



Spatial distribution of pollen grains and spores in surface sediments of Guanabara Bay, Rio de Janeiro, Brazil

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ABSTRACT

Aiming to investigate the deposition of pollen grains and spores in Guanabara Bay, Rio de Janeiro State, 61 surface sediment samples were analyzed. The results showed that the current deposition of palynomorphs in surface sediments of Guanabara Bay represents the regional vegetation of this hydrographic basin. The differential distribution of palynomorphs followed a pattern influenced by bathymetry, tidal currents speed, discharge of numerous rivers, and by human activity. The dominance of representatives of Field Vegetation reflects the changes of the original flora caused by intense human activities in the region. The continued presence and richness of pollen types of rain forest in the samples indicates that their source area might be the vegetation from riparian border of rivers in the western sector of the Bay, where the mangrove vegetation is being preserved. The large amount of damaged palynomorphs may be related to abrasion that occurs during river transport, indicating removal or reworking from their areas of origin.

Key words: palynomorphs, surface sediments, deposition, preservation, Guanabara Bay, Brazil.

INTRODUCTION

Palynological studies are important tools for interpreting the past environments and elucidating questions related to paleoclimates and paleoecology (Ybert et al. 1992, Salgado-Labouriau 2001). However, it is necessary to understand the present environments and the dynamics that controls the deposition of pollen grains and spores before one attempts to interpret the fossil record.

The Palynological analysis of Quaternary sediments has provided important information about the past environment in the coastal region of SE Brazil. Studies have elucidated questions related to sea level oscillation and climate changes as well as to alterations of the natural vegetation as a result of intensive human activities during the Holocene (Toledo et al. 1994, Luz et al. 1999, Barth et al. 2001, 2004, Coelho et al. 1999, Santos et al. 2000). However, pollen studies on surface sediments in lakes and bays that demonstrate the patterns of modern

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pollen deposition and vegetation of this region have not been undertaken to a significant extent. Barreto et al. (2006) presented a palynological analysis of 27 surface sediment samples of Guanabara Bay and reported that the distribution and accumulation of palynomorphs in the bay were influenced by bathymetry, velocity tide and the intensity of fluvial inputs. Studying a lake with tributaries, Luz et al. (2005) verified that fluvial influx, wind action and lakes bathymetry influenced the spatial distribution of pollen grains, spores and algae; an additional control was palynomorph size. Toledo et al. (1994) verified that the deposition of palynomorphs was influenced by the bathymetry and wind direction in a lagoon without any tributaries in the northeastern region of the state of Rio de Janeiro.

It is necessary to understand the processes that control the preservation, transport and deposition of pollen grains and spores in aquatic environment in order to obtain an accurate interpretation of pollen occurrence. The present study offers a better resolution of environmental questions related to modern ecosystems and characterizes the processes of current dynamics that control the deposition and preservation of palynomorphs in distinct sectors of the Guanabara Bay, indicating the best areas to collect sediment cores for future palynological studies.

STUDY AREA

The Guanabara Bay is located in the coastal area of Rio de Janeiro State – Southeast Brazil, between 22°40' - 23°00'S of latitude and 043°00' - 043°20'W of longitude (Figure 1). It lies within a depressed and elongated tectonic band of Tertiary age known as “Baixada Fluminense” or Guanabara Rift, of the half-graben type (Ruellan 1974, Ferrari 1990, Amador 1997). Its origin is also related to climatic and sea level changes that occurred during the Quaternary and that resulted in the drowning of a Pleistocene fluvial valley (Amador and Ponzi 1974, Ireland 1987, Amador 1992, 1997, Martin et al. 1997).

The Guanabara Bay extends in the SO-NE direction, reaching a maximal width of 28 km and a perimeter of 131 km; it possesses a narrow entrance of approximately 1.6 km width. The bay surface area, excluding its islands, currently measures 372 km². Its hydrographic basin covers approximately 4,600 km² and includes the metropolitan regions of the cities of Rio de Janeiro, Duque de Caxias, Niterói and São Gonçalo. There are 45 rivers that discharge in the bay, the Macacu and Caceribu being the most important ones (Amador 1997, Kjerfve et al. 1997). The Guanabara Bay tides are classified as semidiurnal, with one complete tidal cycle of about 12.5 hours (Amador 1997).

The bathymetry of the Guanabara Bay is influenced mainly by the tides. The narrow entrance of the bay is occupied by a big sandy bank that extends upwards from the bay floor to a height of 12 m. This bank promotes the channelization of water flow and is also an obstacle to the tidal circulation. The central channel of the bay has a S-N orientation starting at the bay entrance until the Governador Island and accounts for the deep depths in the bay (around 30 and 40 m deep). The dominant sediments in the channel are medium to very fine sands. The innermost part of the bay (i.e., the north region) has smooth, flat bathymetry (less than 10 m) and a high sedimentation rate. Its sediments are primarily silt/clay (Amador 1992, 1997, Dias and Quaresma 1996, V.S. Quaresma, unpublished data, Kjerfve et al. 1997, L.F. Catanzaro unpublished data).

The climate of the Guanabara Bay region is tropical humid with a well - defined rainy season between December and April, and a dry season between June and August (Denemet 1992). The mean annual air temperature is 23.7°C, and the mean annual relative humidity is 78%, with an annual average precipitation higher than 2,000 mm over the Serra do Mar hills, and 1,000 to 1,500 mm in the lowlands (Baixada Fluminense region) (Amador 1997). The winds most frequently blow from the east (21% of the time), south (17%) and

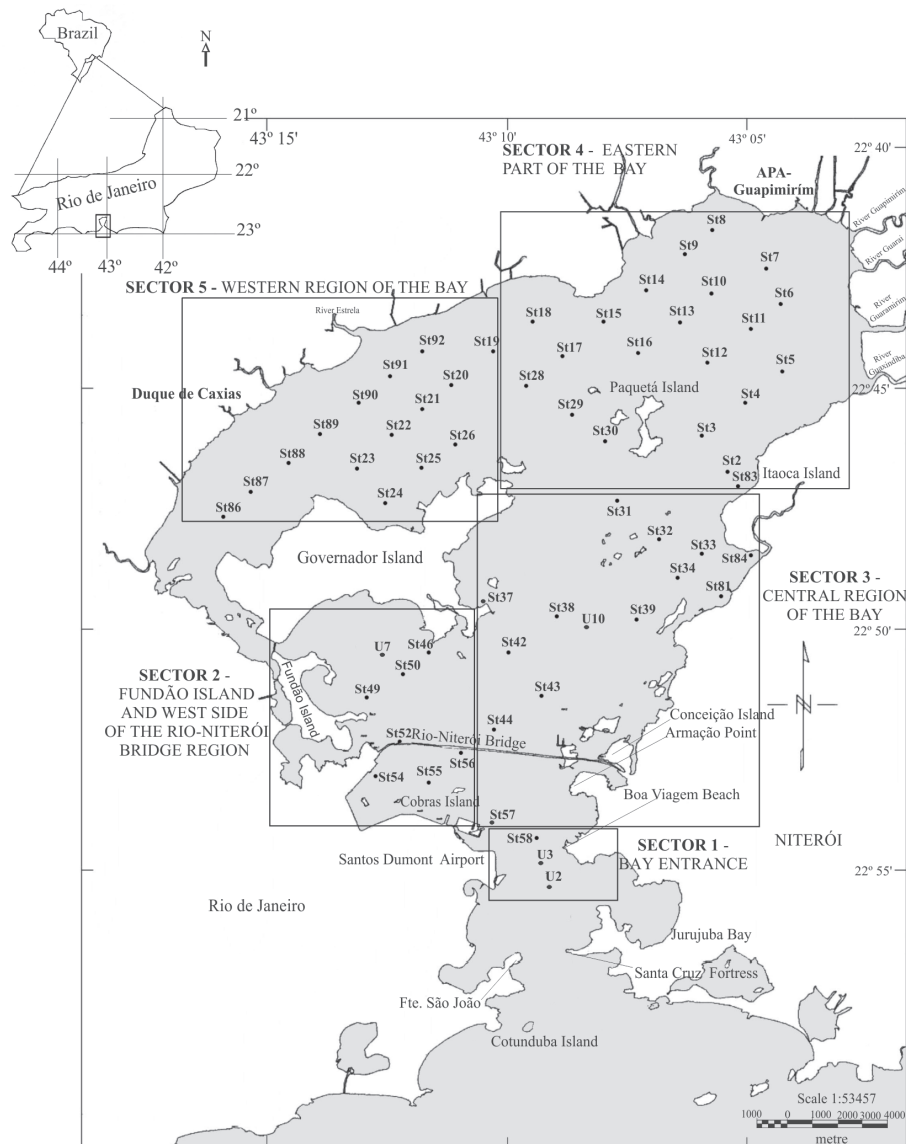


Figure 1 - Map of the study area showing the location of the surface sediment samples and the different sectors of the Guanabara Bay (Vilela et al. 2003).

north (14%), with a mean velocity of 3 m/s in the Santos Dumont Airport area (Kjerfve et al. 1997).

A Tropical Rain Forest (Mata Atlântica) is considered as one of the richest ecosystems. This vegetation is preserved mainly in forest reserves and on the mountain slopes (RadamBrasil 1983, Veloso et al. 1991). According to Veloso et al. (1991) vegetation types such as Ombrophilous Forest (“Floresta Ombrófila”), Mountain Forest (“Floresta Montana”) and Field Vegetation (“Vegetação Campestre”) were

recognized in the area. A phytosociological survey conducted by Guedes (1988) in the Magé municipality, 15 km away from the Guanabara Bay, recorded the following predominant plant associations: an herbaceous stratum of *Aphelandra* (Acanthaceae), *Dorstenia* (Moraceae), *Heliconia* (Heliconiaceae), *Olyra* (Poaceae), *Pfaffia* (Amaranthaceae) and *Polygala* (Polygalaceae); a shrub stratum of *Eugenia* (Myrtaceae), *Faramea* (Rubiaceae), *Miconia* (Melastomataceae), *Myrcia* (Myrtaceae), *Ouratea*

(Ochnaceae), *Psychotria* (Rubiaceae) and *Rudgea* (Rubiaceae); and an arboreal stratum of *Aniba* (Lauraceae), *Aparisthimium* (Euphorbiaceae), *Euterpe* (Arecaceae), *Guapira* (Nyctaginaceae), *Guarea* (Meliaceae), *Newtonia* (Leguminosae-Mimosoidea), *Pera* (Euphorbiaceae), *Sebastiania* (Euphorbiaceae) and *Tapirira* (Anacardiaceae).

The Mangrove vegetation occurs in the innermost part of the bay, mainly in the environmental protection area (APA) of Guapimirim, and bears both arboreal and herbaceous physiognomies. Predominant plants recorded are *Acrostichum* (Pteridaceae), *Avicennia* (Verbenaceae), *Cecropia* (Moraceae), *Clytostoma* (Bignoniaceae), *Crenium*, *Dalbergia* (Fabaceae), *Eichhornia* (Pontederiaceae), *Hibiscus* (Malvaceae), *Laguncularia* (Combretaceae), Loranaceae, *Arecaceae*, *Paspalum* (Poaceae), *Passiflora* (Passifloraceae), *Pistia* (Araceae), *Rhizophora* (Rhizophoraceae), *Surpus*, *Poaceae*, *Tabebuia* (Bignoniaceae) and *Typha* (Typhaceae) (Araújo and Maciel 1979).

MATERIALS AND METHODS

FIELD WORK

In order to examine the patterns of palynomorph deposition across different areas of the Guanabara Bay, a total of 61 surface sediment samples were collected using a "Van-Veen" collector sampler. The samples were grouped into five sectors (Vilela et al. 2003) (Figure 1). Three samples were obtained in the sector next to the bay entrance and were composed of medium to fine sand. Thirteen samples were collected in the central sector, consisting of fine sand. The Fundão Island sector comprised eight samples of silty clay and argillaceous silt sediments, while fifteen samples were collected in the western sector and were also dominated by argillaceous silt. Twenty one samples, composed of muddy sediment with a predominance of clay, were collected in the eastern sector (Catanzaro unpublished data).

LABORATORY ANALYSIS

The samples were chemically treated according to the standard methodology for Quaternary sediments proposed by Ybert et al. (1992). This includes the use of 10% of HCl for the elimination of carbonates, followed by 40% HF for elimination of silicates, then the acetolysis and heavy liquid separation using a ZnCl₂ (density = 2). To estimate the concentration of palynomorphs per volume of sediment, two tablets of exotic *Lycopodium clavatum* spores (about 11,670 spores per tablet) were introduced into each sample prior to processing (Stockmarr 1971). A minimum of three slides was prepared for each sample, and at least 200 pollen grains per sample were counted at 400x magnification.

The Pollen identification was based upon pollen catalogues (Barth 1972, 1976, Barth and Barbosa 1972, 1975, Bove and Barth 1992, Barth and Costa 1993, Luz and Barth 2000, Hooghiemstra 1984, D.W. Roubik and J.E.P. Moreno, unpublished data) and specific papers (Behling 1995, Garcia 1997, 1998, Lorscheitter et al. 1998, 1999). In general, pollen types were identified at family or generic levels.

Palynomorph counts were expressed as relative abundance (percent) and concentration. The percentage calculation was based upon the total sum of pollen grains (herbs, shrubs and trees), excluding algae and fern spores. The software Tilia and Tiliagraph (Grimm 1987) were used for the statistical analysis of the palynological data. The identified palynomorphs were grouped into the respective vegetation types according to Veloso et al. (1991).

Deteriorated pollen grains and spores were analyzed according to Moore et al. (1991).

RESULTS

One hundred thirty-one palynomorph types were identified in the 61 surface sediment samples analyzed. Grassland pollen grains dominated the assemblages, showing high percentages in almost all the samples (more than 66% in sample St16; Figure 2). Poaceae

was the dominant pollen type (more than 50% in samples U2, U10, St37, St16 and St24), followed by *Brassica* (11% in sample St56), *Amaranthus/Chenopodiaceae* (9% in sample St85) and *Borreria densiflora* (3% in sample St50; Figure 3). *Alchornea*, *Arecaceae*, *Celtis*, *Hedyosmum*, *Lecythis*, *Rapanea* and *Trema* were the most important pollen types of the Ombrophilous Forest vegetation (Figure 3). This vegetation presented a great richness of pollen types (55 pollen types), and high percentages in samples St58, St55, St44, St39, St84, St31, St4, St6 and St14 (more than 35%; Figures 2 and 3). Three pollen types, *Drimys brasilienses*, *Podocarpus* and *Podocarpus lambertii*, belonging to the Montane Forest vegetation type, could be identified, with *Podocarpus lambertii* being the most important one (Figure 4). Pollen grains of Cyperaceae, Scrophulariaceae and *Typha* (Hygrophilous assemblage) were observed in all the analyzed samples, with percentages less than 10% (Figure 4). *Avicennia* and *Rhizophora* of the Mangrove vegetation were found in the St50 sample located near the APA of Guapimirim (Figure 4). Asteraceae, Euphorbiaceae, Fabaceae, Melastomataceae/Combretaceae, Myrtaceae and Solanaceae were classified as Wide distribution taxa (Figure 4).

PALYNOLOGICAL ANALYSIS IN DIFFERENT SECTORS OF THE GUANABARA BAY

Bay entrance sector

Three samples were analyzed, and 47 pollen types from the total of 96 pollen types were identified. The pollen of Grassland predominated in two samples taken near the bay entrance (maximum of 56 % in samples U2 and U3). The lowest pollen percentage of this group was observed in the most northerly sample, St58 (31%; Figure 2). Poaceae was the most important pollen type of Grassland (55% in sample U2), and additional pollen types such as *Amaranthus/Chenopodiaceae*, *Borreria densiflora*

and *Chamaesyce* were recorded in very low percentages (Figure 3). The highest percentage of Ombrophilous Forest pollen occurred in sample St58 (31%), and it diminished to 12% near the entrance of the bay (sample U2; Figure 2). *Alchornea*, *Arecaceae*, *Casearia*, *Celtis*, *Cupania*, *Hedyosmum*, *Ilex*, *Lecythidaceae*, *Rapanea*, *Sebastiania* and *Trema* were the most important of Ombrophilous Forest pollen types (Figure 3). Montane Forest pollen types were recorded in only one sample with a very low percentage (sample St58 with less than 5%; Figure 2). Pollen types of the Mangrove vegetation, as well as algae, did not appear in samples of this sector (Figure 2). Hydrophyte pollen types presented a low percentage (less than 5%), and the highest percentage of exotic genera (more than 16% in samples U3) and fern spores (sample U3 with more than 59%) was observed in this section (Figure 2).

The lowest pollen grain and spore concentration was observed in this sector, with less than 4,500 palynomorphs/g in sample St58 and less than 1,500 in samples U2 and U3 (Figure 5).

Fundão island sector

Sixty-two pollen and spore types were identified in eight samples analyzed. The dominant Grassland taxa occurred in 90% of the samples (more than 50% in sample St52; Figure 2). Poaceae presented the highest percentages (more than 25% in all samples), followed by *Amaranthus/Chenopodiaceae* (maximum of 9% in sample St52), *Brassica* (more than 5% in all samples) and *Borreria densiflora* and *Chamaesyce* (percentages usually less than 5%; Figure 3). The highest percentages of Ombrophilous Forest pollen types occurred south of the Rio-Niterói Bridge, near its western end (sample St55 with 40%; Figure 2). *Arecaceae*, *Celtis*, *Lecythidaceae*, *Rapanea* and *Trema* contributed to the increase of percentages of the Ombrophilous Forest pollen type in sample St55 (Figure 3). Montane Forest plant taxa of low percentage (less than 5%) were recorded

in five samples (Figure 2). Pollen types representing the Mangrove vegetation were not observed in this sector (Figure 2), and Hygrophyte pollen presented low percentages in all samples (about 5%), with some increase in sample St55 (11%; Figure 2). Exotic genera were recorded in samples near the margins of Governador and Fundão Islands (samples St52, St49, St50 and St46), and in one sample collected near Rio-Niterói Bridge (sample St56, less than 9%; Figure 2). Fern spore percentages ranged between 5 and 40% in all samples (Figure 2).

The highest concentration of pollen grains and spores was observed in samples next to the Fundão Island (samples St49 – 14,500 and U7 – 17,000 palynomorphs/g) and in a sample between Rio-Niterói Bridge and the Cobras Island (sample St55, more than 4,500 palynomorphs/g). The other five samples presented in general low concentration values (less than 1,000 palynomorphs/g) (Figure 4).

Central sector of the bay

Eighty-eight pollen and spore types were identified in 14 samples analyzed from this area. The Grassland taxa dominated in almost all samples (more than 50% in sample U10; Figure 2). Poaceae percentage was the greatest (more than 15% in all samples), followed by *Amaranthus/Chenopodiaceae* (maximum of 9% in sample St85) and *Borreria densiflora*; *Brassica* occurred in more than 70% of these samples, with abundances usually less than 10% (Figure 3). High percentages of Ombrophilous Forest pollen occurred in samples St44, St42, St39, St84 and St31 (more than 40% in sample St31; Figure 2). *Alchornea*, *Arecaceae*, *Celtis*, *Hedyosmum*, *Lecythis*, *Rapanea* and *Trema* presented their highest percentages. Other Ombrophilous Forest taxa, such as *Anadenanthera*, *Lecythidaceae* and *Piper*, were recorded in very low percentages (less than 6%; Figure 3). *Podocarpus lambertii* was the most common Montane Forest pollen type, with less than 3% (Figure 3). Mangrove

taxa appeared) near the southeastern margin of the bay, close to rivers, but represented less than 1% of the pollen sum (samples St34, St85 and St84; Figure 2). *Rhizophora* was the most common Mangrove pollen type. Hygrophyte plants presented low percentages (1 - 9%; Figure 2). The highest percentage of fern spores was recorded in a sample south of Rio-Niterói Bridge (sample St57), and a very low percentage occurred near the southeast margin (sample St84, less than 5%). Other samples frequently contained 60% spores (Figure 2).

The sediments of the main canal south of Rio-Niterói Bridge (sample St57) and eastward the Governador Island (samples St44, St43, St42, U10 and St38) showed a low concentration of pollen grains and spores (less than 11,000 palynomorphs/g). Low concentration were also observed in samples St32 and St84 (less than 10,000 pollen grains/g of sediment). An increase of pollen grain concentration was observed only in the east margin of the bay near São Gonçalo city, with more than 18,000 palynomorphs/g (Figure 4).

EASTERN SECTOR OF THE INNERMOST PART OF THE BAY, IN THE VICINITY REGION OF PAQUETÁ ISLAND AND IN THE APA OF GUAPIMIRIM

Ninety-seven of the 129 pollen grains and spore types were identified in the 21 samples analyzed from this area. Pollen types of Grassland predominated in almost all samples (more than 35%; Figure 2). Poaceae was the most important (20% to 70%), followed by *Amaranthus/Chenopodiaceae* (1% to 9%), *Borreria densiflora* (1% to 3%) and *Chamaesyce* (1% to 4.5%; Figure 3). The Ombrophilous Forest vegetation taxa presented the highest richness of pollen types (53 pollen types). The highest percentage of this group occurred in the northern margin near the rivers in the APA of Guapimirim area; abundances varied between 35 and 40% in samples St4, St5, St9 and St14 (Figure 2). *Alchornea*, *Arecaceae*, *Cecropia*, *Celtis*,

Hedyosmum, Lecythidaceae, *Lecythis*, *Phyllanthus*, *Rapanea* and *Trema* occurred in more than 50% of these samples (Figure 3). Montane Forest taxa presented lower percentages (1% – 6%; Figure 2). Mangrove taxa were observed in samples located near the mangrove of the APA of Guapimirim and the northern margin of the bay, but with less than 5% relative abundance in seven samples (samples St83, St3, St5, St6, St10, St11 and St14; Figure 2). *Rhizophora* was the most common Mangrove pollen type (less than 5%), and Cyperaceae, *Scoparia* and *Typha* were the dominant Hydrophyte pollen types, though their percentages were less than 9.5% (Figure 4). Fern spore percentages were practically in all samples (Figure 2).

Three samples in this area (samples St9, St14 and St18) presented the highest pollen grain and spore concentration observed in the Guanabara Bay. The highest pollen concentration occurred next to the river inflows in the north margin of the bay (from more than 30,000 palynomorphs/g to a maximum of 49,199 palynomorphs/g). It decreased eastwards of the Paqueta Island (less than 12,000 pollen grains/g in samples St15, St16, St17, St28, St29 and St30) and in one sample of the northeastern margin near the Itaoca Island (less than 10,000 palynomorphs/g in samples St83). In the northeastern margin, near the APA of Guapimirim, approximately 20,000 palynomorphs/g (samples St2, St3, St4, St5, St6, St7, St8, St10, St11, St12 and St131) were observed (Figure 4).

WESTERN SECTOR OF THE INNERMOST PART OF THE BAY,
NORTH OF GOVERNADOR ISLAND

Fifteen samples contained 86 types of pollen and spores identified. The highest percentage of the Grassland taxa (47%) was recorded in samples recovered near the Governador Island (samples St23, St24 and St25; Figure 2). Poaceae (more than 25% in all samples) and *Amaranthus*/Chenopodiaceae (1% to 3.5%) were the most

abundant taxa of this group (Figure 3). Pollen types of the Ombrophilous Forest also occurred (more than 10% in all samples); the highest percentages were observed in samples St19 (38%), St20 (33%) and in a sample collected near the mouth of Estrela river (sample St91, 36%; Figure 2). *Alchornea*, *Anadenanthera*, *Arecaceae*, *Celtis*, *Hedyosmum*, *Lecythidaceae*, *Lecythis*, *Rapanea* and *Trema* occurred in more than 50% of samples (Figure 3). Montane forest taxa occurred in samples collected near the Governador Island (samples St20, St21, St22, St24, St25 and St26) and in one sample located next to the northwest margin of the bay; the abundance in each sample was less than 5% (Figure 2). Representative pollen types of the Mangrove vegetation were not observed in these samples. Among Hydrophytes, Cyperaceae, *Typha* and Scrophulariaceae presented less than 5% (Figure 4). The alga *Botryococcus* was observed in low abundance (less than 1%) in samples St20, St25, St92, St91 and St88 (Figure 4), and fern spores presented a significantly reduced frequency (Figure 2).

Except for St87, all six out of seven samples located near the northwest margin of the bay presented a high concentration of pollen grains and spores (samples St92, St91, St90, St89, St88 and St86). In two of these samples the highest concentration of pollen was more than 24,000 pollen grains/g of sediment. In an area located north of the Governador Island, the pollen concentration of sample St21 was 25,000 pollen grains/g, and there was a significant decrease near the rocks of the Governador Island (less than 7,500 pollen grains/g, samples St23 and St24) (Figure 5).

SPATIAL DISTRIBUTION OF DEGRADED PALYNO MORPHS
IN THE SURFACE SEDIMENTS OF THE GUANABARA BAY

Most pollen and spores presented well preserved exines (in more than 50% of all samples).

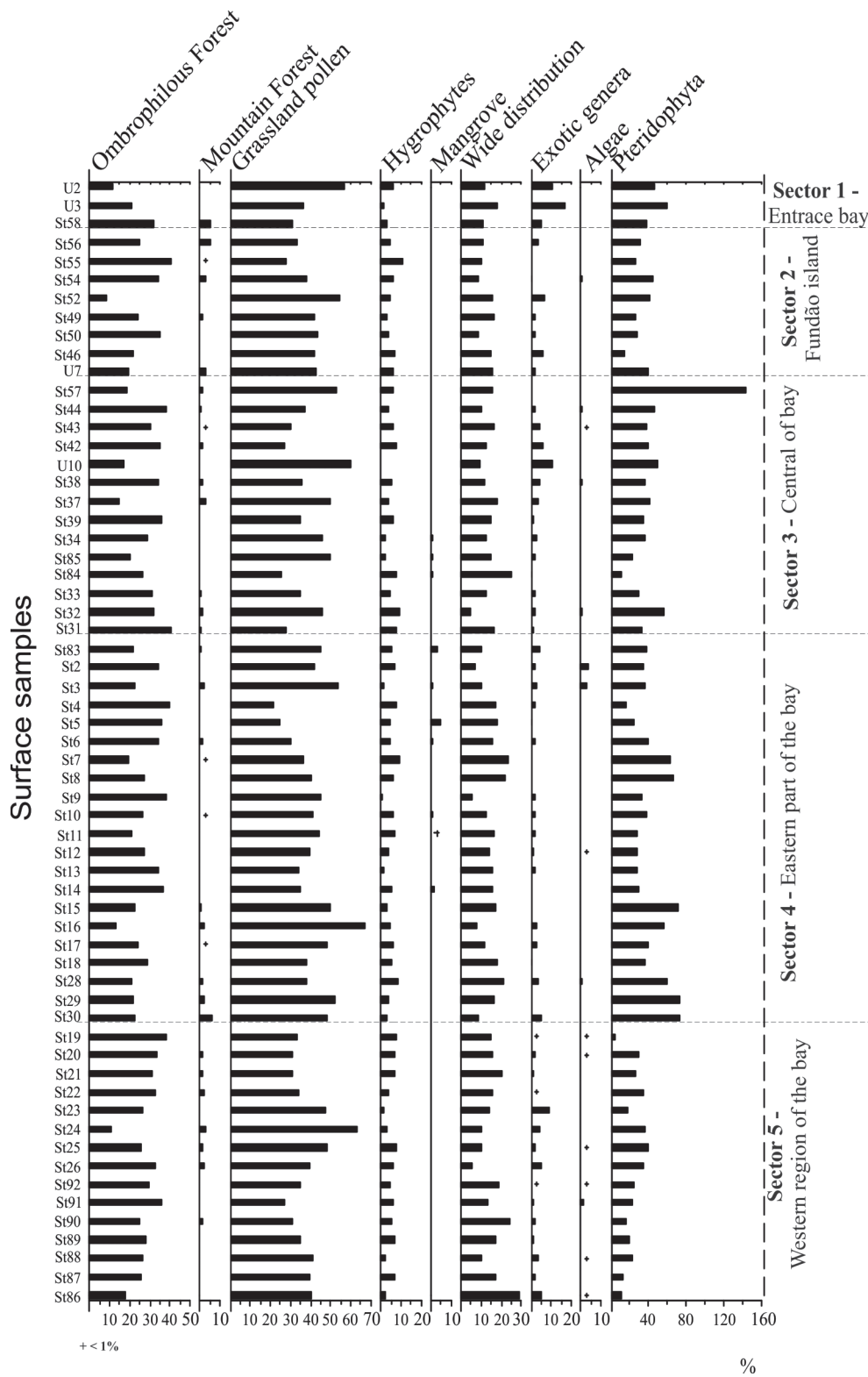


Figure 2 - Percentage palynodiagram of the ecological groups recognized in the surface sediment samples of the Guanabara Bay.

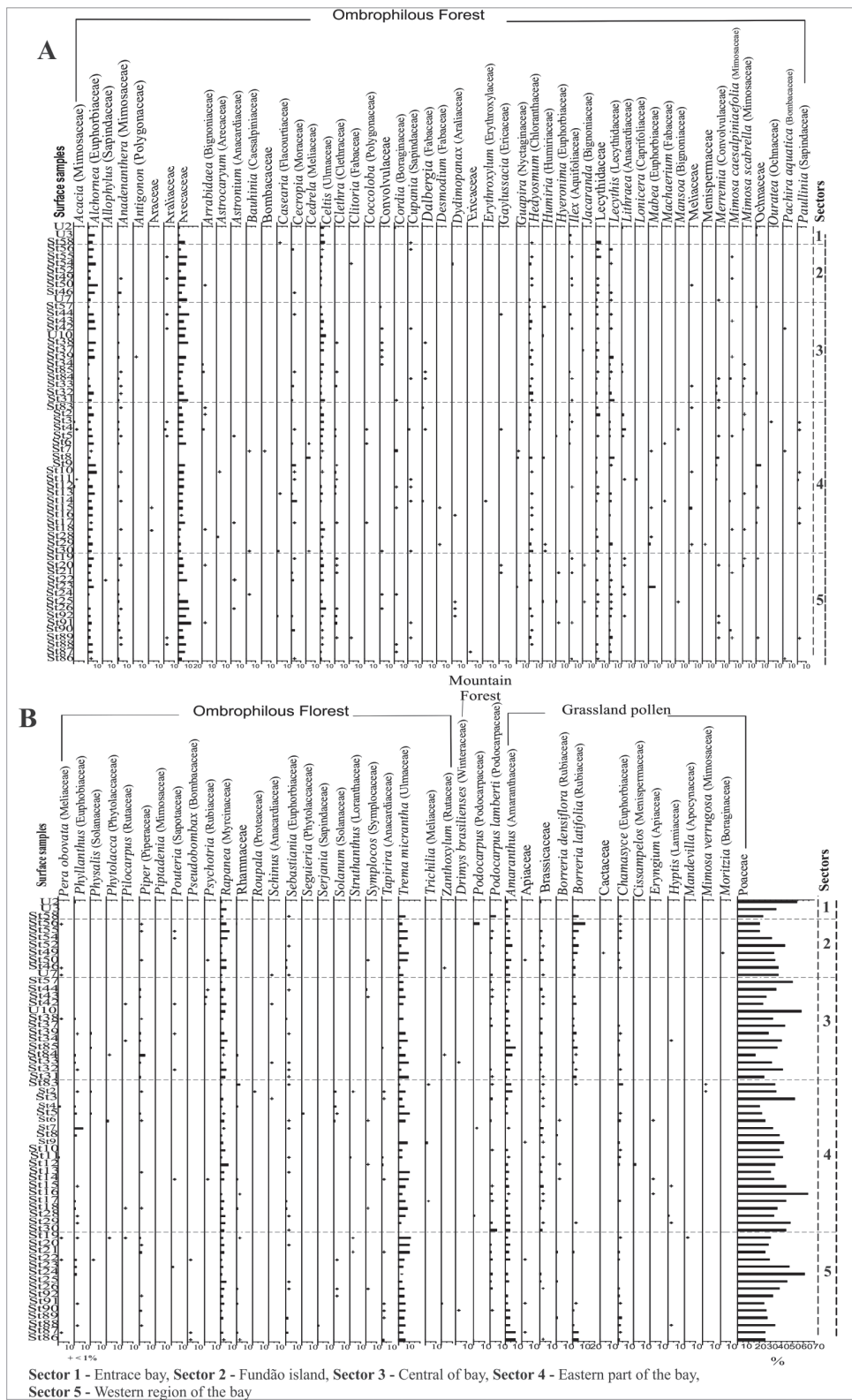


Figure 3 - Percentage palynodiagram of the pollen types grouped into the (A) Dense Ombrophilous Forest vegetation, (B) Montane Forest and Grassland Pollen.

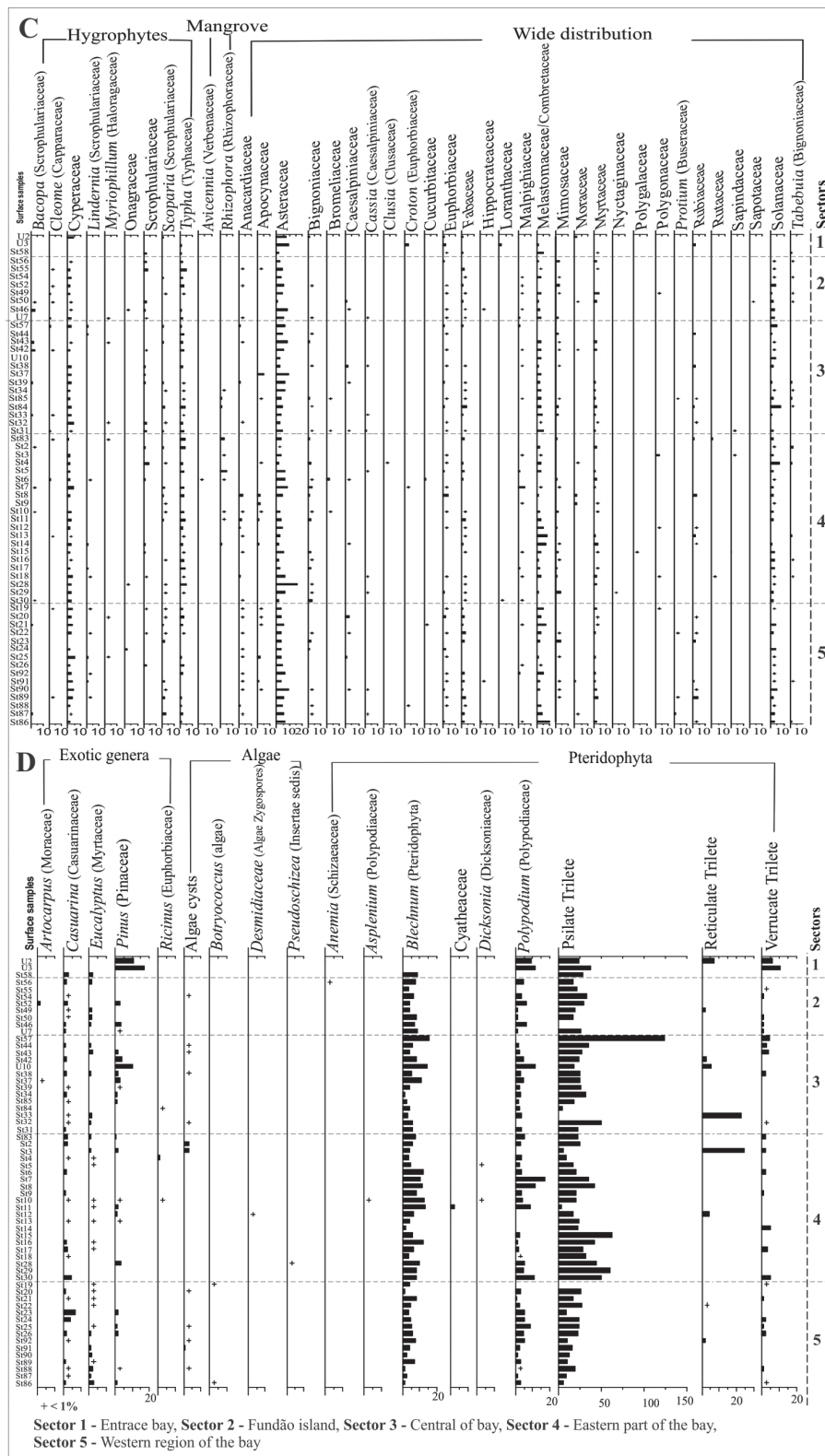


Figure 4 - Percentage palynodiagram of the pollen types grouped into the (C) Hygrophytes, Mangrove, Wide distribution, (D) Exotic genera, Algae and Pteridophyta.

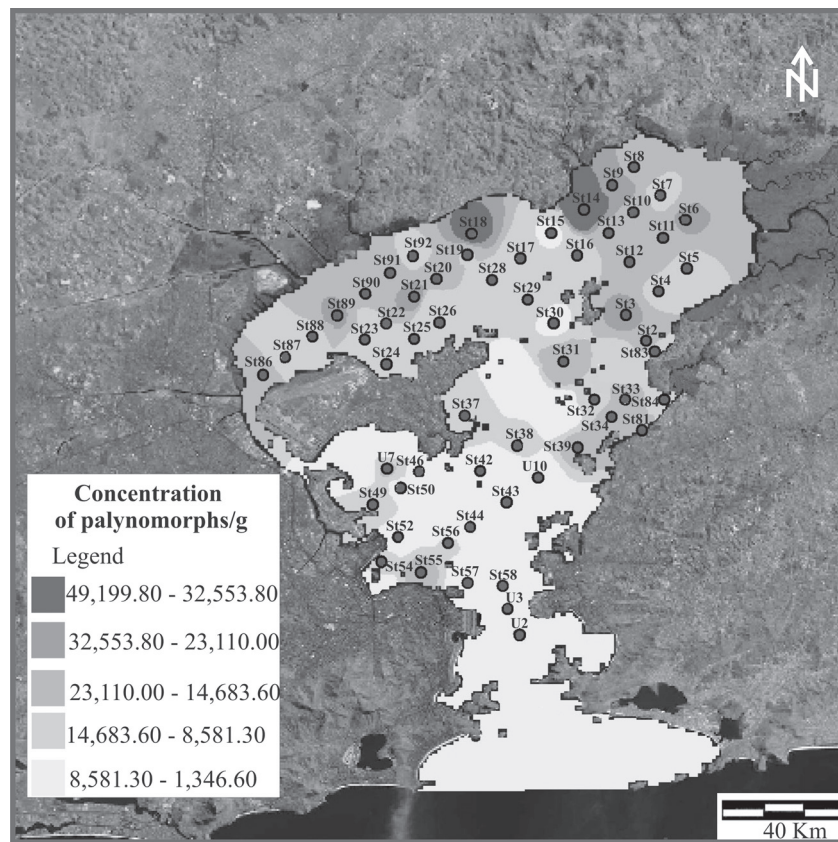


Figure 5 - Map of total concentration of palynomorphs/g observed in surface sediment samples of the Guanabara Bay.

Mechanical damage to palynomorphs was more frequent than corrosion and degradation. The highest level of deterioration was recorded in sample U3, located near in the entrance of the bay between Boa Viagem Beach and Santos Dumont Airport; more than 43% of palynomorphs exhibited damage. In sample St54, near the Fundão Island, more than 30% of palynomorphs showed signs of degradation, particularly samples St57 and St39 in the vicinity of the main channel. An increase of pollen grains presenting corrosion was observed in samples St37, St39 and St33, with the highest percentage in the eastern sector of the bay of about 10% (samples St5, St6, St7, St10 and St11). The western sector of the bay produced samples with the highest percentage of damaged palynomorphs (samples St21 (37%) and St26 (35%)). The damage degree decreased towards the bay margin (less than 10%; Figure 6).

DISCUSSION

PALYNOLOGICAL ANALYSIS/REGIONAL VEGETATION

The palynological analyses carried out in the surface sediments showed that the pollen and spores deposition represented the integration of pollen types from a large source area, which corresponds to the Atlantic Forest vegetation (located on the mountain slopes and in forest reserves) and the open-land plants and results from large deforested areas by intense human activities. The large area of the Guanabara Bay drainage basin (about 4.600 km²) and the existence of many fluvial influxes (more than 40) provide a pollen signal of the regional vegetation as suggested by several studies that have demonstrated the relationship between the size of the catchment and the way in which pollen records reflect vegetational cover (Jackson 1990, Sugita 1993, Stebich et al. 2005).

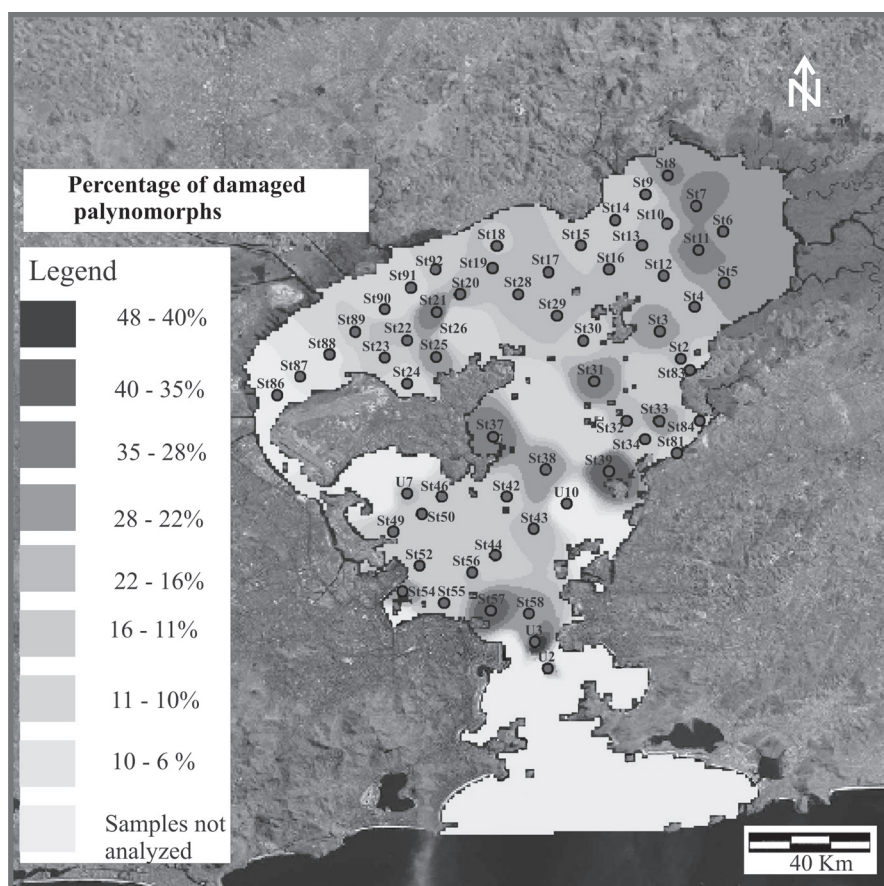


Figure 6 - Map of percentage of damages palynomorphs observed in surface sediment samples of the Guanabara Bay.

According to Jacobson and Bradshaw (1981), in a large aquatic environment, the pollen assemblage tends to be influenced by regional elements, while the majority of pollen grains deposited in smaller basins is dominated by those originated from local elements. Bennett (1986) suggested that most pollen grains arriving at a basin are carried by current water channels than by wind, as it was observed in the present study. Nevertheless, pollen analysis of surface sediments in the Lagoa Salgada, north of Rio de Janeiro State, showed a strong influence of the wind direction in the pollen grain deposition (Toledo et al. 1994).

Herbaceous pollen is prevalent in the Guanabara Bay pollen assemblages. Poacea was the dominant pollen type of the Grassland, followed by *Brassica*, *Amaranthus*/Chenopodiaceae, *Borreria densiflora*

and *Chamaesyce* (Figure 3). Inside the Fundão Island sector, as well as in the western sector, north of the Governador Island, the dominance of Grassland taxa was observed in 90% of the samples analyzed. This reflects the modern vegetation along the island (Fundão and Governador) margins. These plants were observed mainly in degraded areas of the bay and in river margins as well (Radambrasil 1983, Veloso et al. 1991, Amador 1997) (Figure 3). The northwest area of the Guanabara Bay is considered the most degraded area, receiving discharges from the most polluted rivers of the bay (Baptista Neto et al. 2006), and presenting the lowest pollen grain input.

The largest enrichment and high values of the regional pollen types from the Ombrophilous Forest vegetation were observed mainly in sediments close

to the rivers from the APA of Guapimirim (eastern sector of the bay) and in the northern bay margin. In the western sector of the innermost part of the bay, north of the Governador Island, the Ombrophilous Forest pollen types also occurred (more than 10% in all samples); *Alchornea*, *Anadenanthera*, *Arecaceae*, *Celtis*, *Hedyosmum*, *Lecythidaceae*, *Lecythis*, *Rapanea* and *Trema* were the most important ones. In accordance to Veloso et al. (1991), *Alchornea*, *Arecaceae*, *Celtis*, *Hedyosmum*, *Meliaceae* and *Trema* are significant trees of the Ombrophilous Forest vegetation growing in the low landscapes of Rio do Janeiro State.

Podocarpus lambertii, a species of the Montane Forest, was best represented at unique sample close to the northwestern margin of the bay (Figure 3). In accordance to Veloso et al. (1991) and Radambrasil (1983), this pollen type characterizes the vegetation of the Ombrophilous Dense Montane Forest located in the mountain hillsides.

Cyperaceae, Scrophulariaceae and *Typha* were the most important Hydrophyte pollen types. The increase of their percentages in samples near the APA of Guapimirim (Figure 4) may be associated to plants from flooded margins of rivers discharging into this sector of the bay (Araújo and Maciel 1979). The mangrove taxa recorded only in the samples of the southern bay margin in the central and eastern sector of the innermost part of the bay can be associated mainly with the proximity of the mangrove of the APA of Guapimirim. *Rhizophora* was the most common mangrove pollen type and a high pollen producer, while *Avicennia* is a low pollen producer, considering that *Rhizophora* is wind pollinated whereas *Avicennia* is insect pollinated. According to Jackson (1990), pollen grains dispersed by animals tend to be deposited next to the plant source and are not adapted to dispersion by the wind. Barreto et al. (2007) and Barth et al. (2004) studied Holocene sediments of a core located next to the Island of Paquetá (from about 8 km of the Guapimirim mangrove forest), where the presence of pollen

types indicating mangrove in the sediment level of 4.210 years A.P. ago was not recorded. By analyzing a sediment core collected in the northeast portion of the bay next to the APA of Guapimirim, São-Thiago (2005) evidenced a composed floristic scenery for a dense mangrove and river bordering forest vegetation of the domain of Tropical Rainforest.

The largest percentages of exotic genera were observed mainly within the sector of the Bay entrance and in the Fundão Island. These regions were highly impacted by human activities. The *Pinus* pollen, which is an exotic genera, was more common, since it was used for the reforestation of the same areas of the Guanabara Bay highlighting the human activities in the region (Veloso et al. 1991) (Figure 4). Fern spores concentration was practically constant in all samples of this sector (Figure 5). The presence of *Botryococcus* (Algae) indicates the proximity of a freshwater source (Guy-Ohlson 1992) (Figure 4).

The obtained pollen data represented very well the regional vegetation, and different pollen assemblages were observed in different bay sectors. Therefore, it was necessary to analyze separately each sector in order to a better understanding of the pattern distribution of palynomorphs in the bay sediments.

SPATIAL DISTRIBUTION OF POLLEN GRAINS AND SPORES

The variability of the pollen spectra in the sediments of different sectors of the Guanabara Bay reflects the hydrodynamic and bathymetry characteristics and changes in the vegetation surrounding the bay (Sugita 1993, Traverse 1994, DeBusk 1997). The pollen spectra of samples from the bay entrance sector presented the lowest pollen grain and spore concentration (Figure 5). This may be explained by the increase of the tidal water speed due mainly to the narrow bay entrance and its bathymetry that does not the palynomorphs deposition, and induce its transport into the most internal sectors, in the S-N direction. The greatest values of tide speed

occur in this sector, near the Gragoatá Fort and the Santos Dumont Airport (Kjerfve et al. 1997).

A low increase in the concentration values of pollen grains and spores was observed in samples taken next to the Fundão Island (samples St49 and U7) and in a sample between Rio-Niterói Bridge and the Cobras Island (Figure 5). It was due mainly to the low current energy in this area. The geomorphologic strait in the northwest portion of the Governador Island contributed to an increase in the tide current speed, even when dominated by low energy (Amador 1997). It possibly promoted the remobilization of palynomorphs previously deposited in other areas of this sector. According to Wilmschurst and McGlone (2005), lake sediment sources can include the inwash of secondary pollen and spores of mixed ages from eroded soils, river bank sediments and littoral sediments, as well as contemporaneous pollen and spores from aerial deposition, rain-out, surface runoff and inwash of debris from the catchment. The low concentration values of palynomorphs in these samples was related to the poorly covered areas of vegetation of the Governador and Fundão Islands, and next to Praça XV, which is highly impacted by the urban development.

The current intensity and deep depth in the main channel south of Rio-Niterói Bridge (sample St57) and east of the Governador Island (samples St44, St43, St42, U10 and St38) may be responsible for the low concentration of pollen and spores (Figure 5). The intensity of the current in the main channel of the bay decreases the accumulation of pollens in this sector, and allow the deposition of pollens in others areas of the bay. In these sectors an increase of pollen grain concentration was observed only in the east bay margin near to São Gonçalo city, where water current speed was reduced by the widening of the bay in alignment with Santos Dumont Airport - Gragoatá rocky coastal area (JICA 1994).

In the eastern sector of the innermost part of the bay, three samples presented the highest pollen and spore concentrations observed in the Guanabara Bay,

with the maximal pollen concentration occurring next to the river mouths at the north margin of the bay (Figure 5). The ease of palynomorphs deposition in this area can be associated to the low energy level of water flows and the flat bathymetry, which result in mud sedimentation with the predominance of clay (Kjerfve et al. 1997, Amador 1997, L.F. Catanzaro, unpublished data). With the exception of sample St87, all six samples located near the northwest margin of the bay presented high concentrations of pollen and spores. This may be associated to the low water energy and the flat bathymetry (Kjerfve et al. 1997, Amador 1997, L.F. Catanzaro, unpublished data). Numerous tributaries discharge into this sector, and contribute to the strong deposition of pollen grains and spores.

DIFFERENTIAL PRESERVATION OF PALYNO MORPHS

Pollen grains and spores preservation was generally excellent in surface sediment samples of the bay. An abundance of damages observed may be related to collisions occurring during the fluvial transport of palynomorphs, which indicates a removal from its source area (Tyson 1995). In accordance to Campbell (1991), pollen grains and spores damaged by erosion were found in many sedimentary basins and can be interpreted as a result of a new deposition after a period of exposition to the air, including cycles of humid and dry climates.

A high level of deterioration recorded in one sample located in the bay entrance, between Boa Viagem Beach and Santos Dumont Airport (sample U3), may be due mainly to the high energy of transport of different types of sediment, causing the rupture of pollen and spore exines. The geomorphology at northwest of the Governador Island contributes to an increase in the current speed of tides, promoting the remobilization of palynomorphs previously deposited in other areas of this sector. This fact may explain the high percentage of palynomorphs exhibiting damages observed in sample St54. On the other hand, in the

sector of the main channel, the highest percentages of deterioration were observed in samples St57 and St39. The increase of deposition of corroded pollen grains and spores was observed in samples St37, St39 and St33, indicating the exposition to the air. Following Wilmschurst and McGlone (2005), the process of corrosion must therefore occur some time after the pollen grains and spores were released from the source vegetation. In the eastern sector, in most parts of the bay, the high percentage of corroded palynomorphs observed in samples St5, St6, St7, St10 and St11 may be related to an intense action of microorganisms present in the mangrove. In the innermost samples of the eastern region in the bay, the maximal percentage of mechanical damages appeared in samples St21 and St26, decreasing towards the bay entrance. This pattern may be due to both tide currents and river inflows (Figure 6).

CONCLUSION

In summary, the patterns of modern pollen deposition in the Guanabara Bay surface sediments represent the regional vegetation of this hydrographic basin. Irregular spatial distribution of palynomorphs is related to the bay bathymetry, the tide currents, the inflow of numerous rivers and human perturbation. The dominance of grassland taxa reflects the wideranging areas of human occupation. The presence of Ombrophylous Forest pollen grains in all analyzed samples should confirm the presence of forest segments in the low-lands, as well as the hillside and Montane Forest preservation. The damaged pollen grains and spores may be related to abrasion occurring during their fluvial transport, indicating removal and reworking from their source areas.

The present results also contribute to a predictive model for the core samples analysis, improving comparison of Recent and Holocene results, which are very important for the environment monitoring of the Guanabara bay.

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RESUMO

Com objetivo de investigar a deposição dos grãos de pólen e esporos na Baía de Guanabara, Estado do Rio de Janeiro, 61 amostras de sedimentos superficiais foram analisadas. Os resultados mostraram que a deposição atual dos palinórfos nos sedimentos superficiais da Baía de Guanabara representa a vegetação regional de sua bacia hidrográfica. A distribuição diferencial dos palinórfos seguiu um padrão influenciado pela batimetria, velocidade das correntes de marés, descarga dos numerosos rios e pela atividade humana. A dominância dos taxa representantes da Vegetação Campestre reflete as mudanças da flora original causadas por intensas atividades humanas na região. A presença contínua e a grande riqueza de tipos polínicos da Floresta Ombrófila nas amostras, indica que a área fonte pode ser a vegetação das bordas dos rios do setor oeste da Baía, onde a vegetação de mangue está sendo preservada. A grande quantidade de palinórfos danificados pode estar relacionada ao desgaste que ocorre durante o transporte fluvial, indicando remoção ou retrabalhamento de suas áreas de origem.

Palavras-chave: palinórfos, sedimentos superficiais, deposição, preservação, Baía de Guanabara, Brasil.

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