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Modern Diatom Distributions in Guanabara Bay Sediment and Oceanic Areas, Rio de Janeiro (Brazil)

Distribuição das Diatomáceas Modernas nos Sedimentos da Baía de Guanabara e Áreas Oceânicas, Rio de Janeiro (Brasil)

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Abstract

One hundred and fifty three superficial sediments were collected in Guanabara Bay to physical-chemistry and diatom analyses in the ambit to Monitoring Project (CENPES/PETROBRAS). A total of 146 taxa of diatoms were identified where the most frequent taxa in Guanabara Bay were *Amphora* spp., *Coscinodiscus* spp. and *Navicula yarrensis* var. *yarrensis.* These species are potentially harmful that might harm fisheries and mariculture during blooms. The values of ecological indexes like richness and diversity followed the estuarine gradient were the higher values were found in the mouth and de low in the inner part. The multivariate analyzes permitted recognize seven diatom assemblages in the bay. The DCA analyze shows the most influence in the distribution of assemblages were the depth and pH. The diatom assemblages analyze proved to be an efficient tool in the environmental diagnosis of Guanabara Bay.
Keywords: Guanabara Bay; benthic diatoms; environmental diagnosis

Resumo

Cento e ciquenta e três amostras de sedimento superficial da Baía de Guanabara foram coletadas durante o Projeto de Monitoramento Ambiental (CENPES/PETROBRAS). Foram identificados 146 táxons de diatomáceas onde as espécies mais abundantes foram *Amphora* spp., *Coscinodiscus* spp. e *Navicula yarrensis* var. *yarrensis.* Estas espécies identificadas são potencialmente tóxicas e podem prejudicar peixes e a maricultura durante períodos de florescência. Os índices ecológicos de riqueza e diversidade acompanharam o gradiente estuarino sendo maior na entrada da baía e baixos na região interna. As análises multivariadas permitiram reconhecer sete assembléias de diatomáceas na baía. As análises em DCA mostrou que os parâmetros ambientais mais influentes na distribuição das assembléias foram a profundidade e o pH. Os resultados obtidos mostraram que as assembléias de diatomáceas são uma importante ferramenta na caracterização ambiental da Baía de Guanabara.
Palavras-chave: Baía de Guanabara; diatomáceas bentônica; diagnóstico ambiental

1 Introduction

The complex nature of estuaries, derived from their hydrodynamics, as well as the presence of strong physicochemical gradients and intricate biological structure, imposes difficulties in forecasting the extension of anthropogenic impacts. Multidisciplinary approaches, specific sampling strategies, as well as multiple analytical tools and a variety of models, have been used to tackle this problem (Silva *et al.,* 2008).

Monitoring nutrient levels in estuarine systems is problematic because of periodic and diffuse input from non-point sources (Cattaneo & Prairie, 1995).

The micophytobenthos has been recently reviewed and was referred to as a “secret garden” (MacIntyre *et al.,* 1996). Diatoms are considered the most important constituent of this benthic microalgae assemblage in estuarine and shallow coastal environments (Mc Lusky, 1989). Several studies have revealed a highly diverse and productive diatom assemblage within coastal and shelf sediments (Admiraal *et al.,* 1982; Riaux, 1983; Riaux-Gobin *et al.,* 1998) – for instance, the chlorophyll *a* content per m^2 of shelf bottom may exceed that of the entire overlying water column (Cahoon *et al.,* 1990).

Diatoms are widely used to monitor polluted aquatic environments because they are sensitive to water chemistry, especially ionic content, pH, dissolved organic matter and nutrients. Wide geographic distribution and the well-studied ecology of most diatom species are cited as major advantages in using diatoms as indicator organisms (McCormick & Cains, 1994). These assumptions imply that diatom-based water-quality assessment tools should have universal applicability across geographic areas and environments.

Some studies have been done to understand the interactions between diatom populations on mudflats and various environmental factors that explaining their spatial and temporal distribution (Admiraal, 1977; Admiraal & Peletier, 1979; Adimraal *et al.,* 1982). However, the diatom metrics or indexes developed in some geographic area have less successful when reapplied in other areas (Pipp, 2002). This is due not only to floristic differences among regions, but also to environmental differences (Kelly *et al.,* 1998) that modify species’ responses to water-quality characteristics.

Ecological studies on estuarine and shallow coastal water diatoms are few in number, compared with freshwater and open ocean habitats (Sylvestre *et al.,* 2004), and very few studies have been done in tropical areas. The concern is mainly focused on temperate estuaries (Admiraal, 1984; Sullivan, 2001).

Considering the studies of coastal environment monitoring in order to evaluate the use of bio-indicators to assess the impact of human activities on urbanized littoral zone, this paper aims to study the distribution of modern diatoms on the sediment from Guanabara Bay to determine estuarine gradient and the impact of human activities on the quality of bay water and sediment.

2 Environmental Settings

Guanabara Bay is one of the largest bays on the Brazilian coastline, located in Rio de Janeiro State. The bay, including its several islands, has an area of approximately 384 km^2 and presents a coastline 131 km long and a mean water volume of 1.87 x 109 m^3 (Amador, 1997; Kjerfve *et al.,* 1997). The hydrographic basin extends over 4,080 km^2 and includes 45 rivers, 6 of which are responsible for 85% of the runoff (100 ± 59 m^3/s). The mean halfwater volume renewal time is 11.4 days, although in some parts of the bay it is significantly higher. Temperature (24.2 ± 2.6°C) and salinity (29.5 ± 4.8 S) profiles show a well-mixed water condition at the bay mouth, extending up to 15–20 km inwards. Thereafter, the system is moderately stratified. A sandbank located on the ocean side of the bay mouth greatly influences the inner water circulation due to current channeling (Kjerfve *et al.*, 1997).

Tides are mixed mainly semidiurnally with a range of 0.7 m and peak spring tidal currents reach 0.5 m/s inside the bay and 1.6 m/s near the bay entrance. The central channel, with depths of 30-40 m and delimited by the 10 m depth isoline, transports the sand into the bay. The bottom topography is influenced by tidal currents that drain through the central channel, and by a strong sediment input. The increase in width after the entrance channel results in a decrease of tidal current velocities, leading to the deposition of fine sands and mud. Coarse sands predominate in the central channel and in the regions near the bay mouth. Extensive mud deposits resulting from the active transport of clastic material and from intensive primary production are found in the bay's northern area (JICA, 1994; Kjerfve *et al.,* 1997).

A strong stratification of dissolved oxygen is observed in areas where depths are under 10 m. Surface oxygen values reach 300% oversaturation in the photic zone (< 5 m), while bottom (4-5 m) concentrations may stay below 1 ml/l (Rebello *et al.,* 1990). Approximately 11 million inhabitants live in the Greater Rio de Janeiro metropolitan area and, as a result of rapid urbanization and population growth, untreated sewage is discharged directly into the bay.

This area is the second largest industrial region in Brazil and has over 12,000 industries operating along the Guanabara Bay drainage basin, and these account for 25% of the organic pollution released into the bay (FEEMA, 1990). Two oil refineries process 7% of the national oil and approximately 2,000 commercial ships dock in the port of Rio de Janeiro every year, making it the second largest harbor in Brazil. The bay is also homeport to two naval bases, a shipyard, and a large number of ferries, fishing boats and yachts (Kjerfve *et al.*, 1997). Over the past 100 years, catchment areas around Guanabara Bay have been greatly modified by deforestation and uncontrolled settlement. These activities have increased river flow velocities and transport of sediment load, resulting in a sediment deposition of 1 to 2 cm/year (Godoy *et al.,* 1998). Guanabara Bay is considered one of the most polluted environments on the Brazilian coastline (Rebello *et al.,* 1986; Baptista-Neto *et al.,* 2006).

3 Material and Methods

One hundred and fifty three sediment samples were collected with Ekman grab between October 2005 and May 2007 as part of the PETROBRAS Guanabara Bay Environmental Monitoring Project (Figure 1). Sample sites were chosen to represent the different perimeter characteristics, including natural and human impacts. Surface sediment samples were collected (10 ml) by scraping 5 mm from several points within the grab area, in order to reduce bias due to patchy distribution of diatom cells. The measurements of physical-chemical patterns were taken with portable equipment.

Grain size analyses were performed according to Suguio (1973) method, in which wet sediment samples pass through a 0.062 mm sieve. The sand is separated from the mud. The silt and clay fractions were analyzed using the pipette method.

Total organic carbon (TOC) and total nitrogen (TN) were determined on precisely weighed (2–5 mg) sediment samples using a Carlo Erba EA 1110 elemental analyzer. Inorganic carbon was removed prior to the analyses with hydrochloric acid, following the method of Hedges & Stern (1984). Quantification was performed by using calibration curves and cystine as standard. Reference material MESS-2 (National Research Council of Canada) was used to verify accuracy. Analytical precision was G1.7% for TOC and G2.8% for TN while detection limits were G0.06% for TOC and G0.01% for TN.

The sediment (10 ml) was processed with 10% HCl and 30% H_2O_2 to remove carbonates and organic matter, respectively. A small quantity of sample (0.4 ml) was evaporated onto cover slips, and subsequently mounted onto a glass slide with Naphrax. A minimum of 300 diatom valves were identified and counted along parallel transects from each sample using a Zeiss light microscope (1,000 x magnifications).

Taxonomic identifications were based on several works, including Hendey (1964), Schoeman (1973), Ehrlich (1975), Germain (1981), Krammer & Lange-Bertalot (1986–1991), Noël (1984), Ehrlich & Dor (1985), Simonsen (1987) and Ehrlich (1995). Data concerning ecology of the taxa were compiled from previous references, in addition to Noël (1982), Poulin *et al.* (1984, 1986), Gasse (1986), Dor & Ehrlich (1987) and Witkowski (1994).

Ecological index such as abundance, richness (number of species), constancy, diversity and equitability were used in interpreting the data on the identified species.

Abundance is the individual percentage of a given species in relation to the total population. Constancy is the relationship between the species and the samples, expressed as a percentage according to C=100p/P, where p is the number of samples that contain a given species and P is the total number of samples. Species are considered constant when they are present in more than 60% of samples (Tinoco, 1989).

Diversity (*H'*) is an index proposed by Shannon-Wiener (1949) that is appropriate for random samples of species from the community or sub-community of interest and is estimated by $H' = \Sigma p_i \mathrm{Ln} p_i$, where p_i represents the proportion of the *i*-th species in the sample and Ln is the natural (base e) logarithm. For calculation of the diversity (*H*') index the Software MVSP 3.1 was used. Equitatibility (*J'*) refers to the individual's distribution among species, being proportional to the diversity and inversely proportional to the dominance. It compares the Shannon-Wiener diversity with the distribution of the observed species, maximizing the diversity. This index is obtained through $J' = H'/\mathrm{Ln}\ (S)$, where S is the richness of species, *H*' is the Shannon diversity index and Ln is the natural (base e) logarithm. The Software MVSP 3.1 was used.

To multivariate analyses we used stations in which the number of frustules counted was greater than 100. Diatom abundance data were standardized to the square root of 0.5. Detrended Correspondence Analysis (DCA or DECORAMA) was used to show which of the environmental variables measured influences community structure. To calculate percentage of variance, Relative Euclidean Distance in PCord 4.0 software was used. Environmental variables used in DCA analysis were temperature, salinity, carbon concentration, pH, Eh, depth, oxygen, nitrogen, phosphorus and C/N relation.

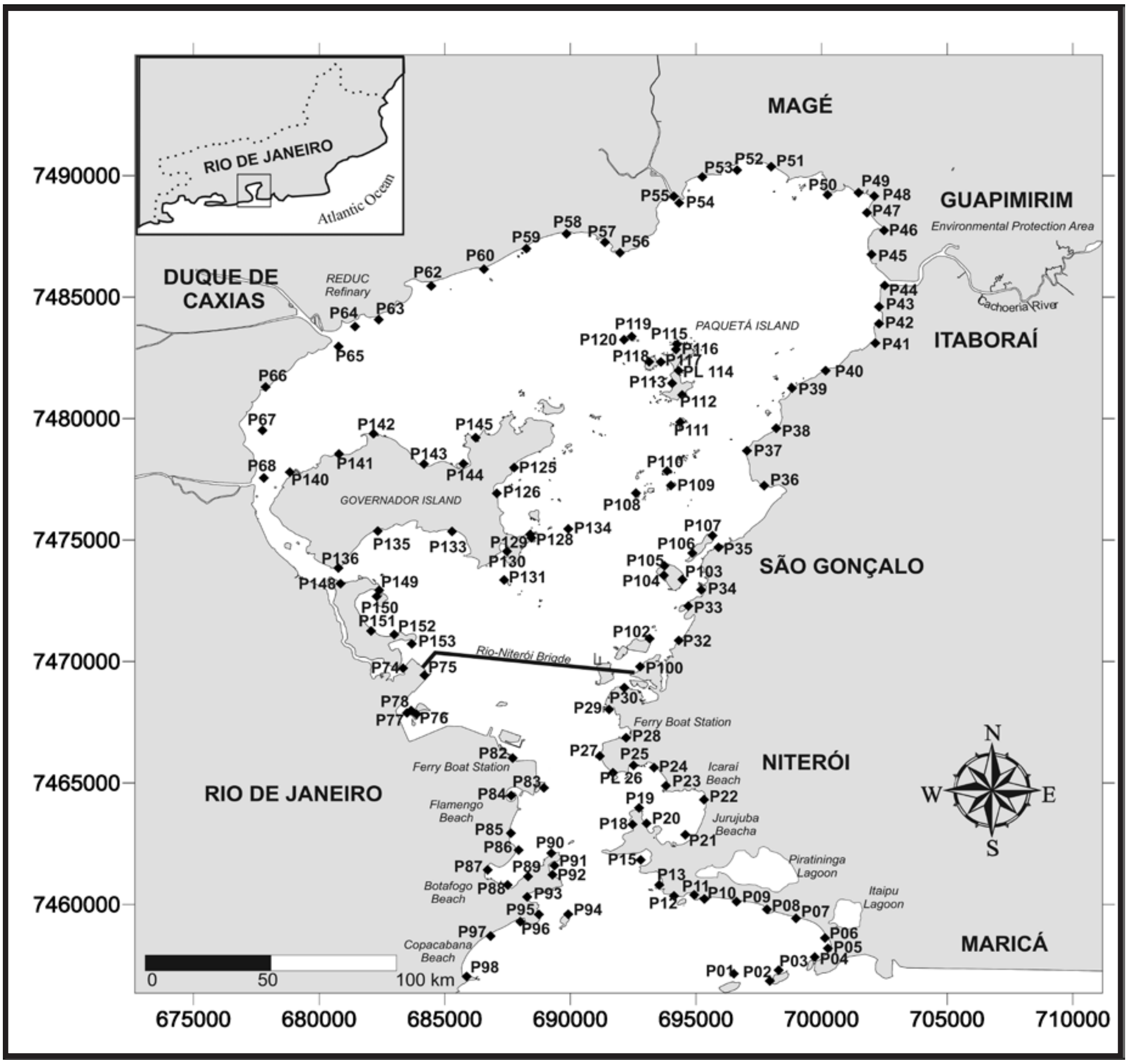

Figure 1 Location map showing the position of the sampling sites in Guanabara Bay, Rio de Janeiro, Brazil.

4 Results

4.1 Abiotic

The temperature, salinity and pH values ranged from 23.0 - 25.0 °C, 10.0 - 36.0, and 6.68-7.85, respectively. The means were 23°C, 30 and 7.48, respectively. The highest temperature values were found at the river mouths and in the northwestern bay. Salinity and pH were highest in the central channel (Figure 2).

The Eh and dissolved oxygen values ranged from -700 – 326 and 0.0 - 8.3 mg/l, respectively. Mean values were -123 and 1.9 mg/l, respectively. The highest values were found at the mouth of the bay (Figure 3).

The values of total organic carbon (TOC), nitrogen and phosphorus ranged between 1.09 - 8.14%, 0.23 - 1.27% and 531 - 1032 ug/g, respectively. Mean values were 2.00%, 0.37% and 159.92 ug/g, respectively. The highest values were found in the northwestern part of the bay and at the river mouths (Figures 3 and 4).

The C/N rates ranged between 7 - 15% and the mean was 12%. The highest values were found before the Rio de Janeiro-Niterói Bridge on both sides of the bay mouth (Figure 4).

The grain size distribution reflects the tidal current energy near the bottom, which is directly influenced by bottom morphology and the Guanabara Bay shoreline contour. Bay bottom sediment ranges from clay to coarse sand. Sedimentary textures can comprise from 0% to 100% sand, 0% to 92% silt and 0% to 85% clay. The samples from Guanabara Bay were classified into three principal groups: sand, silt and mud, by mean (Figure 5).

4.2 Biotic

A total of 146 diatom taxa were identified (Tables 1-5) in seventy six samples, while 51 are exclusively benthic and 18 exclusively planktonic. In 77 stations no diatom frustules were identified, and at some stations like P38, P40, P42, P45, P46, P48, P52, P134 and P150 the number of frustules was not greater than 100 (Tables 1-5).

Navicula spp., *Plagiogramma pulchellum* and *Navicula sulcata* were the dominant species at sampling stations, with 15-56% total frustules. *Amphora* spp. and *Gramatophora marina* displayed highest abundance values at the stations facing the bay mouth. *Bidduphia* spp. showed most significant frequencies behind Governador Island. *Paralia sulcata* was found abundantly at São Gonçalo coast and Paquetá and Governador islands (Tables 1-5).

Navicula yarrensis var. *yarrensis* presented the highest constancy index, being present at 83% of stations sampled. *Amphora* spp. (78%), *Plagiograma* spp. (73%), *Coscinodiscus* spp. (78%), *Cocconeis* spp. (52%) and *Coscinodiscus marginatus* (50%) also presented high constancy index in Guanabara Bay (Figure 6).These taxa's highest frequencies occurred at the stations in the central area of the bay, in small inlets like Botafogo and Jurujuba and in the area behind Governador and Paquetá islands.

Chaetocerus spp. presented low constancy index (10%) concentrated in the mouth of bay (stations P04, P05, P15, P20, P87, P89, P94 and P95) and Paquetá Island (P112, P114,P117 and P120) with the abundance between 1-9%.

Coscinodicus centralis showed low constancy index (15%) and low abundance (1-3%) in the mouth of bay (P01, P03, P04, P15, P19, P20, P27) and São Gonçalo coast (P103, P108, P111).

Gyrosigma spp. presented low values of constancy index (25%) distributed dispersal along the bay showed abundance between 1-20%.

Pseudo-nitizschia spp. was presented in 30% of stations principally distributed in the inner portion of bay when it showed low values of abundance (0-3%).

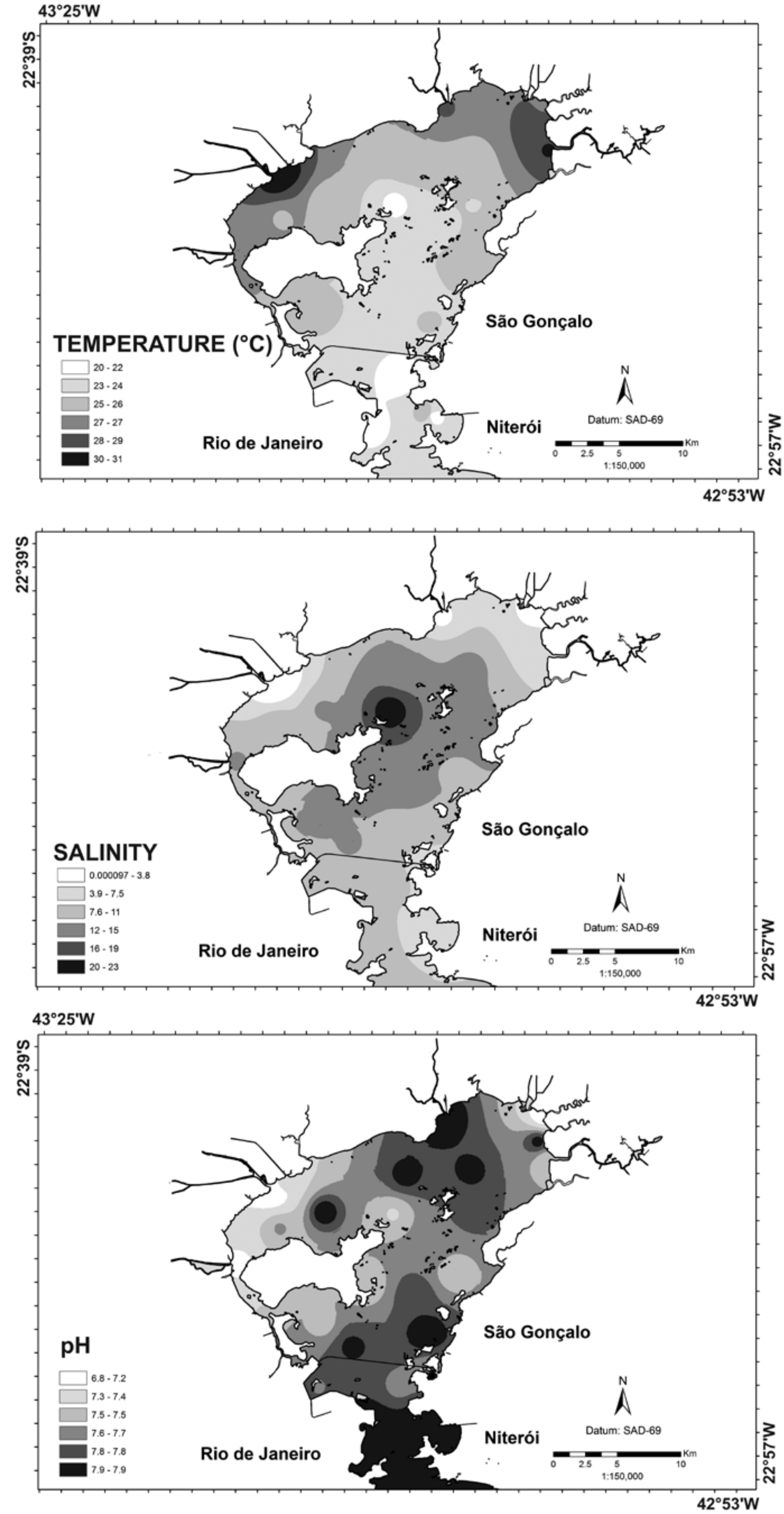

Figure 2 Abiotic parameters (temperature, salinity and pH) from Guanabara Bay. These dates were collected during the Guanabara Monitoring Project by PETROBRAS.

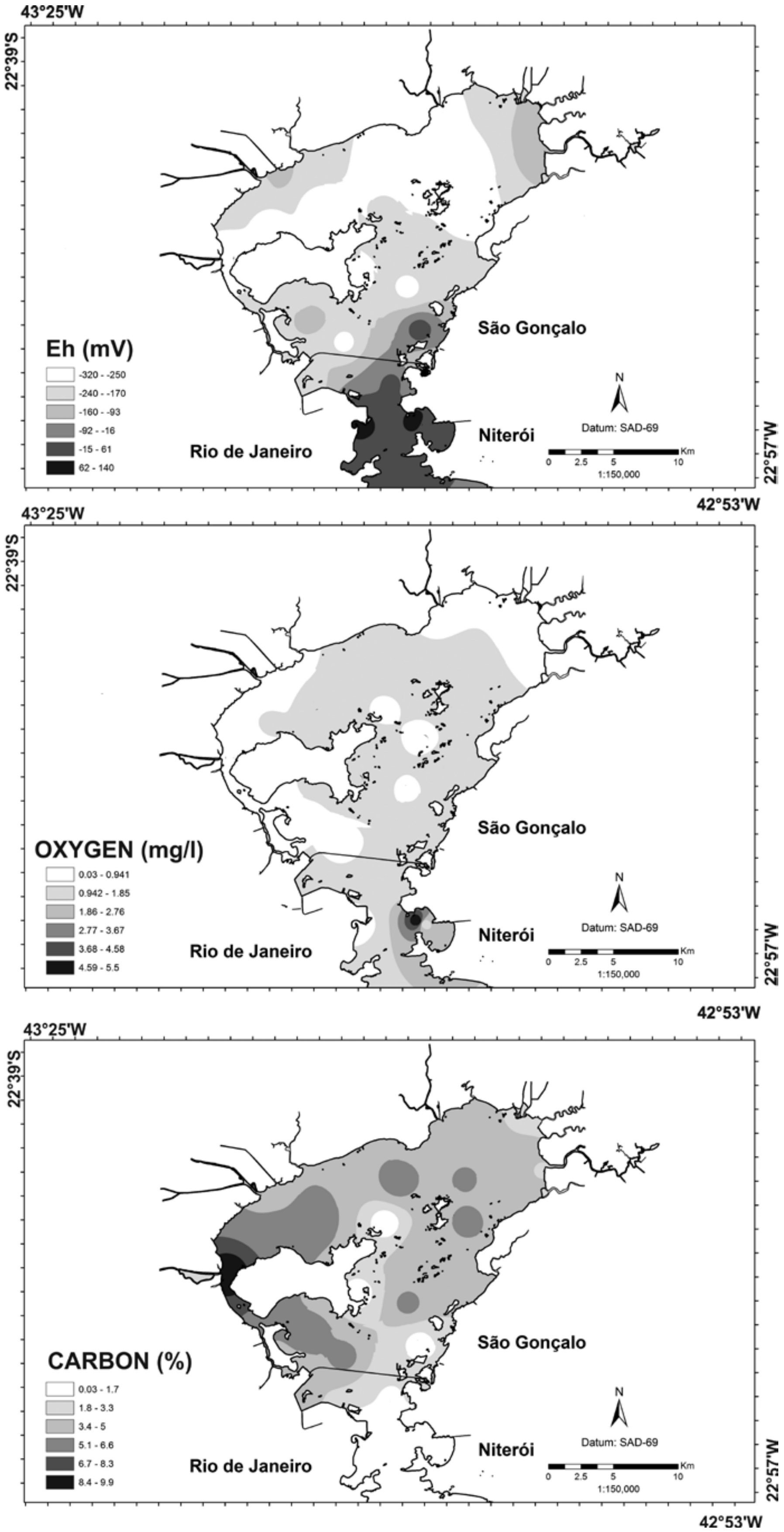

Figure 3 Abiotic parameters (Eh, Oxigen and Cabon-TOC) from Guanabara Bay. These dates were collected during the Guanabara Monitoring Project by PETROBRAS.

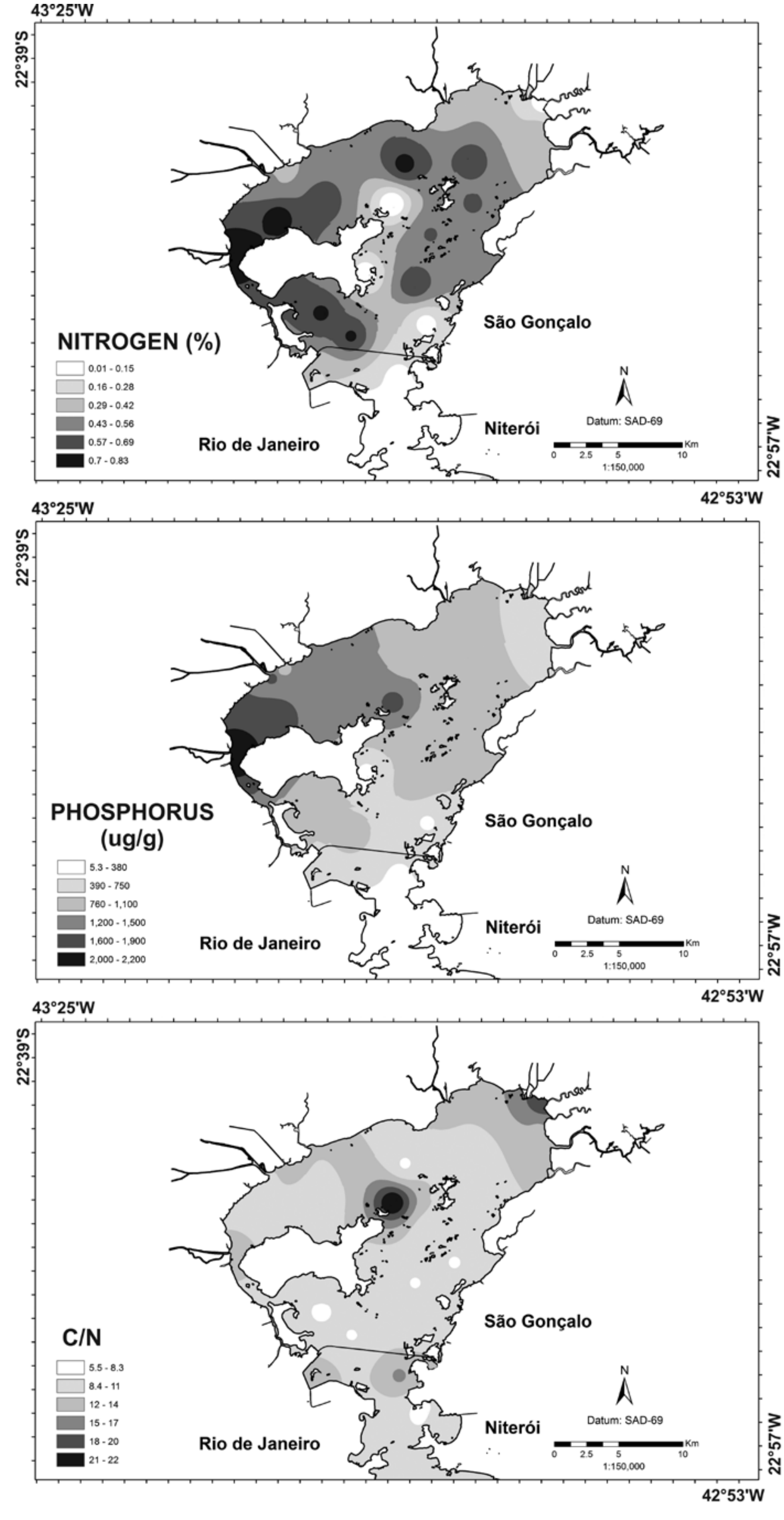

Figure 4 Abiotic parameters (nitrogen, phosphorus and C/N) from Guanabara Bay. These dates were collected during the Guanabara Monitoring Project by PETROBRAS.

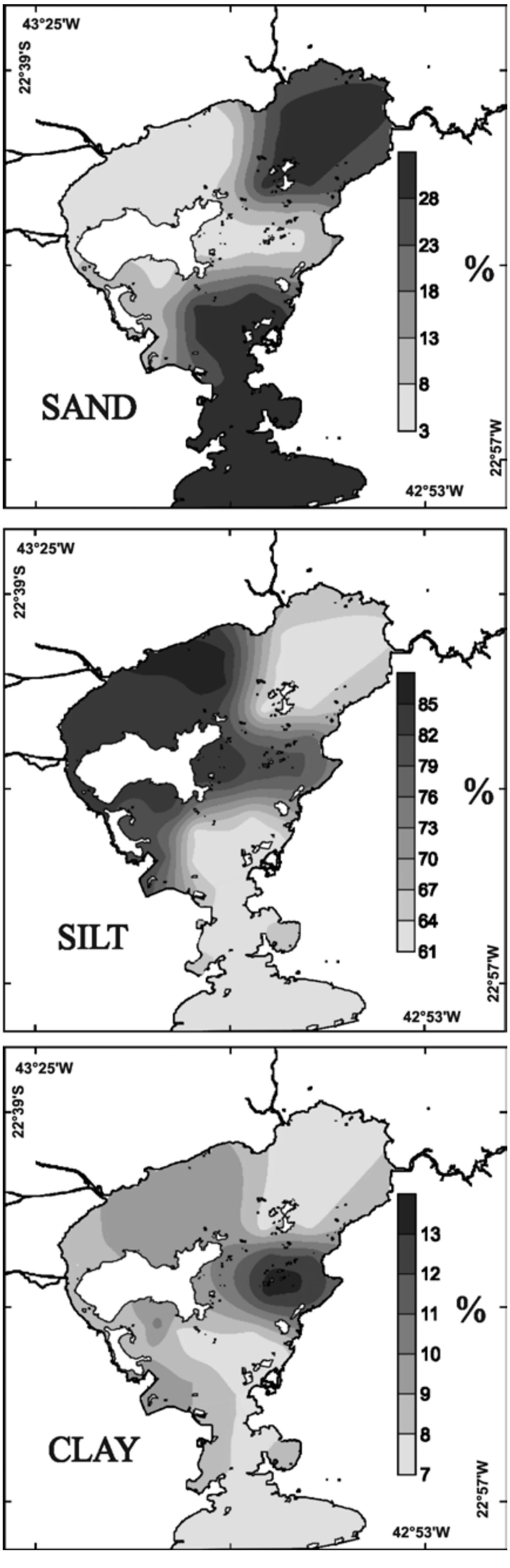

Figure 5 Grain size analysis from Guanabara Bay.

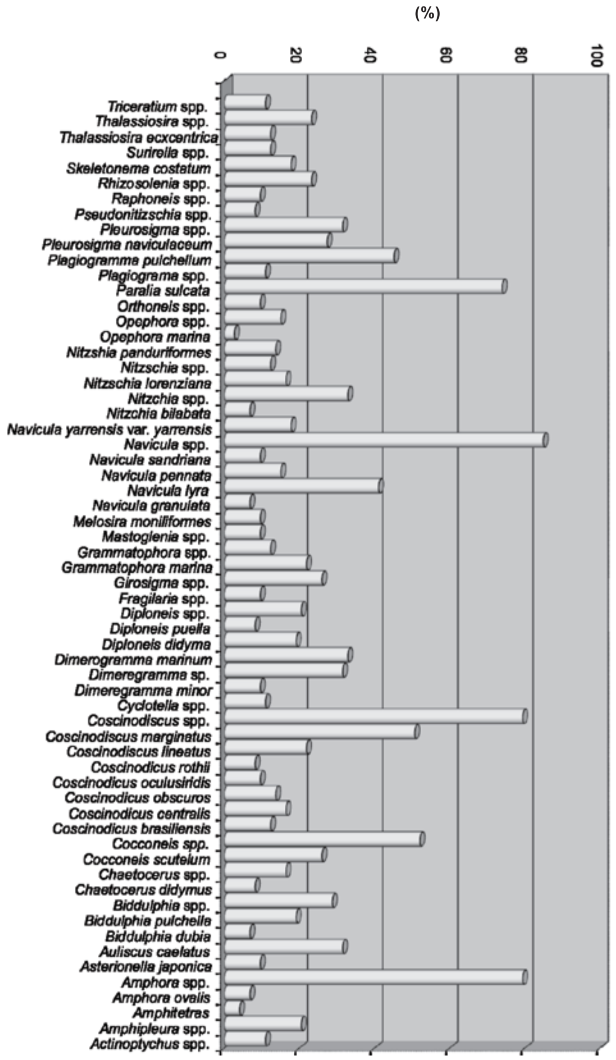

Figure 6 Constancy of diatoms species in Guanabara Bay.

Richness decreased toward the inner area of Guanabara Bay. Mean richness at the bay mouth was 17 species/station, while in the inner bay it was 15 species/station. Stations P 50 (2 species), P52, P45, P46 and P48 (3 species), P40 (4 species) and P42 (5 species) presented the lowest richness values in the inner bay. In the middle region, with a mean of 16 species/station, only 3 stations presented very low index: P150 (5 species), P38 and P48 (8 species) P48. At the bay mouth the only anomalies were seen at station P07, which presented 2 species, and at P21, with 8 species (Tables 1-5).

A decreasing gradient was also seen for the diversity index *H'*, with values of 2.1, 2.0 and 1.7 for the bay mouth, middle region and inner bay, respectively. The station presenting lowest diversity was P 116 (0.3) in the inner bay, and the one presenting the highest was P 15 (2.8), in the middle part. The equitability index values were between 0.2 in the station P116 and 1.0 in the stations P07 and P40 (Tables 1-5).

Q-mode cluster analysis generated seven station groups using a cutting at the 60% level (Figure 7): Group A comprised stations in the inner bay except for P01; Groups B and C comprised stations spread all over the bay; Group D comprised stations from the most confined region of Governador Island; and Groups E, F and G were composed of stations in the bay's middle region, including Paquetá and Governador islands.

Multivariate DCA analysis presented a correlation coefficient between distances of 47% for axis 1 and of 13% for axis 2, defining six stations groups (Figure 8). Environmental variable pH, followed by depth, was the most influential variable on axis 1. On axis 2 salinity displayed the largest vector, followed by temperature, carbon and Eh. The C/N ratio presented a 45º vector and therefore showed no significant influence in the analysis. Oxygen, nitrogen and phosphorus had very short vectors and were at the center of the axis.

Group I (P33, P53, P112, P113, P114, P115, P116, P117, P118, P119, P125, P120, P126) comprised all stations positively correlated to pH and negatively correlated to depth from around Paquetá island, as well as those negatively correlated to salinity and positively correlated to temperature, carbon and Eh. Group II was more dispersed in the graph, behaving towards the variables but similar to Group I. Group III (P63, P114, P130, P145) comprised samples from Governador island's most confined region and from station P63 on the bay's west region. This group correlated negatively to pH and positively to depth on axis 1. On axis 2 it correlated negatively to salinity and positively to temperature, carbon and Eh. Group IV (P01, P02, P03, P05, P15, P19, P20, P27, P36, P87, P89, P92, P90, P94, P103, P108, P129, P141) comprised all stations related to sandy sediment regions. These stations were negatively correlated to pH and positively correlated to depth. In relation to axis 2, stations were very close to the center of the axis, not showing great influence. Group V comprised stations facing the mouth of the bay. These stations correlated negatively to pH and positively to depth. In relation to axis 2, this group was the one that correlated most positively to salinity and most negatively to temperature, carbon and Eh. Group VI was situated very near the center of the axis and had

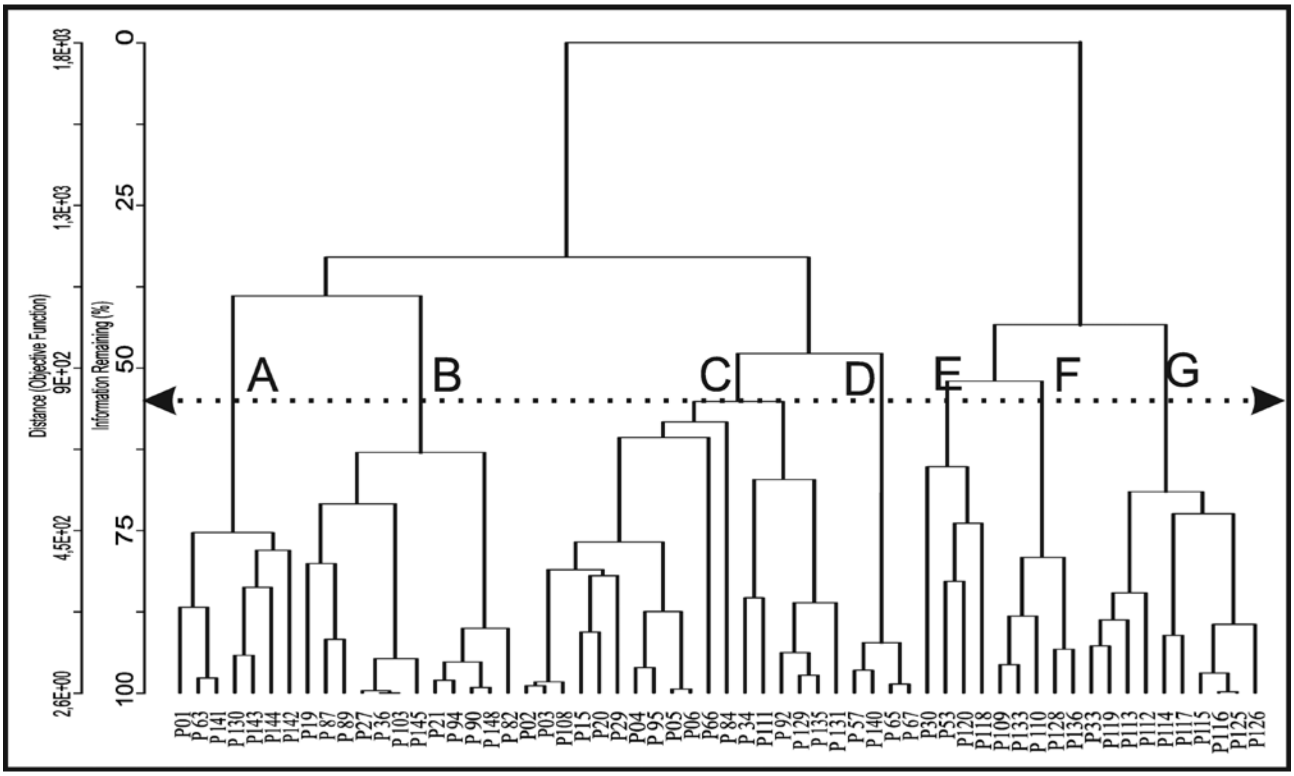

Figure 7 Cluster analysis in Q-mode of diatoms samples stations in Guanabara Bay.

no significant relation to axis 1. On axis 2 this group correlated positively to salinity and negatively to temperature, carbon and Eh (Figure 8).

The same analysis, when performed with benthic diatoms, showed that *D. marinum, Cymbella* spp., *N. henedy, N. granulata, C. hustedii, C. obscuros, Orthoneis spp., N. sandriana, P. lineatus* and *P. agutum* were the species most correlated to basic pH and shallower depths, and *P. fasciola* was most correlated to acid pH and greater depths. In relation to axis 2 parameters, *Pleurosigma* spp. and *Navicula* spp. correlated to the highest salinities and lowest temperatures, while *P. acominatum*, *E. alata* and *N. yarrensis* correlated to the lowest salinity value and the highest temperatures, carbon and Eh (Figure 8).

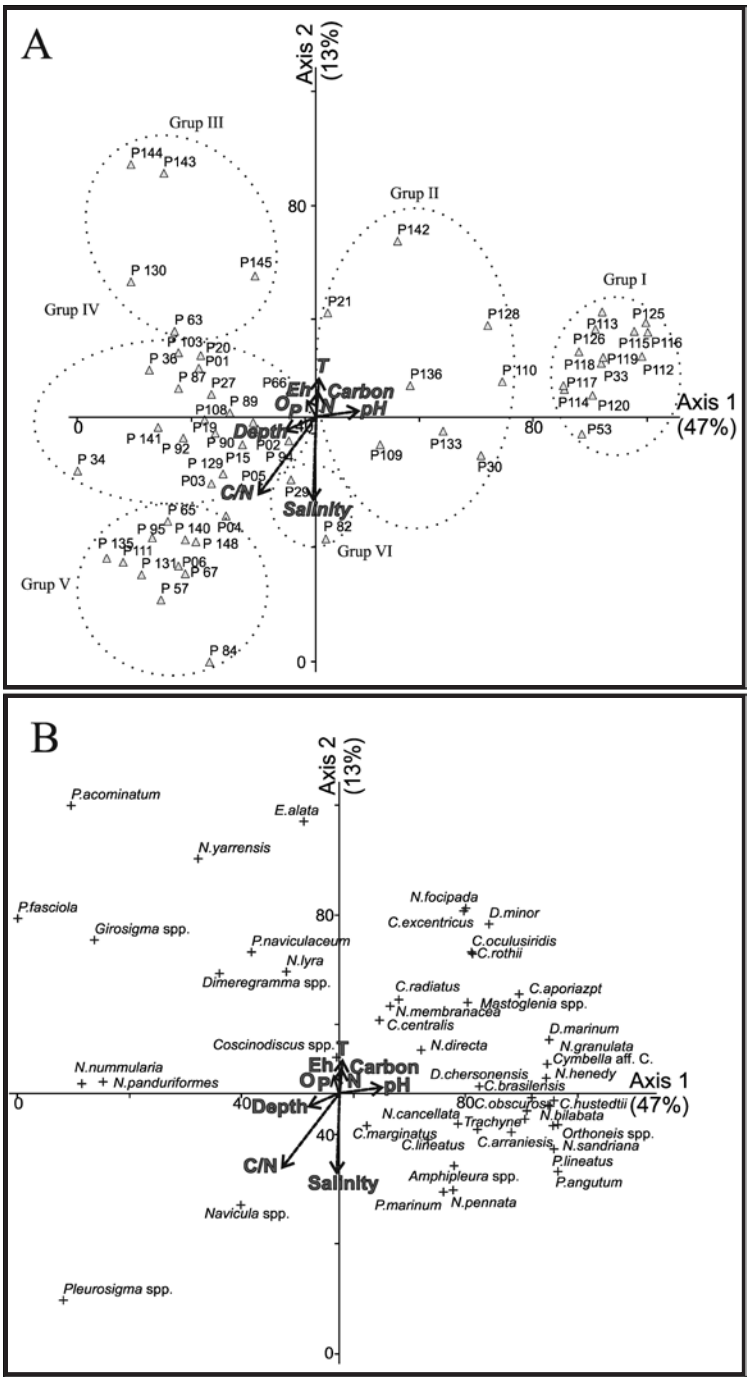

Figure 8 DCA analysis of Guanabara Bay. When O = oxygen; T = Temperature; P = phosphorus.

5 Discussions

The physicochemical patterns (temperature, salinity and dissolved oxygen) identified in Guanabara Bay agreed with those found by other authors. FEEMA (1990) took measurements near the surface and near the bottom at 13 stations during the period 1980-1993, and found a mean salinity of 29.5 ± 4.8$\%_0$ with a total range of 9.9 - 36.8$\%_0$. Based on 660 measurements by FEEMA at the same depths and stations, the mean water temperature is 24.2 ± 2.6°C with a total range of 17.0 - 31.0°C. As could be expected, net salinity decreases horizontally from the mouth towards the inner reaches of Guanabara Bay, at the surface from 31.8 to 21 and near the bottom from 34.59 to 26.1, due to the fresh water discharge along the inner margins. At the same time, the temperature increases from the mouth to the inner reaches of the bay, at the surface from 24.6°C to 26.5°C and near the bottom from 21.4°C to 25.5°C, due to the advection of colder ocean water into the bay. The entrance of cold water into Guanabara Bay on a regular basis, particularly during the austral summer, is associated with the Cabo Frio Island upwelling system (Kjerfve *et al.,* 1997).

Kjerfve *et al.* (1997) founded that dissolved oxygen concentrations show large temporal fluctuations in both surface and bottom waters. Mean values do not vary significantly horizontally, with the exception of the sites near the discharge of pollution-rich runoff, where bottom dissolved oxygen concentrations varied from 3.1 to 4.3 mg.l^{-1}. On the other hand, the bay shows strong vertical stratification, with dissolved oxygen in the bottom layer 2.3-4.8 mg.l^{-1} (20-45%) lower on the average than in surface waters. In surface waters, the mean dissolved oxygen concentration for all stations was 8.4 mg.l^{-1} (124% saturation), and in the bottom layer 5.1 mg.l^{-1} saturation. Dissolved oxygen concentrations at the inner bay sites at times reach anoxic conditions near the bottom. Surface waters, in contrast, are frequently supersaturated with respect to dissolved oxygen, even in highly polluted areas, which reflects the high rate of phytoplankton primary production.

The sand sediment occurs in the mouth of bay and follows the main channel, which constitutes the deepest part of the bay. This area is subject to intense hydrodynamic action from waves and tidal currents, indicated by the presence of sand waves (Catanzaro *et al.,* 2004). According to Quaresma *et al.* (2000) and Kjerfve *et al.* (1997), these sand waves occur along the eastern margin of the central channel between the 10 and 6 m isobaths. These sand waves attain heights of 0.5-2.5 m, lengths of 18-98 m, and decrease in both height and wavelength from the ocean into the bay in response to decreasing tidal energy. The sand waves have steeper slopes facing the bay, indicating wave progression and bottom sand transport into Guanabara Bay.

The north and center areas of the bay are also characterized by the presence of muddy sediments. In the bay's innermost region, in the north of Governador Island (NW), predominance of clay-silts is seen, a coarser sedimentation than in the NE side in the same region. This probably occurs because rivers providing input to this area are strongly impacted by human activity, which indicates significant population density in the region. On the other hand, in the NE bay muddy sediments clays predominate. Such sedimentation can be explained as a product of the combination of lower hydrodynamics with the presence of mangrove vegetation, which acts as a trap, which allows only the finest sediment to pass into the bay.

TOC results obtained were similar to those from the literature. Baptista-Neto *et al.* (2000) found 3-5% variation in total organic carbon for Jurujuba Inlet, Guanabara Bay. The authors justified these values by the restricted entrance of water and the high levels of domestic effluents. The lowest levels were found in higher energy environments, at the Cachoeira River mouth and the southernmost part of the inlet. Carreira *et al.* (2001), looking for an indicator of recent pollution for domestic sewage in the bay, sampled 8 stations and found TOC values of 2.83–5.54 %. The highest value was found more at northeast, near the mangrove forests, indicating high contamination levels. This region is characterized by water input from a great number of contaminated rivers and by the low water renewal rate. Eichler *et al.* (2003) found similar values when they collected samples in winter and summer in Guanabara Bay, obtaining values ranging from 0.018 to 5.763% in winter and 0.243 to 6.023% in the summer. Vilela *et al.* (2003) found TOC values of 0.04–4.14 % (bay mouth); 1.9 – 3.89% (central channel); 0.31– 6.13 % (Rio de Janeiro harbor); 3.23–4.2 % (Niterói harbor); 3.7-4 % (Guapimirim APA) and 3.09–4.81 % (REDUC). Vilela *et al.* (2003) concluded that the high TOC values in some samples can be accounted for by the proximity to oil refinery pipelines and industrial and domestic sewage discharges. In the central area, TOC values increased as depth decreased, close to the coasts of Rio and Niterói.

The distribution of brackish planktonic species along the central channel and at the bay mouth indicates an efficient circulation in the system, although the highest values of brackish species abundance were found in low-energy regions such as behind Governador and Paquetá Islands, and in Botafogo and Jurujuba Inlets. *Pseudo-nitzschia* spp. was identified only in Paquetá Island stations (P111, P113, P114 and P119). These species occur in chains of up to eight cells (Lange *et al.,* 1994) and are abundant in estuarine systems. The low occurrence of *Pseudo-nitzschia* spp. frustules in Guanabara Bay was interpreted to indicate that these thin-walled, poorly silicified planktonic diatoms failed to preserve their frustules in saline (32–34), slightly alkaline (7.6–7.8) and anaerobic sediments. The genus *Pseudo-nitzschia* has been known as a potential domoic acid producer (Hasle, 2002). High concentrations of this acid in water, caused by *Pseudo-nitzschia* blooms, can be toxic because domoic acid accumulates in the food chain (Bates *et al.,* 1989). Intoxication effects are stomach disturbance, vertigo and, in serious cases, death of the organism (Procopiak *et al.,* 2006).

The acidophilic taxon *Frustulia* is normally found up rivers (Wetzel, 2001). Its occurrence at the mouth of the bay may be the result of water exchange between Itaipu Lagoon and Guanabara Bay. Thus, the occurrence of the marine species *Amphora* spp., *Gramatophora marina* and *Coscinodiscus centrales* (Sylvestre *et al.,* 2004) at the bay mouth signals the transport of marine sediment and of ocean water into the bay.

Navicula yarrennsis was the most constancy species in Guanabara Bay but it was not found in the lecture information about its ecological preferences

Paralia sulcata was the second constant species in Guanabara Bay. This species is habitually found in coastal plankton, and can also be benthically associated to sand sediment. It is very adaptable to depositional conditions, low depths, salinity variation and mud sediments rich in organic matter (Gutiérrez & Schillizzi, 2002).

The genera *Nitzschia* and *Gyrosigma* are characterized by high motility rates within the sediment (Admiral, 1984), are particularly adapted to fluid sediment conditions and could probably be considered as biological indicators of degree of substrate stability. On the other hand, *Navicula* spp. is the taxon which grows under more stable sediment conditions (Syvestre *et al.,* 2004). In Guanabara Bay, *Nitzchia* spp. and *Gyrosigma* spp. were most frequently found in organic mud sediment, low oxygen conditions, acid pH and low carbon concentrations (P34, P40, P63, P130).

Some species are considered as potentially harmful but not toxic, because their blooms have been related to mortality of filter-feeding organisms. The genus *Chaetoceros* has been reported in the literature to harm the gills of filter-feeding organisms, because of the ornamentation arrows in their frustules. On the Rio de Janeiro State coast, this genus has been found with more significant abundance at the mouth of Guanabara Bay. *Coscinodiscus centralis* produces polysaccharides which, at high concentrations, can render the environment anoxic. This species is also abundantly found in other bays in southern Brazil (Procapiak *et al.,* 2006). In Guanabara Bay it shows constant but low abundance. We could not find any information in the literature on the potential toxicity of other *Coscinodiscus* species.

Both diversity and richness values were found as a result of the estuarine character of Guanabara Bay. At the mouth, the exchange with oceanic water collaborated to the existence of more species. However, in the inner bay, with its low hydrodynamics and a limited renewal of oligoelements, species numbers fall.

The Shannon diversity index was used in several studies to assess the occurrence of pollution in biologic sampling. Values >3 can be considered as indicators of non-polluted conditions; values between 1 and 3 of moderated polluted conditions; and values <1 of a highly polluted condition (Matta & Flym, 2008). There were no stations with a Shannon index >3 in Guanabara Bay. Diversity index means in Guanabara Bay stayed between 1.7 and 3, indicating a moderately polluted condition. According to the Shannon diversity index, the most polluted regions were Piratininga Beach (P07), Guapimirim and Magé coasts (P45, P50, P52 and P 57), Duque de Caxias coast (P66), Paquetá Island (P115) and Governador Island (P125). In addition, stations P66, P116 and P125 showed a lower equitability index. This is the reflex of the diatom population disequilibrium in these regions.

The distribution pattern of assemblages varied significantly among sampling sites, and indicated changes in the floristic composition based on ecological factors. Cluster analysis and DCA indicate that diatom distribution in Guanabara Bay was influenced by environmental factors such as pH, salinity and temperature.

Q-Mode cluster analysis revealed individual compartments in the bay. Groups A and D represented the most parallic environment in the bay. On the other side, Groups B and C represented the central channel, where higher hydrodynamics exist. Groups E, F and G represented channels between the islands.

DCA showed that the Paquetá and Governador Island stations (Groups I and II) were the most acidic sites. These regions receive discharge from rivers and tidal channels in the coastal. Consequently, they have low salinity, low depth, high temperature, high Eh and carbon concentration. The other groups (III, IV, IV and VI) were separated basically by depth and salinity.

Ponader *et al.* (2007) found through multivariate analysis that nutrient concentrations (phosphorus and nitrogen total) were important in explaining variations in diatom assemblage composition. In our analysis, these patterns showed secondary importance to diatoms distributions. The oceanic influence can plays the most important role in the biological features of the bay.

Most nutrient concentrations are caused by discharge water from drains and channel that runoff to the bay. High human population density and high levels of atmospheric pollution characterize this area (Amador, 1980; Baptista-Neto *et al.,* 2006). Among the physical and chemical variables, particularly organic concentration and eutrophication seem to be the most important environmental factors determining the composition and structure of diatoms species composition (Oliveira *et al.,* 2001). In the DCA we did not test for TOC influence on assemblages. Nevertheless, we could see that at the stations where high values of TOC were measured, diversity, richness and equitability were low.

> We did not consider that in harbor regions such as Guanabara Bay the increase in turbidity and suspended solids during dredging significantly changes light penetration. Fine, living particles in suspension interfere with light penetration and constitute an important environmental factor in growth distribution of both attached and planktonic algae (Reynolds, 1996). Benthic diatom density can be decrease immediately after dredging or any events that revolve the sediment (Licursi & Gómes, 2009). In turbid habitats, implicated in sediment loading/resuspension, periphyton can actually bloom, partly because of an enhanced access to nutrients from close association with the incoming sediments that become an accumulated in substrate. Licursi & Gómes (2009) found the diversity and number of species increased in sites where dredging works were carried out.

6 Conclusion

The physicochemical parameters identified along Guanabara Bay do not differ from those already reported in the literature where an estuarine gradient can be clearly defined. The back part of Governador Island and the river mouths that cross the mangroves accumulate fine sediment and organic matter, becoming an anoxic, acid environment with great nutrient concentration. On the other hand, the central and outer parts of the bay present sandy sediment with organic matter concentrations restricted to the inlets, conditions which reflect the high hydrodynamics.

The great diatom species richness could be identified in the bay with dominance of *Navicula* spp. and *Plagiogramma* spp. and the most constant species in the bay was *Navicula yarrensis* var. *yarrensis.*

Potentially harmful species that might harm fisheries and mariculture during blooms were identified. Tourism might also be harmed, since the algae secrete compounds that create bad odors and confer a disagreeable appearance to the water, compromising balneability. However, these species' populations were small during sampling.

Low diversity and equitability index were identified, showing polluted conditions especially at Paquetá and Governador islands.

The applied multivariate analyses indicated the existence of seven groups of diatoms in Guanabara Bay, mainly by pH, depth, salinity and temperature.

The benthic diatom species *D. marinum, Cymbella* spp.*, N. henedy, N. granulata, C. hustedii,* *C. obscuros, Orthoneis* spp., *N. sandriana, P. lineatus* and *P. agutum* were the species most correlated to basic pH and shallower depths, and *P. fasciola* was the species most correlated to acid pH and greater depths, and may be used as environmental bioindicators for these conditions.

Analysis of diatom assemblages proved an efficient tool in the environmental diagnosis of Guanabara Bay. These results can be used in monitoring and environmental planning studies, as well as in studies of Quaternary paleoenvironmental reconstruction. It is important to point out that harbor regions such as Guanabara Bay, where ships from all over the world dock, may be contaminated with exotic species through ballast water discharge. Thus, cataloguing and understanding species distribution along the bay becomes needed, as an aid in the elaboration of environmental management plans to minimize possible impacts.

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ESPÉCIES / ESTAÇÕES	P01	P02	P03	P04	P05	P06	P07	P15	P19	P20	P21	P27	P29	P30	P33	P34
Número de fústulas	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	223
Número de espéces	22	18	20	24	22	15	2	28	13	20	8	13	20	24	26	17
Diversidade Shannon	2,5	2,1	2,5	2,7	2,3	2,0	0,7	2,8	1,8	2,4	1,0	2,1	2,3	2,3	2,0	2,3
Equitabilidade	0,8	0,7	0,8	0,8	0,8	0,7	1,0	0,8	0,7	0,8	0,5	0,8	0,8	0,7	0,6	0,8
Achnanthes spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Actinocyclus octonarius	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Actinoptychus spp.	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Amphipleura spp.	0	0	0	1	0	0	0	0	0	0	0	0	0	21	12	0
Amphora ovalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Amphora proteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphora spp.	1	0	10	21	23	14	50	6	5	8	0	9	4	1	4	2
Asterionella japonica	0	0	0	0	0	35	0	0	0	0	0	0	2	0	0	0
Asteromphalus spp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Auliscus caelatus	0	0	0	0	0	0	0	1	1	0	1	0	2	0	1	0
Biddulphia spp.	1	0	0	0	1	0	0	0	0	0	0	2	1	0	0	0
Chaetocerus didymus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Chaetocerus spp.	0	0	0	0	2	2	0	4	0	1	0	0	0	0	0	0
Cocconeis arraniesis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cocconeis pellucida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Cocconeis scutelum	1	1	0	0	1	4	0	1	8	1	0	2	1	1	0	0
Cocconeis spp.	3	2	1	7	3	3	0	1	3	1	1	16	5	0	1	0
Coscinodicus brasiliensis	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0
Coscinodicus centralis	1	0	2	1	0	0	0	1	2	3	0	0	1	0	0	0
Coscinodicus gigas	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodicus obscuros	0	0	0	0	0	0	0	0	0	0	1	0	1	4	2	0
Coscinodicus oculusiridis	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Coscinodicus radiatus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Coscinodicus rothii	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Coscinodiscus excentricus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Coscinodiscus lineatus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Coscinodiscus marginatus	6	12	9	5	13	4	0	11	1	10	0	1	13	1	1	4
Coscinodiscus spp.	13	21	11	11	3	2	0	14	1	10	2	4	17	1	2	8
Cyclotella spp.	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
Diatoma spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Dimeregramma sp.	1	0	0	2	0	0	0	0	0	7	0	9	0	1	1	0
Dimerogramma marinum	0	0	0	0	0	0	0	0	0	0	0	0	0	26	54	0
Diploneis chersonenis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Diploneis didyma	3	1	0	2	1	0	0	1	0	1	0	0	1	0	1	0
Diploneis spp.	0	4	1	0	0	0	0	6	1	0	1	0	0	1	0	1
Entomoneis alata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epithemia spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Fragilaria spp.	0	0	0	3	0	0	0	0	0	0	0	0	1	0	2	0
Frustulia spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora flexuosa	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Grammatophora marina	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora spp.	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Mastogloia angulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Mastogloia spp.	1	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0
Melosira moniliformes	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4
Navicula directa.var renota	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Navicula lyra	4	1	1	2	3	1	0	2	22	2	2	1	0	0	0	0
Navicula membranácea	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula nummularia	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Navicula pennata	0	0	0	2	1	1	0	0	1	0	0	0	1	0	0	0
Navicula sandriana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Navicula spp.	24	10	12	18	10	22	0	20	25	5	0	10	5	20	0	26
Navicula yarrensis	12	2	1	0	0	0	0	0	0	0	0	0	0	1	0	1
Nitzschia bilabata	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Nitzschia spp.	0	1	0	2	1	3	0	2	0	3	0	9	0	1	0	4
Nitzschia lorenziana	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Nitzschia tryblionella	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Nitzschia panduriformis	0	0	0	1	0	1	0	3	0	5	0	0	1	0	0	0
Opephora marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoneis spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	8	2	0
Plagiogramma spp.	0	0	20	0	1	0	0	5	0	0	0	0	0	0	0	0
Plagiogramma pulchellum	4	0	7	4	0	0	0	0	31	6	55	32	2	0	1	2
Planktoniella sol	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma fasciola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Pleurosigma marinum	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma naviculaceum	0	3	0	0	1	0	0	2	0	1	0	0	2	1	0	3
Pleurosigma spp.	0	3	5	3	3	2	0	0	0	0	0	0	0	0	0	16
Raphoneis spp.	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0
Rhizosolenia spp.	0	0	2	0	1	0	0	1	0	0	0	0	0	1	1	1
Skeletonema costatum	0	0	0	3	0	0	0	0	0	0	0	0	10	0	0	0
Skelotenema spp.	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
Surirella spp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
Thalassiosira nanolineata	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Thalassiosira eccentrica	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira spp.	0	1	2	2	0	0	0	0	0	0	0	0	0	1	0	0
Trachyneis spp.	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Triceratium spp.	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0

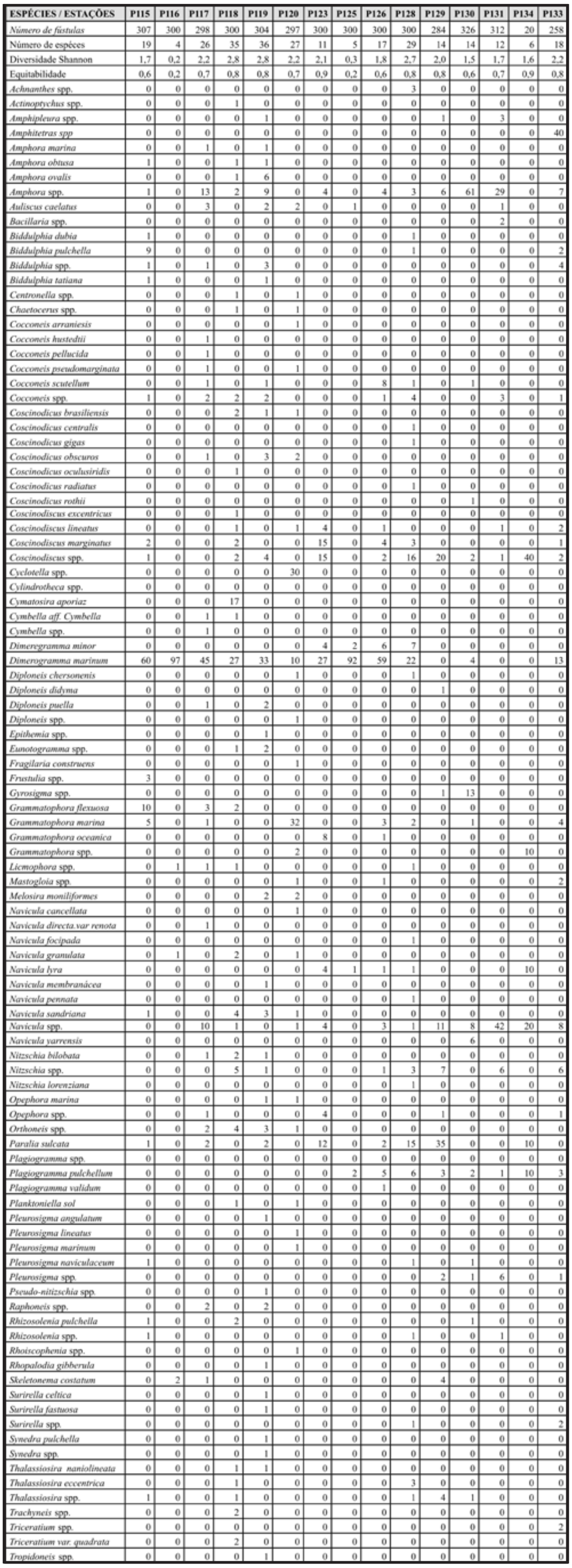
Table 1 Relative abundance of diatoms species from Guanabara Bay.

ESPÉCIES / ESTAÇÕES	**P36**	**P38**	**P40**	**P42**	**P44**	**P45**	**P46**	**P48**	**P50**	**P52**	**P53**	**P57**	**P63**	**P65**	**P66**	**P67**
Número de fústulas	308	64	20	44	180	90	42	36	6	56	306	404	210	300	300	284
Número de espéces	12	8	4	5	11	3	3	3	2	3	25	5	16	10	10	6
Diversidade Shannon	1,6	1,9	1,3	1,3	2,1	0,7	0,6	1,0	0,6	0,7	2,9	0,9	2,5	1,4	0,8	0,9
Equitabilidade	0,7	0,9	1,0	0,8	0,9	0,7	0,6	0,9	0,9	0,7	0,9	0,5	0,9	0,6	0,4	0,5
Amphipleura spp.	0	6	0	0	4	0	0	22	0	0	0	0	2	0	0	0
Amphora hyalina	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
Amphora ovalis	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Amphora proteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphora spp.	2	6	40	0	4	0	10	0	0	0	0	27	14	13	1	0
Auliscus caelatus	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
Biddulphia dubia	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Biddulphia pulchella	5	0	0	9	0	0	0	0	0	0	0	0	0	0	0	1
Biddulphia spp.	3	0	0	0	0	0	0	22	0	0	0	0	3	0	0	0
Coscinodicus brasiliensis	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Coscinodicus obscuros	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Coscinodiscus marginatus	0	0	0	0	2	0	0	0	0	4	1	0	0	3	0	8
Coscinodiscus spp.	2	0	0	0	9	7	10	0	0	0	0	2	10	12	81	6
Diatoma spp.	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Dimeregramma minor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimeregramma sp.	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimerogramma marinum	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0
Diploneis chersonenis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diploneis didyma	0	0	0	9	0	0	0	0	0	0	2	0	0	0	0	0
Diploneis puella	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Diploneis spp.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Frustulia spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Gyrosigma spp.	0	6	20	0	11	0	0	0	0	0	0	0	0	7	0	0
Grammatophora marina	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora spp.	5	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Mastogloia angulata	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
Melosira spp.	0	0	0	0	0	0	0	0	0	0	7	0	7	0	0	0
Navicula sandriana	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Navicula granulata	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Navicula henedy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula lyra	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Navicula pennata	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
Navicula sandriana	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0
Navicula spp.	10	13	20	55	18	20	0	56	67	71	4	67	16	59	10	75
Navicula yarrensis	0	0	0	0	0	0	0	0	0	0	0	0	14	1	1	0
Nitzschia bilobata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Nitzschia spp.	0	0	0	0	0	0	0	0	0	0	0	0	10	2	1	1
Nitzschia lorenziana	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Orthoneis spp.	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Paralia sulcata	0	19	0	18	20	73	81	0	33	25	4	2	6	1	3	8
Pleurosigma angulatum	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0
Pleurosigma fasciola	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Pleurosigma marinum	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma naviculaceum	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
Pleurosigma spp.	0	25	0	0	22	0	0	0	0	0	0	0	0	0	1	0
Pseudo-nitizschia spp.	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Raphoneis spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Rhizosolenia spp.	0	0	0	0	0	0	0	0	0	0	8	0	1	0	0	0
Rhopalodia gibberula	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Skeletonema costatum	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0
Surirella robusta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Surirella spp.	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Talassiotrhrix spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Terpsitone spp.	54	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassionema spp.	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachyneis spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Triceratium spp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0

Table 2 Relative abundance of diatoms species from Guanabara Bay.

ESPÉCIES / ESTAÇÕES	P82	P84	P87	P89	P90	P92	P94	P95	P103	P108	P109	P110	P111	P112	P113	P114
Número de fústulas	334	300	300	298	294	314	300	126	310	300	300	260	300	301	300	300
Número de espéces	14	21	24	15	19	14	14	18	17	26	14	26	21	19	21	23
Diversidade Shannon	1,6	2,1	2,6	2,3	1,8	2,1	1,5	2,6	2,1	2,7	2,0	2,6	2,4	1,8	2,0	2,5
Equitabilidade	0,6	0,7	0,8	0,8	0,6	0,8	0,6	0,9	0,7	0,8	0,7	0,8	0,8	0,6	0,6	0,8
Actinoptychus spp.	0	0	0	0	0	0	0	0	1	0	1	0	3	2	0	0
Amphipleura spp.	9	5	0	3	0	8	0	0	0	0	0	4	0	0	0	0
Amphora hyalina	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Amphora marina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Amphora ovalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Amphora spp.	11	5	9	11	3	38	0	16	28	2	18	2	1	0	2	7
Asterionella japonica	0	1	0	0	7	4	1	3	0	0	0	0	0	0	0	0
Asterolampra marilandica	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Auliscus caelatus	0	0	1	0	0	0	0	0	1	1	0	1	0	0	1	3
Auliscus spp.	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1
Aurachronodiscus ornatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Biddulphia dubia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Biddulphia pulchella	0	0	3	4	0	0	0	0	0	0	1	0	0	1	0	0
Biddulphia spp.	0	1	3	1	1	2	1	0	0	0	0	0	0	0	0	6
Biddulphia tatiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Capartogramma spp	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Chaetocerus didymus	0	0	0	1	58	0	60	16	0	1	0	0	0	0	0	0
Chaetocerus spp.	0	0	1	0	4	0	9	2	0	0	0	0	0	1	0	3
Climascosphenia elongata	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cocconeis arraniesis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Cocconeis scutellum	0	0	0	0	1	0	0	0	0	3	0	10	0	0	0	0
Cocconeis spp.	7	1	0	0	1	2	0	0	1	1	1	1	1	1	0	0
Coscinodicus brasiliensis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
Coscinodicus centralis	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0
Coscinodicus obscuros	0	0	0	0	0	0	0	0	0	0	0	0	0	10	1	0
Coscinodicus oculusiridis	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0
Coscinodicus rothii	0	0	0	0	0	0	0	0	0	1	0	2	0	0	1	0
Coscinodiscus excentricus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Coscinodiscus lineatus	1	1	0	4	0	0	2	0	0	1	0	1	2	0	0	0
Coscinodiscus marginatus	0	4	1	0	0	0	0	0	1	7	1	4	10	1	0	0
Coscinodiscus spp.	3	9	7	6	11	6	0	8	3	13	13	10	10	0	2	0
Cyclotella meneghiniana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0
Cyclotella spp.	0	0	1	0	1	0	0	0	0	0	0	2	0	1	0	0
Cymatosira aporiazpt	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Dimeregramma minor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Dimeregramma sp.	0	0	13	9	1	14	1	0	12	0	0	0	1	0	1	0
Dimerogramma marinum	0	0	0	0	0	0	0	0	0	0	23	32	0	50	50	37
Diploneis didyma	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0
Diploneis puella	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2
Epithemia spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Fragilaria spp.	0	0	0	0	0	0	3	0	0	0	0	0	0	2	2	0
Frustulia spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Gyrosigma spp.	0	0	2	1	0	2	0	0	0	2	0	0	1	0	0	0
Grammatophora marina	0	1	2	0	0	0	0	2	25	0	0	0	1	0	0	0
Grammatophora oceanica	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora spp.	0	0	0	0	0	0	0	6	0	0	1	0	0	0	2	0
Margaritum terebro	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mastoglenia spp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Melosira moniliformes	0	0	0	0	0	0	0	0	0	0	0	0	0	10	3	2
Navicula sandriana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Navicula cancellata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula directa.var renota	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Navicula granulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Navicula hennedyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Navicula lyra	1	1	15	8	0	0	0	2	1	0	0	0	3	0	2	0
Navicula membranacea	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Navicula sandriana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Navicula spp.	8	5	17	16	3	11	2	14	6	10	24	5	16	0	0	8
Nitzschia spp.	0	3	1	1	1	0	0	2	0	0	0	6	2	0	0	0
Nitzschia lorenziana	0	0	1	0	0	2	0	0	0	1	0	0	0	1	0	0
Nitzcshia panduriformis	0	1	0	0	2	0	0	3	0	0	0	0	1	0	0	0
Opephora spp.	1	1	1	0	0	0	0	0	0	2	0	1	0	0	0	0
Orthoneis spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paralia sulcata	1	5	1	8	0	1	0	10	5	17	1	2	17	0	0	0
Plagiogramma spp.	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
Plagiogramma pulchellum	56	0	13	27	0	4	0	0	12	20	12	5	0	0	0	0
Pleurosigma linearis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Pleurosigma naviculaceum	0	1	1	0	0	0	1	2	1	3	0	0	0	0	0	0
Pleurosigma spp.	0	3	1	0	1	5	0	5	0	1	0	0	25	0	0	0
Raphoneis spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Rhizosolenia spp.	0	1	0	0	0	0	0	0	0	1	0	0	0	2	0	2
Skeletonema costatum	1	47	5	0	0	0	0	5	1	0	0	2	0	0	0	0
Skeletonema spp.	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0
Surirella robusta	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Surirella celtica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Surirella spp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Talassiotrhrix spp.	0	0	0	0	2	0	1	3	0	0	0	0	0	0	0	0
Terpsitone spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassionema spp.	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Thalassiosira eccentrica	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0
Thalassiosira spp.	1	3	0	0	2	0	0	2	0	2	1	2	0	0	0	0
Triceratium spp.	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Tropidoneis spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Table 3 Relative abundance of diatoms species from Guanabara Bay.



ESPÉCIES / ESTAÇÕES	P115	P116	P117	P118	P119	P120	P123	P125	P126	P128	P129	P130	P131	P134	P133
Número de fústulas	307	300	298	300	304	297	300	300	300	300	284	326	312	20	258
Número de espéces	19	4	26	35	36	27	11	5	17	29	14	14	12	6	18
Diversidade Shannon	1,7	0,2	2,2	2,8	2,8	2,2	2,1	0,3	1,8	2,7	2,0	1,5	1,7	1,6	2,2
Equitabilidade	0,6	0,2	0,7	0,8	0,8	0,7	0,9	0,2	0,6	0,8	0,8	0,6	0,7	0,9	0,8
Achnanthes spp.	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Actinoptychus spp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Amphipleura spp.	0	0	0	0	1	0	0	0	0	0	1	0	3	0	0
Amphitetras spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Amphora marina	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Amphora obtusa	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Amphora ovalis	0	0	0	1	6	0	0	0	0	0	0	0	0	0	0
Amphora spp.	1	0	13	2	9	0	4	0	4	3	6	61	29	0	7
Auliscus caelatus	0	0	3	0	2	2	0	1	0	0	0	0	1	0	0
Bacillaria spp.	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Biddulphia dubia	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Biddulphia pulchella	9	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Biddulphia spp.	1	0	1	0	3	0	0	0	0	0	0	0	0	0	4
Biddulphia tatiana	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Centronella spp.	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Chaetocerus spp.	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Cocconeis arraniesis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Cocconeis hustedtii	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cocconeis pellucida	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cocconeis pseudomarginata	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Cocconeis scutellum	0	0	1	0	1	0	0	0	8	1	0	1	0	0	0
Cocconeis spp.	1	0	2	2	2	0	0	0	1	4	0	0	3	0	1
Coscinodicus brasiliensis	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0
Coscinodicus centralis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Coscinodicus gigas	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Coscinodicus obscuros	0	0	1	0	3	2	0	0	0	0	0	0	0	0	0
Coscinodicus oculusiridis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Coscinodicus radiatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Coscinodicus rothii	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Coscinodiscus excentricus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus lineatus	0	0	0	1	0	1	4	0	1	0	0	0	1	0	2
Coscinodiscus marginatus	2	0	0	2	0	0	15	0	4	3	0	0	0	0	1
Coscinodiscus spp.	1	0	0	2	4	0	15	0	2	16	20	2	1	40	2
Cyclotella spp.	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
Cylindrotheca spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymatosira aporiaz	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0
Cymbella aff. Cymbella	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Cymbella spp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Dimeregramma minor	0	0	0	0	0	0	4	2	6	7	0	0	0	0	0
Dimerogramma marinum	60	97	45	27	33	10	27	92	59	22	0	4	0	0	13
Diploneis chersonenis	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Diploneis didyma	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Diploneis puella	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
Diploneis spp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Epithemia spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Eunotogramma spp.	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
Fragilaria construens	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Frustulia spp.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma spp.	0	0	0	0	0	0	0	0	0	0	1	13	0	0	0
Grammatophora flexuosa	10	0	3	2	0	0	0	0	0	0	0	0	0	0	0
Grammatophora marina	5	0	1	0	0	32	0	0	3	2	0	1	0	0	4
Grammatophora oceanica	0	0	0	0	0	0	8	0	1	0	0	0	0	0	0
Grammatophora spp.	0	0	0	0	0	2	0	0	0	0	0	0	0	10	0
Licmophora spp.	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0
Mastogloia spp.	0	0	0	0	0	1	0	0	1	0	0	0	0	0	2
Melosira moniliformes	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0
Navicula cancellata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Navicula directa.var renota	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Navicula focipada	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Navicula granulata	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0
Navicula lyra	0	0	0	0	0	0	4	1	1	1	0	0	0	10	0
Navicula membranácea	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Navicula pennata	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Navicula sandriana	1	0	0	4	3	1	0	0	0	0	0	0	0	0	0
Navicula spp.	0	0	10	1	0	1	4	0	3	1	11	8	42	20	8
Navicula yarrensis	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
Nitzschia bilobata	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0
Nitzschia spp.	0	0	0	5	1	0	0	0	1	3	7	0	6	0	6
Nitzschia lorenziana	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Opephora marina	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Opephora spp.	0	0	1	0	0	0	4	0	0	0	1	0	0	0	1
Orthoneis spp.	0	0	2	4	3	1	0	0	0	0	0	0	0	0	0
Paralia sulcata	1	0	2	0	2	0	12	0	2	15	35	0	0	10	0
Plagiogramma spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagiogramma pulchellum	0	0	0	0	0	0	0	2	5	6	3	2	1	10	3
Plagiogramma validum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Planktoniella sol	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Pleurosigma angulatum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pleurosigma lineatus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pleurosigma marinum	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pleurosigma naviculaceum	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Pleurosigma spp.	0	0	0	0	0	0	0	0	0	0	2	1	6	0	1
Pseudo-nitizschia spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Raphoneis spp.	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0
Rhizosolenia pulchella	1	0	0	2	0	0	0	0	0	0	0	1	0	0	0
Rhizosolenia spp.	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Rhoiscophenia spp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Rhopalodia gibberula	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Skeletonema costatum	0	2	1	0	0	0	0	0	0	0	4	0	0	0	0
Surirella celtica	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Surirella fastuosa	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Surirella spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Synedra pulchella	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Synedra spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Thalassiosira naniolineata	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Thalassiosira eccentrica	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0
Thalassiosira spp.	1	0	0	1	0	0	0	0	0	1	4	1	0	0	0
Trachyneis spp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Triceratium spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Triceratium var. quadrata	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Tropidoneis spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Table 4 Relative abundance of diatoms species from Guanabara Bay.

ESPÉCIES / ESTAÇÕES	**P135**	**P136**	**P140**	**P141**	**P142**	**P143**	**P144**	**P145**	**P148**	**P150**
Número de fústulas	340	304	295	270	300	300	300	300	302	60
Número de espéces	14	14	11	15	25	21	20	20	8	5
Diversidade Shannon	2,1	2,1	1,5	2,2	2,7	2,4	2,0	2,2	1,9	1,5
Equitabilidade	0,8	0,8	0,6	0,8	0,8	0,8	0,7	0,7	0,9	0,9
Actinodiscus spp.	0	0	1	0	0	0	0	0	0	0
Actinoptychus spp.	0	0	0	1	0	0	0	0	0	0
Amphitetras spp	0	2	0	0	0	0	0	0	17	0
Amphora lanceolata	0	0	0	0	0	1	0	1	0	0
Amphora hyalina	0	0	0	5	0	0	0	0	0	0
Amphora obtusa	0	0	0	0	3	0	0	0	0	0
Amphora proteus	0	0	0	0	0	1	0	0	0	0
Amphora spp.	26	3	7	19	17	30	43	9	15	33
Auliscus caelatus	11	5	0	0	4	1	0	3	17	0
Biddulphia dubia	0	0	0	0	0	0	0	1	0	0
Biddulphia pulchella	2	4	0	0	0	0	0	2	30	0
Biddulphia spp.	0	0	1	0	1	0	0	1	0	0
Capartogramma	1	0	0	0	0	0	0	0	0	0
Ceratalus spp.	0	0	0	0	1	0	0	0	0	0
Cocconeis spp.	1	0	0	1	1	1	3	1	0	13
Coscinodicus brasiliensis	0	1	0	0	0	0	0	0	0	0
Coscinodicus centralis	0	1	0	0	0	0	0	0	0	0
Coscinodicus oculusiridis	0	0	0	0	0	0	1	0	0	0
Coscinodiscus excentricus	0	0	0	0	0	0	2	0	0	0
Coscinodiscus lineatus	0	0	0	0	1	0	0	0	0	0
Coscinodiscus marginatus	0	6	0	1	2	0	0	1	0	0
Coscinodiscus spp.	7	30	17	9	4	4	1	5	3	7
Cyclophora spp.	0	0	0	0	1	0	0	0	0	0
Cymatosira aporiaz	0	0	0	0	0	0	0	2	0	0
Cymbella spp.	0	0	0	0	0	0	0	0	3	0
Dimeregramma minor	0	0	0	0	10	0	0	1	0	0
Dimeregramma sp.	3	0	2	0	0	0	9	11	0	0
Dimerogramma marinum	0	18	0	0	10	3	0	2	0	0
Diploneis chersonenis	0	1	0	0	0	0	0	0	0	0
Entomoneis alata	0	0	0	0	1	1	1	0	0	0
Entomoneis spp.	0	0	0	0	1	0	0	0	0	0
Epithemia spp.	0	0	1	0	0	0	0	0	0	0
Gyrosigma spp.	1	0	0	0	0	2	2	0	0	0
Grammatophora marina	0	3	0	0	2	0	0	0	0	0
Margaritum terebro	0	0	1	0	0	0	0	0	0	0
Navicula focipada	0	0	0	0	1	0	0	0	0	0
Navicula lyra	0	0	0	1	3	3	1	4	0	0
Navicula spp.	16	6	52	20	3	4	7	1	8	0
Navicula yarrensis	0	0	0	10	8	21	24	0	0	0
Nitzschia lorenziana	0	0	0	0	1	1	1	0	0	0
Nitzschia panduriformis	0	0	0	0	0	1	0	0	0	0
Opephora spp.	0	0	0	0	0	0	1	5	0	0
Paralia sulcata	5	18	14	19	6	5	1	8	0	0
Plagiograma spp.	0	0	0	0	0	5	2	1	0	0
Plagiogramma pulchellum	15	3	0	0	19	6	1	40	0	33
Pleurosigma acominatum	0	0	0	0	0	0	1	0	0	0
Pleurosigma naviculaceum	0	0	0	1	0	1	0	0	0	0
Pleurosigma spp.	9	0	2	4	0	0	0	0	0	0
Rhizosolenia spp.	0	0	0	1	0	1	0	0	0	0
Skeletonema spp.	0	0	0	0	0	0	1	0	9	0
Surirella robusta	0	0	0	0	1	0	0	0	0	0
Surirella fastuosa	0	0	0	0	2	5	0	0	0	0
Surirella spp.	0	0	0	0	0	0	0	1	0	13
Thalassiosira spp.	1	0	0	0	0	0	0	0	0	0
Triceratium spp.	0	0	1	1	0	0	0	0	0	0

Table 5 Relative abundance of diatoms species from Guanabara Bay.

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