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Foraminiferal Assemblage and Bioindicators for Evaluation of the Anthropogenic Impact in the Guanabara Bay, Rio de Janeiro, SE Brazil

Assembleia e Bioindicadores de Foraminíferos para Avaliação do Impacto Antropogênico na Baía de Guanabara, Rio de Janeiro, SE Brasil

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Abstract

In January 2000, Guanabara Bay in Rio de Janeiro experienced a major oil spilling caused by a break down in one PETROBRAS oil pipeline. Over than 1.3 tons of fuel oil escaped into the bay water in the northern region. Studies of foraminiferal taphonomic assemblages in sediment samples collected on three periods in the same stations, before and after the spilling, were important for the pollution impact evaluation during eight years. In 2005, in the north region, TOC values were higher than in 1999. It was observed the increase of test abnormalities, corrosion and dwarfism. Abundance and species richness reduced in 2005 and increased in 2008 but they did not reach the 1999 levels. Trends of dominant species confirmed the increase of pollution values in 2005: Abundance of *A. tepida* increased while *B. elegantissima* reduced. In 2008 there was an increase in the species richness with the occurrence of agglutinated species.
Keywords: pollution; foraminifera; oil spilling; Guanabara Bay

Resumo

Em janeiro de 2000, ocorreu o maior derramamento de óleo na Baía de Guanabara, RJ, causado pelo rompimento de um duto da PETROBRAS. Mais de 1,3 ton de óleo combustível escaparam para as águas da baía, na região norte. Estudos de assembleias tafonômicas de foraminíferos em amostras de sedimentos coletadas em três períodos nas mesmas estações, antes e depois do derramamento, foram importantes para a avaliação do impacto da poluição durante oito anos. Em 2005, na região norte, os valores de COT foram maiores que em 1999. Observou-se um aumento de tecas deformadas, corroídas e diminutas. A abundancia e a riqueza específicas diminuíram em 2005 e aumentaram em 2008, porém não alcançaram os níveis de 1999. Tendências das espécies dominantes confirmaram os índices de aumento da poluição em 2005: a abundancia de *A. tepida* aumentou enquanto a *B. elegantissima* diminuiu. Em 2008 houve um aumento da riqueza específica com a ocorrência de espécies aglutinantes.

Palavras-chave: poluição; foraminíferos; derramamento de óleo; Baía de Guanabara

1 Introduction

Guanabara Bay, in Rio de Janeiro state, southeastern Brazil, is surrounded by the large Rio de Janeiro City, and other large cities as Niterói, São Gonçalo and Duque de Caxias, in addition to other districts and municipalities. Over than seven million people live around Guanabara Bay, in those cities.

That important tourist and economic centre includes two harbours, two oil refineries and thousands of industries. Untreated domestic and industrial sewage and products of runoff from urban streets are carried into the Guanabara Bay water and sediment. It is surrounded by beaches and mangrove forests, which have nearly all been destroyed by the pollution (Kjerfve *et al.*, 1997, 2001; Amador, 2012). Nevertheless, in the northern region, there is a protected area that includes an intact mangrove forest.

Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals are common in urbanized areas like the city of Rio de Janeiro and neighbourhood. The PAHs and heavy metal origins are associated to anthropogenic sources like fossil fuels. They can be introduced in the environment by untreated domestic and industrial sewage, and atmospheric deposition through incomplete combustion of fossil fuels. Likewise, high contents of PAHs are daily transported from ships and oil pipelines to refineries located in the Guanabara Bay margin, such as the REDUC (Refinaria Duque de Caxias), from PETROBRAS. REDUC has several pipelines passing through the sediment-water interface in the Guanabara Bay, conducting the oil from and until the PETROBRAS terminals. Oil spills sometimes occur, and the association with particulate material carries hydrocarbons from the surface to the interior of the water column leading to the accumulation in sediments.

In January 2000, the Guanabara Bay experienced major oil spilling from a PETROBRAS oil transport pipeline. About 1.3 tons of fuel oil escaped into the bay water in the northern region and spreaded by near 2/3 of the total sea-water extension and sediment-water interface, with high consequences for the life in all trophic levels and for

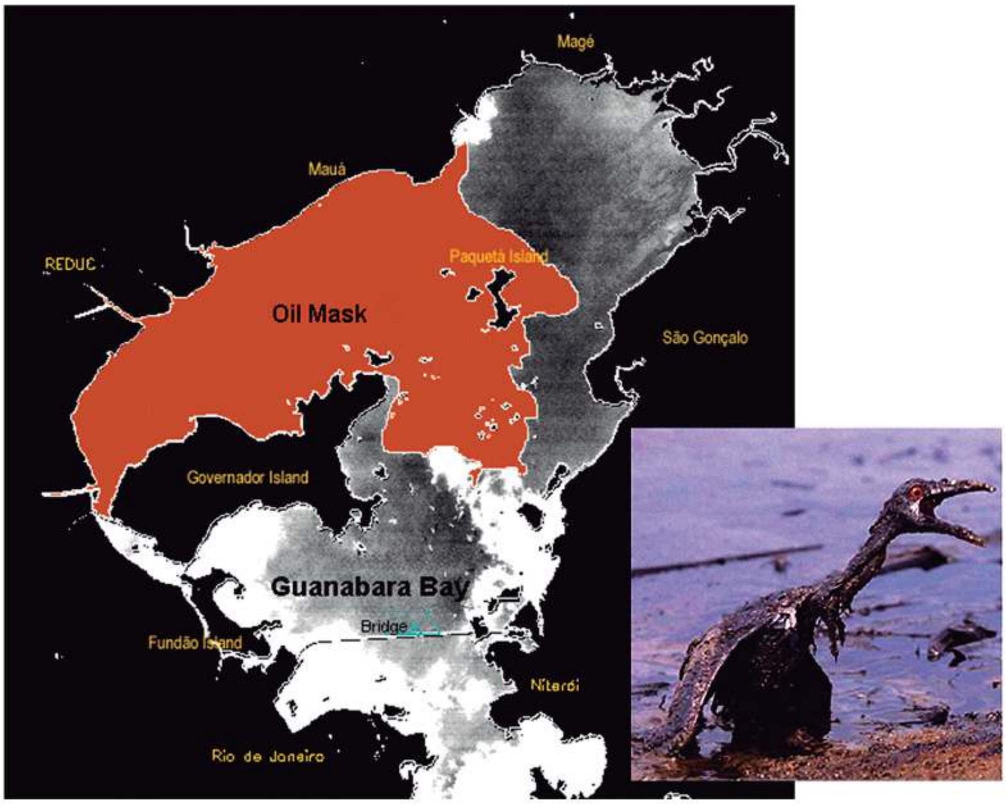

Figure 1 Mask of the oil spilling in Guanabara Bay on Jan. 19th, 2000 (modified from Kampel & Amaral, 2001). Published photo in O Globo newspaper, on Jan 20th, 2000: http://acervo.oglobo.globo.com/fotogalerias/fotos-premiadas-do-globo-17032062

the fishing (Figure 1).

Foraminifera are largely studied to interpret environment characteristics, like salinity, pH, organic matter, anoxic events, and changes by human impacts (Boltovskoy *et al.*, 1980; Culver & Buzas, 1995; Geslin *et al.*, 2002; Murray, 2006). Foraminiferal tests are commonly abundant in the sediments and they are easily collected in distinct Brazilian estuaries, bays and lagoons (Vilela *et al.*, 2003, 2011; Barbosa *et al.*, 2005; Eichler *et al.*, 2006; Machado & Araujo, 2014). Foraminiferal studies in the central and northeast regions of the Guanabara Bay pointed out the occurrence of bioindicator species and similarity between dead and living assemblages (Eichler *et al.*, 2014; Martins *et al.*, 2016a, 2016b). The use of foraminiferal assemblages and bioindicator species bring good responses in the evaluation of the pollution effects, in special the damages caused by hydrocarbons (Bates & Spencer, 1979; Alve, 1991; Yanko *et al.*, 1994; Debenay *et al.*, 2000; Samir, 2000). The responses of benthic foraminifera to organic and inorganic pollution have been evaluated in many marginal marine regions at all latitudes and have proven their utility for pollution monitoring (Seiglie, 1968; Culver & Buzas, 1995; Minhat *et al.*, 2014).

Previous studies in the Guanabara Bay and Rodrigo de Freitas Lagoon, Rio de Janeiro (Vilela *et al.*, 2003, 2004, 2011, 2014) characterized assemblages and bioindicator species that responded to the ecological parameters and pollution levels. These works evidenced that *Ammonia tepida* was the most abundant species in samples at the sediment-water interface. The *A. tepida – Elphidium excavatum* foraminiferal assemblage represented an environment under stress (Vilela *et al.*, 2011). At the Guanabara Bay, foraminiferal results at sediment-water interface presented *A. tepida, Buliminella elegantissima* and *Quinqueloculina seminulum* as dominant species at different regions. *E. excavatum, E. poeyanum* and *Textularia earlandi* were abundant (Vilela *et al.*, 2003, 2004). Sediment cores collected in different regions of Guanabara Bay showed that *B. elegantissima* is the dominant species at deeper intervals dated by radiocarbon in more than 550 years BP, with high contents of organic matter (TOC). These results reflected a native environment before the discovery and the European settlement. At the upper intervals, the dominance of *A. tepida* is a pollution bioindicator (Vilela *et al.*, 2014).

The aim of this work is to evaluate the benthic foraminiferal assemblage and bioindicator species, and its responses to ecological parameters in three moments near one decade, respectively in 1999, 2005 and 2008, in the Guanabara Bay, Rio de Janeiro. The results were evaluated in the same hotspots stations, at the sediment-water interface. The great oil spill which occurred in 2000 was taken into account considering the foraminiferal responses. TOC values in the sediment samples were evaluated and compared with the results of microfauna.

2 Material and Methods

Nineteen surface sediment samples were collected in the northwest and central regions in the Guanabara Bay, in three distinct periods, respectively in November 1999, July/August 2005 and March/May 2008 (Figure 2; Table 1). The samples were collected at the sediment-water interface, with a Van Veen grab sampler, the exact position of each sample was recorded using Global Position System (GPS). Collected samples in 1999, 2005 and 2008 were in the same coordinate stations. The samples were standardized at 80 cm^3, and the treatment for the microfaunal studies consisted of washing, wet sieving with a 0.063 mm-mesh sieve and drying in an oven at 50^o C. After treatment, benthic foraminifera were picked, counted and classified to the species level. The samples were splitted, when necessary, for a minimum count of 100 specimens per sample that were used for statistical analyses, according to Fatela & Taborda (2002). The determination of genera followed Loeblich and Tappan (1988), and the species classification were based on classic works, including the catalogue of Ellis and Messina (1940-et seq.) and several specific works, such as Cushman (1930, 1931, 1939, 1942), Barker (1960), Bermúdez & Seiglie (1963), Tinoco (1971) and Debenay *et al*. (2000).

Foraminiferal absolute and relative abundance indices were evaluated with ecological parameters of dominance and diversity. Species with 10% or higher relative abundance in the samples were considered to be dominant (Boltovskoy & Totah, 1985). The species diversity was calculated using the Shannon *H'* diversity index (Shannon, 1948), which considers the number of species and their relative abundance in the assemblage. For the Shannon diversity index, the considered confidence level for absolute abundance was higher than 40 specimens per sample. Diversity values in samples with less than 40 specimens were not calculated.

Particle size was analysed using a Malvern 2000 hydroG laser analyser after the removal of organic matter by digesting in 30% H2O2 (Folk, 1974). The total organic carbon and inorganic carbon contents were determined using a CS infrared analyser model Eltra Metalyt 1000CS. The geochemical methods consisted of pulverisation, acidification, washing and drying of the samples. Then, the samples were placed in an oven for burning with O2, and the organic carbon was measured. The TOC analyses expressed the percentage of organic carbon in samples.

3 Results

The foraminiferal assemblage in the Guanabara Bay was in general abundant. Absolute abundance values reduced in 2005, in the samples located in the northern area which directly suffered the spilling consequences, and in the central area under the influence of the spilling. In 2008, there was an increase in abundance in almost all samples. Total abundance values in those areas did not reach 7,000 in 2005, but were much higher in 1999 and 2008 (e.g. Table 1; Figure 3). Sample 1, in the northwest, must be disregarded as its location is under disturbance, which influences the sediment pattern.

TOC values and Shannon diversity were compared. Considering reference values (Semensatto, 2003; Eichler *et al.*, 2006; Semensatto *et al.*, 2009), Shannon diversity values in 1999 are considered high for bays, estuaries and environments under stress, ranging from 2.0 to 2.5 in the northwest and central regions. In 2005, diversity values decreased in both regions, with values from 1.5 to 2.0. In 2008, those values were a little higher (Figure 4). TOC values were in general inversely proportional

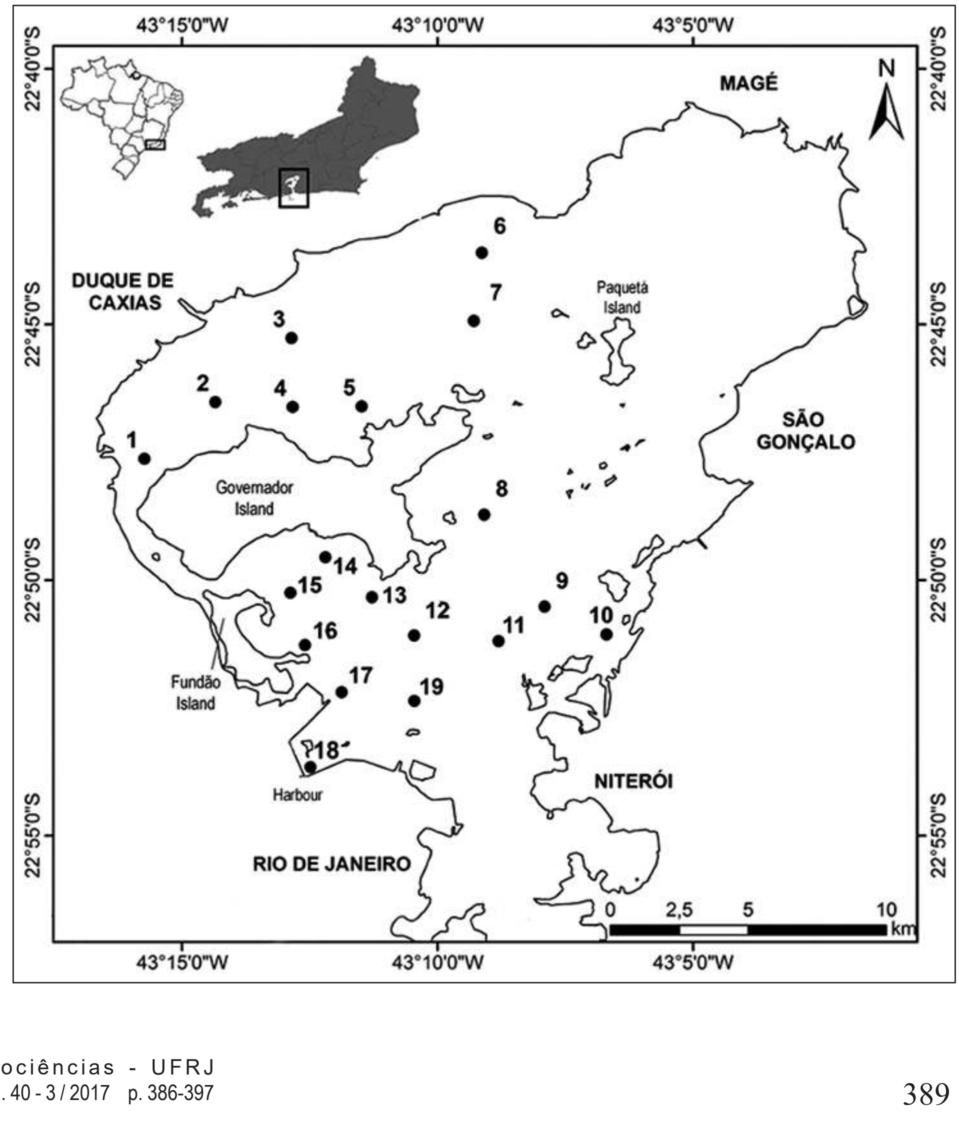

Figure 2 Location of the collected samples in 1999, 2005 and 2008, Guanabara Bay, Rio de Janeiro, SE Brazil.

Samples	Lat (S)	Long (W)	1999		Silt-clay %	TOC %	2005		TOC %	2008		TOC %
			Abs. Ab.	Abn. %			Abs. Ab.	Abn. %		Abs. Ab.	Abn. %	
1	22° 46’30”	43° 14’07”	1	0	99.4	4.5	849	3.0	3.3	x	x	x
2	22° 45’17”	43° 12’48”	2512	3.2	99.4	3.3	13	23.5	4.8	24704	6.0	5.6
3	22° 46’35”	43° 12’48”	1472	2.0	97.5	3.6	14	0	4.4	888	8.0	5.8
4	22° 46’35”	43° 11’25”	6848	0	98.6	4.0	71	8.0	3.9	888	1.0	4.9
5	22° 44’54”	43° 09’12”	13952	0	98.0	4.2	232	3.0	4.2	45056	0	3.3
6	22° 48’43”	43° 09’05”	8448	19.4	99.5	3.7	4992	5.0	5.1	x	0	x
7	22° 50’31”	43°07’54”	6912	1.0	99.4	4.5	2256	0	4.1	1936	0	3.9
8	22° 51’03”	43° 06’41”	804	0	83.2	3.3	568	0	2.9	12672	0	3.5
9	22° 51’11”	43° 08’48”	392	1.4	97.1	3.3	540	0	3.5	744	0.7	3.4
10	22° 51’04”	43° 10’27”	9472	0	94.0	3.3	9600	3.3	4.2	113848	0	3.3
11	22° 50’20”	43° 11’17”	3200	0	21.1	0.7	464	0	1.6	928	0	1.8
12	22° 49’33”	43° 12’11”	720	25.2	1.9	0.2	2192	8.0	0.4	22784	0	1.2
13	22° 50’15”	43° 12’52”	13184	30.8	93.6	4.4	1712	3.7	4.6	4160	0	5.0
14	22° 51’16”	43° 12’35”	3744	0	83.1	3.8	544	16.9	5.1	8448	10.6	4.2
15	22° 52’11”	43° 11’52”	872	11.0	0.0	0.3	1064	0	6.8	2912	10.3	1.3
16	22° 53’39”	43° 12’29”	872	7.3	49.7	3.4	424	0	3.8	6944	2.0	4.6
17	22° 53’21”	43° 10’27”	880	0	82.1	2.8	9152	0	3.5	992	0	4.4
18	22° 58’04”	43° 10’17”	15	0	83.6	6.1	44	24.1	8.4	19	11	5.2
19	22° 58’18”	43° 10’39”	11648	0	20.6	2.0	2464	5.6	3.1	1424	0	4.1

Table 1 Sample coordinates in Guanabara Bay, absolute abundance values (Abs. Ab.) per sample, percentage of abnormal specimens (Abn.) per sample, silt-clay percentage (in 1999) and total organic carbon (TOC) .

to the diversity. It is important to observe that there were higher TOC values in 2005 than in 2008, for the samples directly influenced by the great oil spill (Figures 4 and 5). One sample in the central region, western area (at Rio de Janeiro harbour area), must be disregarded, as it is always under high levels of hydrocarbons and heavy metals derived from ship activities (Baptista Neto *et al*., 2005). That sample (station 18) showed high values for TOC in the three dates of collection.

The foraminiferal tests were dwarf and abraded or corroded, making difficult the identification. Deformed and abnormal tests occurred in high percentages in the three periods of collected samples, however, percent values were reduced in 2008 (e.g. Table 1).

The most common and dominant species in the sediment samples in the three periods were *Ammonia tepida*, *Elphidium excavatum, Buliminella elegantissima, Textularia earlandi, E. poeyanum* and *Quinqueloculina seminulum.*

4 Discussion

In the studied area, the sediment analyses showed muddy sediments with high content of silt and organic matter (e.g. Table 1), favoured by the position of samples in the central and north regions of the bay (Catanzaro *et al*., 2004). The diameter of the grains determines important physicochemical

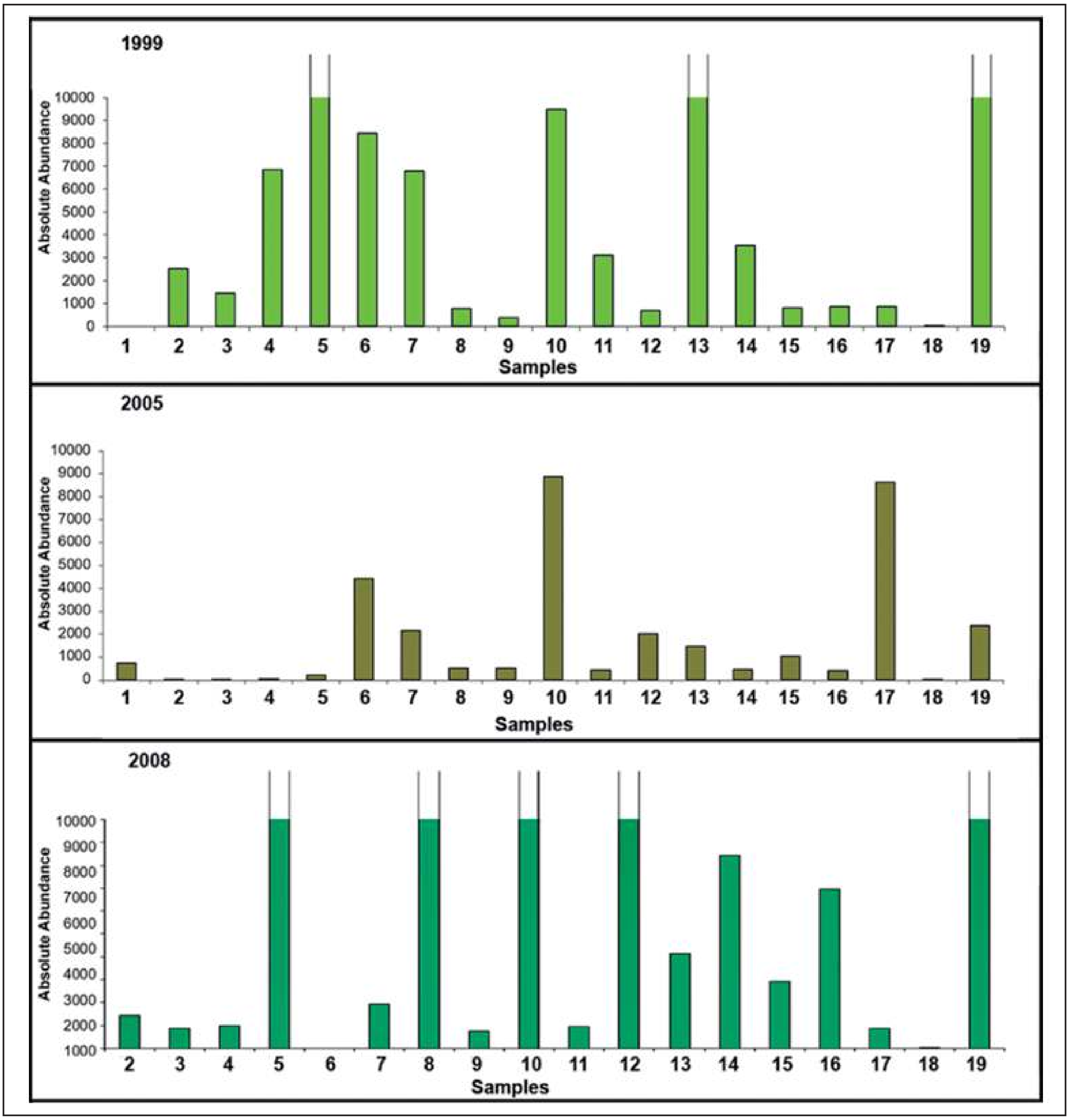

Figure 3 Comparative graphics with absolute abundance values for each sample. In 1999 and 2008 the values were standardized in 10,000 specimens and there were cuttings in the graphic columns, for better comparisons.

properties which affect the potential of absorption of pollutants. While it reduces the size of the particles, it is increased specific superficial area and the capacity of exchange cations, as well as the concentration of pollutants in the same ones (Laybauer & Bidone, 2001). Northwest and central regions in the Guanabara Bay experience the highest impact from the oil spill occurred in 2000, even considering the high pollution levels from untreated domestic and industrial sewage. The consequences for that accident may remain for years. Two of the main constituents in the fuel oil, the PAHs and the heavy metals, are considered by their lack of biodegradability. Particulate material carries hydrocarbons (PAHs) from the water column to the sediment interface, leading to the accumulation and concentration in sediments (Stefens *et al.*, 2007). Heavy metal concentrations in bottom sediments are higher in fine grained deposits and their transport and depositional patterns are similar of those in small particles. Heavy metals and hydrocarbons are deposited and accumulated in the sediments, and constitute a long-term of contamination (Burton, 2002, *in* Baptista Neto *et al.*, 2017).

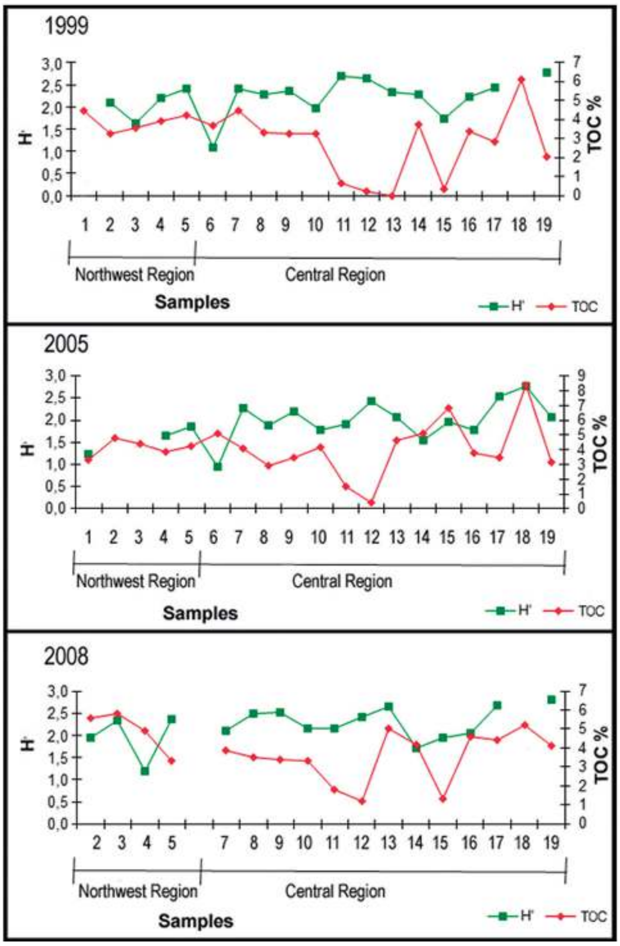

Figure 4 Diversity versus TOC in 1999, 2005 and 2008. Diversity was not calculated in samples less than 40 specimens. Missing samples were not collected.

The most common and dominant species in the sediment samples in the three periods were considered bioindicators of environmental changes in the Guanabara Bay by previous studies. Vilela *et al.* (2003) characterized different regions in the bay by the assemblage abundance and diversity values, and the dominance of *A. tepida, B. elegantissima* and *Q. seminulum*. Vilela *et al.* (2004) analysed the assemblage near the Niterói harbour, in the southeastern area of the bay, considering high values of pollutants derived from the harbour activities. The assemblage had low abundance and was very poor, with small and fragile tests of opportunistic species such as *A. tepida, B. elegantissima* and *Bolivina lowmani*. Vilela *et al.* (2014) detected foraminiferal bioindicators of organic matter and human pollution by analyses in cores at different regions of the bay. It was possible to characterize the European influence by the increase in organic matter (TOC values) along the cores. Organic matter values increased in the environment by domestic

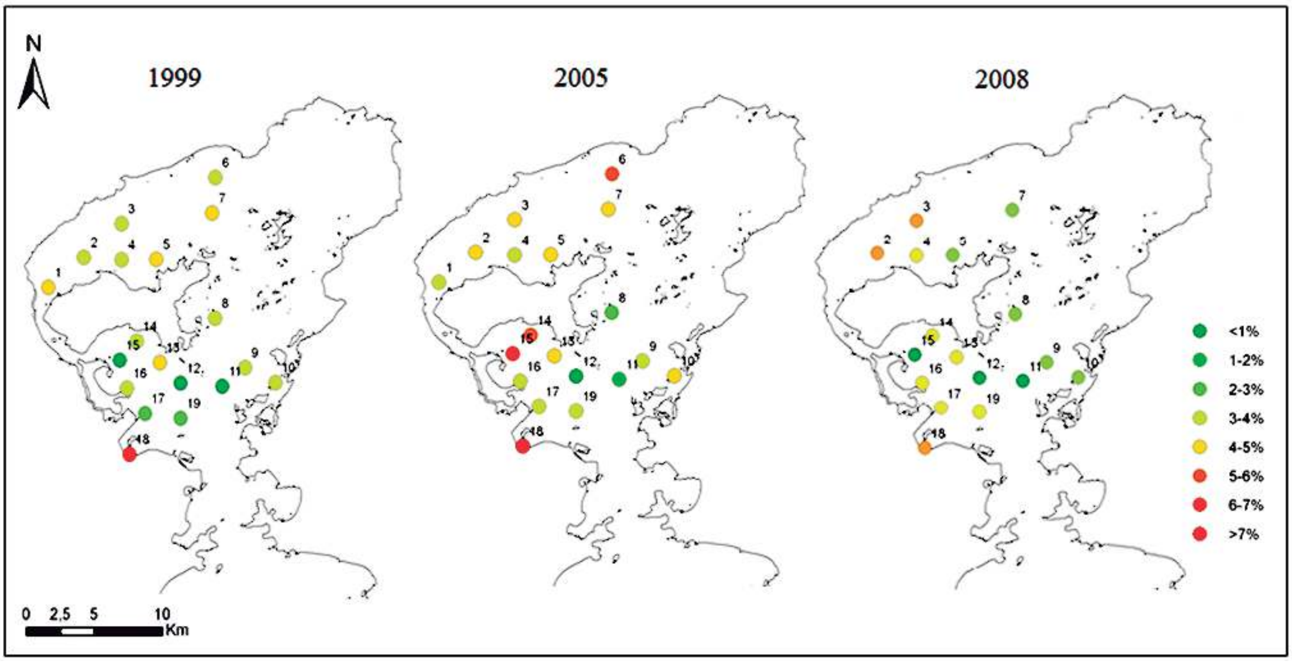

Figure 5 TOC values in the samples in 1999, 2005 and 2009

sewage and agricultural activities. The foraminiferal bioindicator responses in the Guanabara Bay, such as *A. tepida, B. elegantissima, Textularia earlandi* and *E. excavatum,* helped to evaluate the historical pollution increase.

Considering the three periods of collection, the damages in the microfauna, including abnormalities and low diversity, were distinct in 2005 (e.g. Table 1; Figure 4). Abnormalities like test corrosions, deformities and dwarfisms of the foraminiferal assemblage in the Guanabara Bay have been described by Vilela *et al.* (2004), Fonseca *et al.* (2007) and Santos *et al.* (2007). Yanko *et al.* (1998, 1999) verified that even low values of trace metals can cause test dwarfisms, commonly in *Ammonia tepida*. Several papers like Peréz-Cruz & Machain-Castilho (1990), Samir & El Din (2001), Armynot du Châtelet *et al.* (2004) and Vilela *et al.* (2011) considered those test changes as responses to oxygen low values, high PAHs and heavy metals. Geslin *et al.* (2002) pointed out that the tests' abrasion and corrosion processes are related to the organic matter and hydrocarbons dissolution by bacterial activity, causing the sediment acidification by the interstitial and bottom water. In this work, after comparing the assemblages in the three dates of collection, it was observed that abnormalities in the foraminiferal tests increased in 2005 and reduced in 2008 (e.g. Table 1).

Species diversity values were high, considering previous studies in Brazilian bays and estuaries (Eichler *et al.*, 2006; Semensatto-Jr. *et al.*, 2009). In several coastal regions trends of diversity correlated with TOC values were inversely proportional (Yanko, 1994; Culver & Buzas, 1995). In the three periods of sampling in Guanabara Bay, those trends occurred, and this pattern was already observed in previous works in the bay (Vilela *et al.*, 2003, 2004; Figueira *et al.*, 2007, Santos *et al.*, 2007). In 2005, diversity values decreased in both northwest and central regions. In 2008, those values were higher (e.g. Figure 4).

In the three periods of collection, distinct responses of the dominant species *Ammonia tepida*, *Elphidium excavatum, Buliminella elegantissima, Textularia earlandi, E. poeyanum* and *Quinqueloculina seminulum* can easily be recognized. Previous works have pointed out that *Ammonia tepida* is an opportunistic species which can resist to damage from domestic sewage, chemical effluents and heavy metals even when other species disappear. *Elphidium* spp. and *B. elegantissima* are cited as common and dominant in impacted coastal areas (Yanko *et al.*, 1994, 1999; Alve, 1995; Collins *et al.*, 1995; Culver and Buzas, 1995; Sen Gupta *et al.*, 1996; Murray & Alve, 2002; Vilela *et al.*, 2003). *Quinqueloculina seminulum* can represent anoxic conditions (Sen Gupta & Machain-Castilho, 1993). Vilela *et al.* (2014), analysing sediment cores in Guanabara Bay, considered the dominant species *A. tepida* as a pollution bioindicator whereas *B. elegantissima* was characteristic of organic matter high values in the past, but disappeared or decreased with the increase of the anthropogenic pollution. Abundance of both species was inversely proportional in the studied sediment cores in all studied areas in the Guanabara Bay (Vilela *et al.*, 2014). Eichler *et al.* (2014) found *A. tepida* in the study area as dominant species and as a response for the oil spills. They considered the presence of *B. elegantissima* fragile and weak tests caused by the acidity. Vilela *et al.* (2014) considered *E. excavatum* and other *Elphidium* species as common species in the past and recent sediments. *Q. seminulum* was inexpressive in the sediment cores, in the ancient assemblages before the Europeans settlement (Vilela *et al.*, 2014) but were important in bottom sediment samples, characterizing Guanabara Bay regions (Vilela *et al.*, 2003).

In the present work, the occurrence of the six dominant species, respectively *Ammonia tepida, Elphidium excavatum, Buliminella elegantissima, E. poeyanum, Quinqueloculina seminulum* and *Textularia earlandi*, can be considered as a response for the environment degradation levels during almost one decade. Abundance values of the bioindicator species *A. tepida* were the highest. *A. tepida* and *E. excavatum* were opportunistic with increased values in 2005. *B. elegantissima, T. earlandi* and *E. poeyanum* decreased in 2005 and increased slightly in 2008 (e.g. Table 1; Figures 6, 7). Values for *B. elegantissima* decreased mainly in the northwest region, in 2005, as a response for the increased degradation. *Q. seminulum* presented an opportunistic trend, as being abundant in 2005, comparing with another dominant species except *A. tepida*. The agglutinated species *T. earlandi*, that disappeared in 2005, were present in 2008, contributing for the increase in the species richness

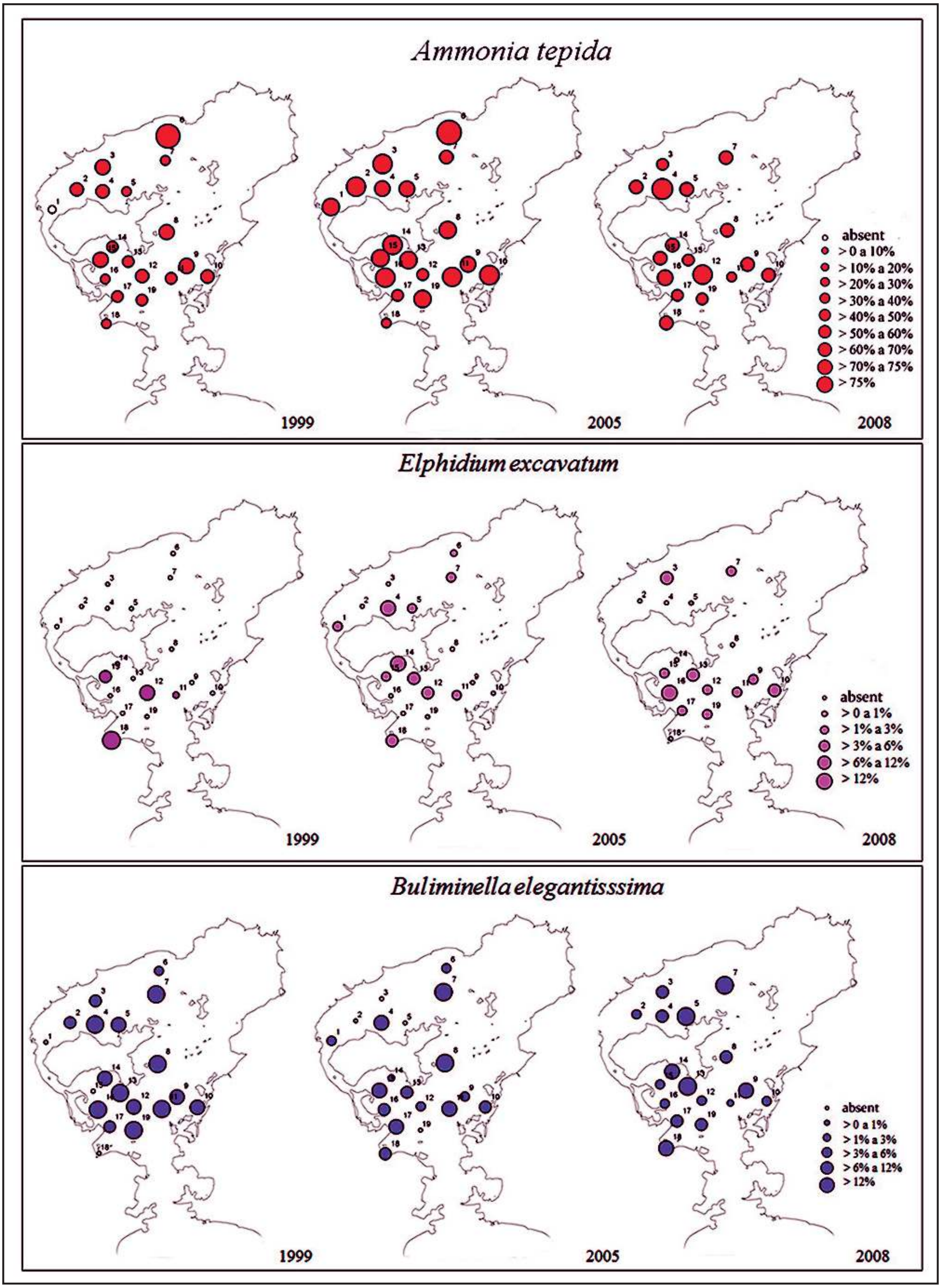

Figure 6 Relative abundance values of *Ammonia tepida, Elphidium excavatum* and *Buliminella elegantissima* in the samples, in 1999, 2005 and 2008.

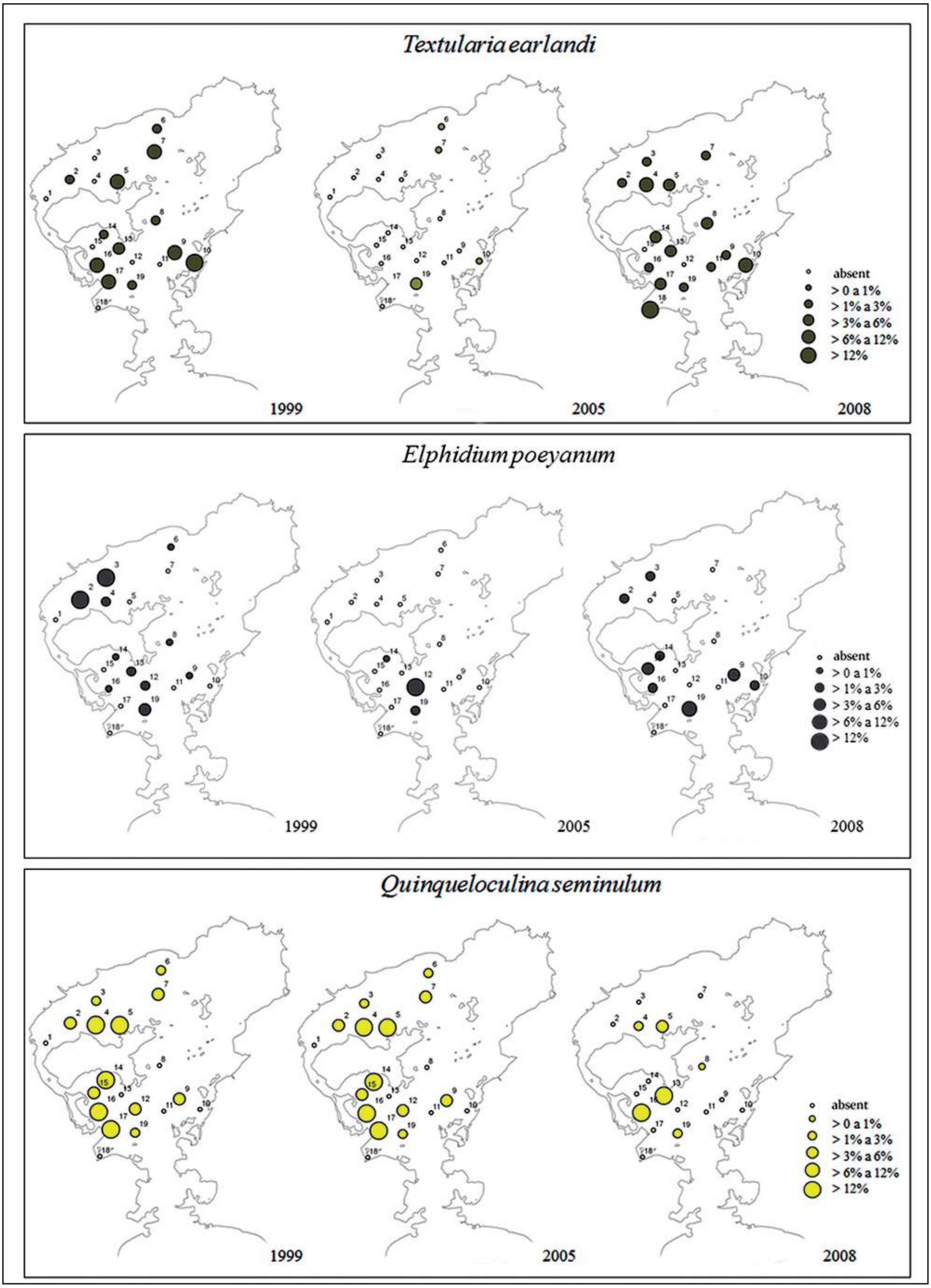

Figure 7 Relative abundance values of *Textularia earlandi, Elphidium poeyanum* and *Quinqueloculina seminulum* in the samples, in 1999, 2005 and 2008.

(e.g. Figures 6, 7).

5 Conclusion

The evaluation of the foraminiferal assemblage responses may be important for monitoring the consequences for the 2000 great oil spilling, in the Guanabara Bay. The dominant species in three periods of sampling were *Ammonia tepida, Elphidium excavatum, Buliminella elegantissima, Textularia earlandi, E. poeyanum* and *Quinqueloculina seminulum*. Those foraminiferal tests remained in the sediments as witnesses, with abundance and diversity indexes varying in three periods of sampling during eight years. They measured the degradation levels as tools for the anthropogenic impacts. In 1999, the values for abundance and species richness were higher, but decreased in 2005 and increased again in 2008. Opportunistic species dominated when all abundance values had reduced, while the environments experience the consequences for the major oil spill.

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