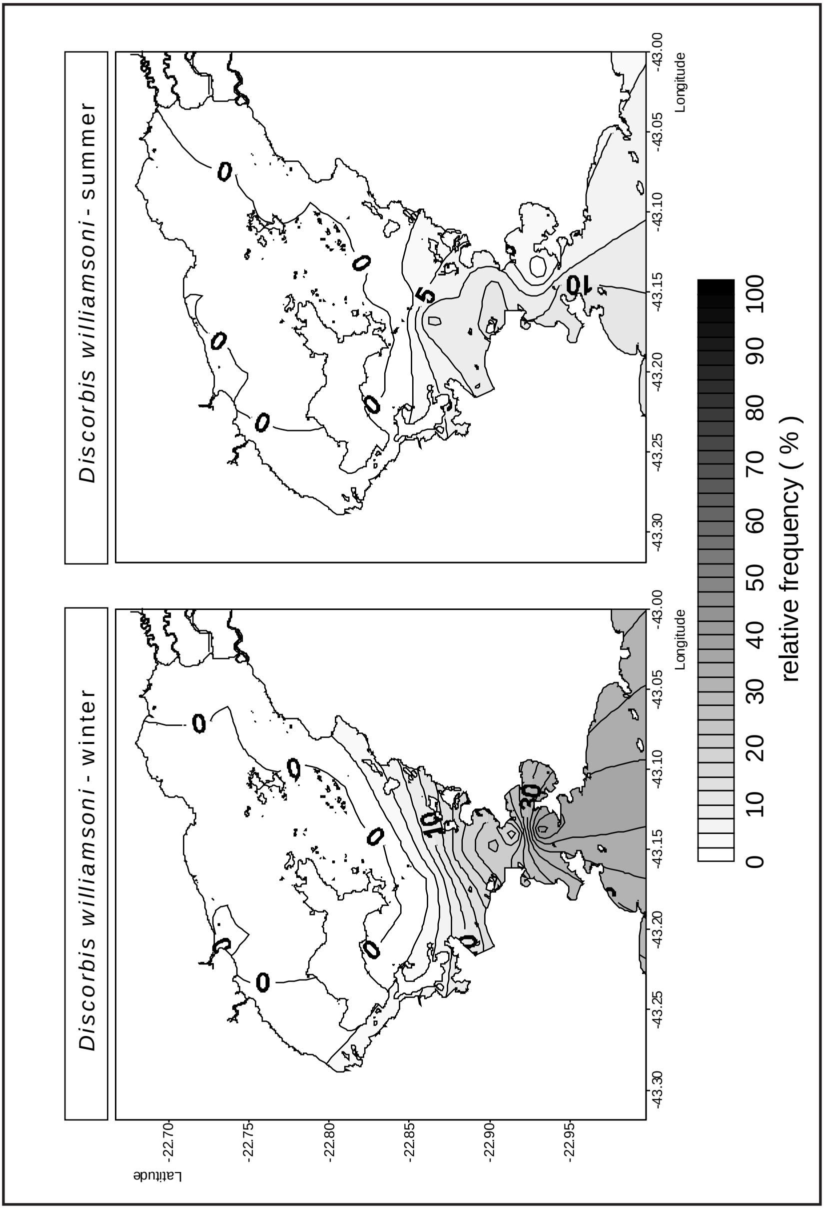

Figure 3 Spatial distribution of relative frequency of *D. williamsoni*

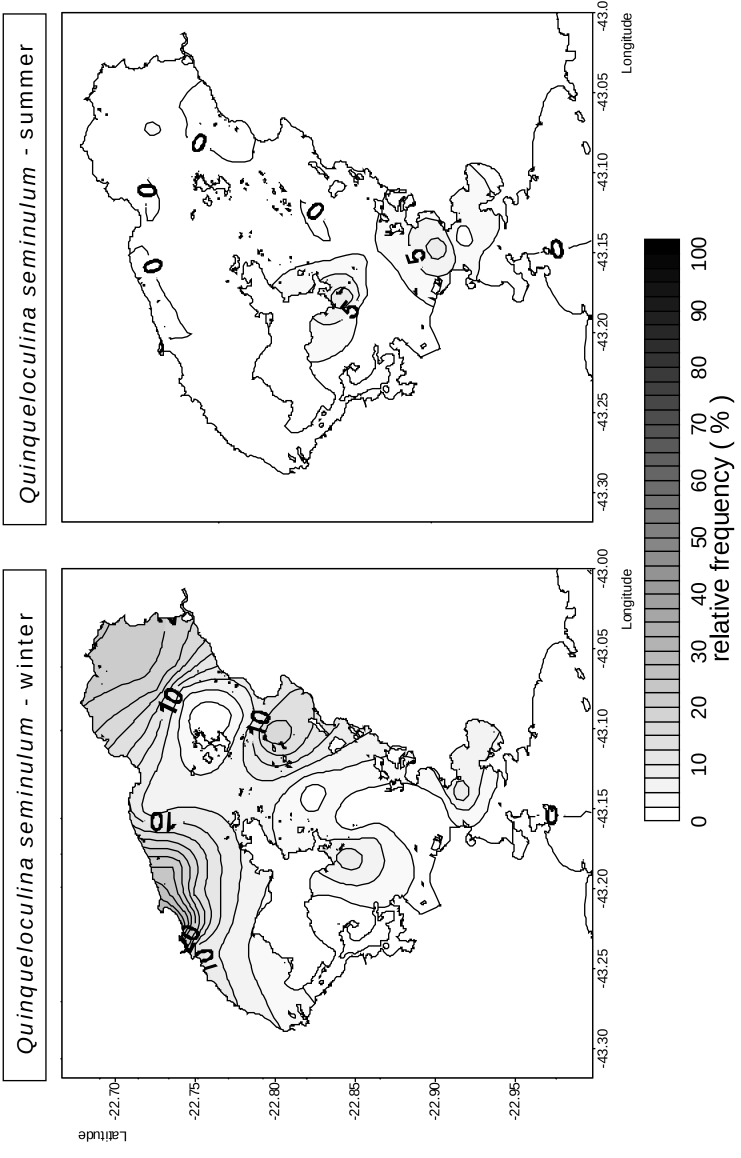

Figure 4 Spatial distribution of relative frequency of *Q. seminulum.*

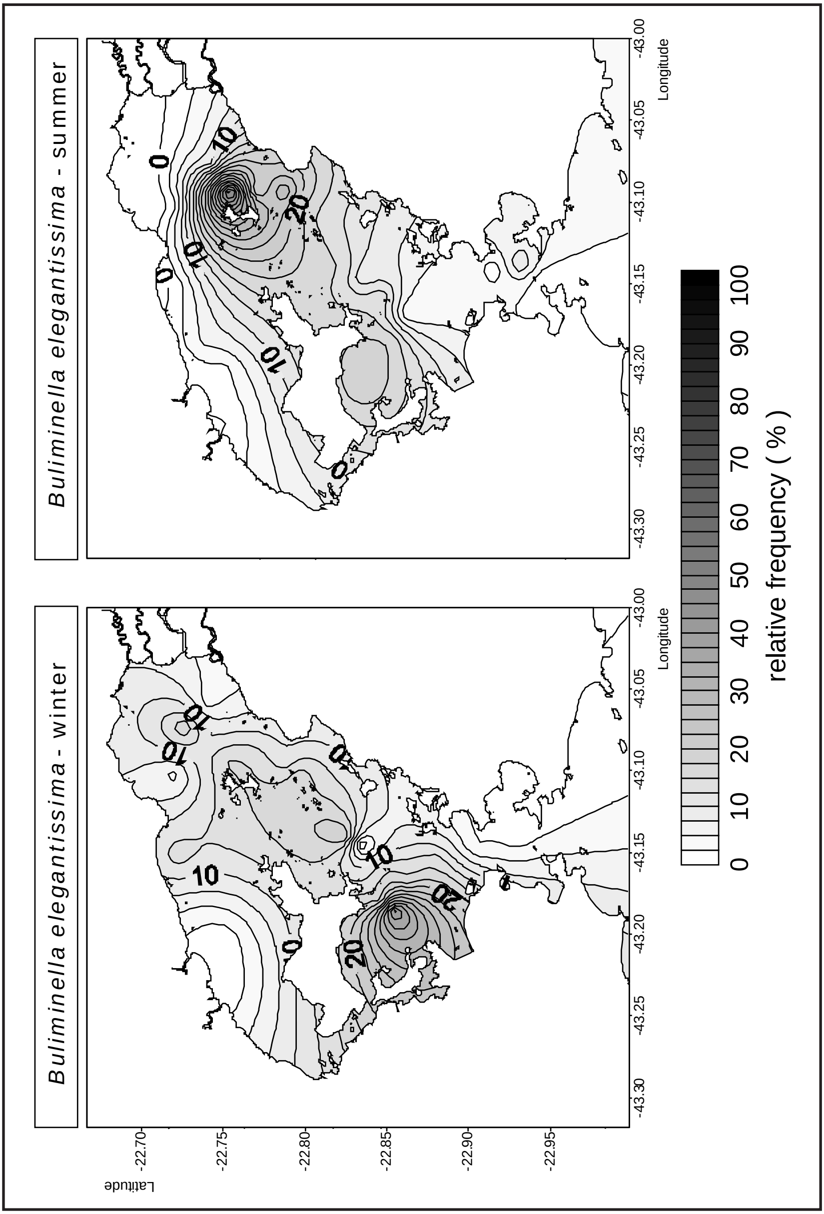

Figure 5 Spatial distribution of relative frequency of *B. elegantissima*.

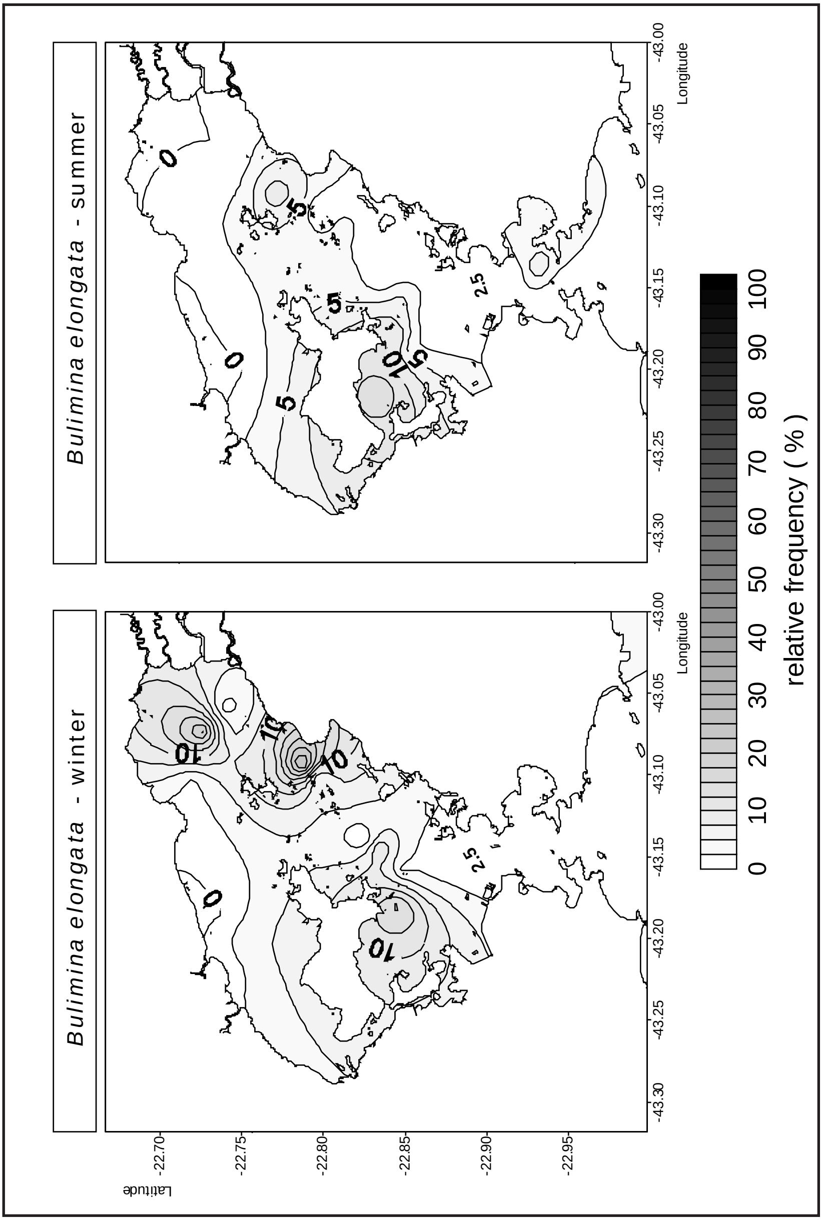

Figure 6 Spatial distribution of relative frequency of *B. elongata.*

blages. The low oxygen levels presumably have been originated from a high flux of organic matter. The eutrophic species *B. elegantissima* and *B. elongata* flourishes under low oxygen concentration and under conditions of rapidly accumulating organic matter which can be seen in spatial distribution of organic carbon (Tables 1 and 2). In summer, the organic matter is enriched in the central part of the bay due to the increase of domestic sewage from touristic activities during vacation periods. Besides that, microbial activity leads to destruction of organic matter causing anoxic sulphidic conditions at the sediment–water interface. In the winter the cool temperatures slow down microbial activities.

5 Discussion

Environmental monitoring is very difficult because little is known about its complex and highly dynamic nature of interactions in Brazilian coastal areas. Also, if we study an area subjected to different sources of inputs it gets really confuse to separate whether the effects are natural or antropogenic. Therefore, an evaluation of system health is dependent on either a spatial or temporal comparison with an identical situation. An indicator species is an organism whose presence can be used, as the name suggests, indicating well defined environmental conditions.

In the present study it was defined the principal environmental factors which appear to most strongly influence the habitat species. *Cassidulina subglobosa* and *Discorbis williamsoni* prefer high salinities and lower temperatures. According to Stevenson *et al.* (1998), *D. williamsoni* is known as temperate water species typical of the Argentine Province and their presence in the entrance of the bay indicate the penetration of cold waters in this area. In relation to availability of oxygen in the water, *Quinqueloculina seminulum* is intolerant to low oxygen bottom water whereas *Buliminella elegantissima, Bolivina striatula* and *Bulimina elongata* are tolerant to low dissolved oxygen content in bottom waters and high organic carbon content. These findings are related to the distributionn of species found in areas affected by sewage outfall all over the world. Bandy *et al.* (1965) have found .*B. elegantissima* populations adjacent to sewage outfall in California, and Seiglie (1968) found *Bulimina, Buliminella, Florilus, Nonionella* and *Fursenkoina* associated with sewage outfalls in Venezuela. The seasonality of food supply is largely dependent on local environmental features and temporal environmental characteristics of the Guanabara Bay tropical system which it is more productive in summer than in winter. In summer, the temperature elevation ocasionate increase in evaporation, rain and consequently increase of river flux and organic matter transport to the bay waters. These changes associated to tidal movements increase organic load and productivity and create different habitats to be occupied by foraminiferal species.

6 Conclusion

The use of foraminifera as indicator species facilitates the observation of the system vulnerability and the regions that needs more attention to not be polluted or have to be recuperated very soon. The south of Ilha do Governador and central parts of the bay where the presence of *Buliminella elegantissima, Bolivina striatula* and *Bulimina elongata* reaches higher dominances is the place where the saline water from the ocean is not capable to penetrate and oxygenate local waters, suggested by the dominance of *Cassidulina subglobosa* and *Discorbis williamsoni* only in the entrance of the bay. Therefore, if the water renewal is low the environment gets very susceptible to intense microbial action. By the other hand, the northeast of the Guanabara Bay, which is located in the Environmental Preserved Area of Guapimirim mangrove, is a place that is highly threatened by pressure of domestic sewage and occasional oil spills in the refineries located in the northwestern part (Duque de Caxias Refinarie-REDUC).

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8 References

Bandy, O.L.; Ingle, J.C. & Resig, J.M. 1965. Foraminiferal trends, Hyperian outfall, California. *Limnology and Oceanography, 10*: 314-332.

Debenay, J.P.; Eichler, B.B.; Duleba, W., Bonetti, C. & Eichler, P.P.B. 1998. Water stratification in coastal lagoons: Its influence on foraminiferal assemblages in two brazilian lagoons. *Marine Micropaleontology, 35*: 67-89.

Denne, R.A. & Sen Gupta, B.K. 1993. Matching of benthic foraminiferal depth limits and and water masses boundaries in the northwestern Gulf of Mexico: An investigation of species occurrences. *Journal of ForaminiferalResearch, 23*(2): 108-117.

Eichler, P.P.B. 2001. Avaliação e diagnóstico do Canal de Bertioga (São Paulo, Brasil) através da utilização de foraminíferos como indicadores ambientais. Unpublished PhD thesis, University of São Paulo, 240p and CD-Rom.

Kaiho, K. 1994. Benthic foraminiferal dissolved-oxygen indexand dissolved-oxygen levels in the modern ocean. *Geology, 22*: 719-722.

Seiglie, G.A., 1968. Foraminiferal assemblages as indicators of high organic content in sediments and of polluted waters: *American Association of Petroleum Geologists Bulletin, 52*: 2231-2241.

Stevenson, M.R.; Dias-Brito, D.; Stech, J.L. & Kampel, M. 1998. How do cold water biota arrive in a tropical bay near Rio de Janeiro, Brazil? *Continental Shelf Research, 18*: 1595-1612.