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Influence of submarine sewage outfall in the sediment quality of São Sebastião channel (São paulo, br) through foraminiferal assemblages

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Abstract

Benthic foraminifera are used as environmental bio-indicators, especially in polluted environments where their sensitivity to pollutants may be expressed by alterations of the assemblages. Eighty-one sediment samples were collected in nine sampling trips in spring and summer (October/98, January/99, November/00, November/01) and in autumn and winter (May/99, May/00, May/01, August/99 and July/02) in the São Sebastião Channel for the study of foraminiferal assemblages. This work is related to the monitoring of a submarine outfall, considering that it is subjected to oceanographic variations and anthropic influences. We intend to determine the quality of the interface sediment-water in the TEBAR (Almirante Barroso Maritime terminal, PETROBRÁS) through foraminiferal species indicator of vulnerable environments. Results show the large number of living organisms, young and adults reveal that water circulation and dynamics favor the establishment and development of well-oxygenated foraminiferal species explaining the absence of eutrophication caused by TEBAR and the urban sewage of São Sebastião and Ilhabela. However, the low number of species recorded along the São Sebastião channel is not normal for inner shelf. The number of species in the Channel is comparable to estuarine environments where freshwater limits the distribution of organisms. This low number of species could be attributed to some of the condition that results from the effects of various sources of contamination in the Channel, such as sewage from cities, harbor, TEBAR, primary surface runoff, hydrocarbon spills among others dividing the environment in two groups. The opportunist tolerant group: *Ammonia* spp., *Buliminella elegantissima, Bulimina marginata, Bolivina striatula* and *Fursenkoina pontoni*, proliferate where high organic matter indicates terrestrial contribution, anaerobic environments in the central regions of the Channel and should be used as bio-indicator of pollution. The second more oxygenated tolerant group includes *Quinqueloculina spp., Elphidium poeyanum, Hanzawaia spp., Discorbis williamsoni, Discorbis floridana, Pyrgo sp., Cassidulina minuta, Cassidulina subglobosa* and *Pararotalia cananeiaensis*, indicative of well-oxygenated environments, high dynamic currents in the region, and penetration of marine currents in the channel.

Keywords: foraminifera, são sebastião channel, submarine outfall, environmental quality, interface sediment-water.

Introduction

The problems arising from the pollution of waters in coastal areas close to urban and industrial centers in Brazil, as well as in several coastal countries globally are rapidly worsening. This has led an increasing number of governmental and non-governmental environmental protection agencies, public health agencies and universities becoming involved in pollution detection, assessment and monitoring plans in these areas. This topic has to have an interdisciplinary approach, taking into account the close interrelationships between geological, physical, chemical and biological aspects inherent to the marine environment.

Many studies in coastal regions make it possible to know their hydrodynamic, chemical and biological characteristics. In spite of the existence of numerous hydrological and geochemical parameters that can be used to control environmental variations, the reproducibility of its analysis and consequent interpretation is difficult to perform. In addition, most of these analyzes, especially those of the water column, provide no more than an instantaneous image of the environmental parameter. The value of this image can be doubted if its extreme variability is taken into consideration, even in a temporal scale equivalent to a tidal cycle.

It is only through a cooperative effort between the different scientific areas of knowledge that it is possible to obtain a wide spectrum of information, essential to effective environmental management.[1–3] It is therefore appropriate to consider the use of a simple and inexpensive management marker, capable of synthesizing the general characteristics of the environment, highlighting short-term environmental variations. This indicator needs to be sensitive enough to react rapidly to variations in the environment. In this sense, the foraminifera react very effectively and show water-sediment interface conditions. In Los Angeles (LA) County Outfall area, a zone without live specimens occurs beneath part of the sewage field; excepting for the dead zone, hyaline species are more than 8 times as abundant as arenaceous and porcelaneous species in living populations of the entire outfall area. Species thriving within this LA outfall area include *Bulimina marginata denudata, Buliminella elegantissima*, and *Discorbis columbiensis*.[4]

The effects of pollution, domestic and agricultural wastes on the foraminiferal distribution have been extensively studied since the sixties in lagoons, mangroves, estuaries and shelves,[5–23] paper mill effluent,[8,9,24] oil spill,[7,21,25] and trace metals in sediments.[25–28] They all have pointed out that foraminifera are very sensitive to pollution and contamination and provide one of the most sensitive and inexpensive markers available for indicating deterioration of coastal environment. Therefore, foraminiferal assemblages should be used as part of integrated programs of pollution monitoring, including chemical analysis of the contaminants. Their use should include routine long-term surveillance programs, hazard assessment at specific discharge sites, and monitoring of the effectiveness of remedial actions.[29]

Here we show a long-term foraminiferal assemblage of São Sebastião Channel, considering that this location is subject to oceanographic variations and to anthropic effects. We intend to determine the influence of the submarine outfall of TEBAR (Terminal Maritimo Almirante Barroso) in the sediment quality of the São Sebastião Channel due to changes in the environment and to point out, through the foraminiferal indicator species, the most vulnerable sub-environments of this coastal region.

Methodology

Sediment collection for the analysis of the foraminiferal fauna of the São Sebastião Channel was performed in the monitoring (1998-1999, 2000-2001 and 2002), totaling nine samples distributed in nine sampling stations. For each sample, a 10cm^3 aliquot of sediment was removed, separated into 0.500 and 0.062mm sieves, washed to remove silt and clay, and oven dried at 60°C. After separation, the split of samples, sorting and picking foraminiferal species. They were then transferred with the help of a brush to special black background slides for later identification. Species determination was done using the stereomicroscope Stemi SV11 from Zeiss.

Analytics of results

The statistical tests applied in this research are based on descriptive and analytical analyzes. Descriptive statistical analyzes are composed of absolute and relative frequency tables. Analytical statistical analysis consists of univariate and multivariate methods.

Descriptive statistics

From the identification of foraminifera species found in the São Sebastião channel region, the individuals were summed up and the absolute frequency of individuals (alive+dead) per sampled station was obtained.

Analysis statistics

Univariate analyzes: number of species, indices of diversity, dominance and evenness.

Univariate techniques are effective when used together to assess changes in community structure. The calculated indices were the diversity index of Shannon-Wiener in base E, Simpson dominance index and Pielou Evenness index.

Multivariate analysis: cluster analysis and MDS

In order to corroborate the data obtained in the descriptive statistical analyzes, CLUSTER and MDS analyzes were applied as well.

Absolute frequency data for each sampled station were submitted to cluster analysis to evidence associations of foraminifera. The distance from Bray-Curtis was used to measure the proximity between samples and Ward's method of attachment was used to arrange the species in a hierarchical dendrogram (R Mode). The data were then ordered using the non metric Multi Dimensional Scaling (MDS) correlation,[30] where the fauna data were transformed into the square root and the similarity matrices were constructed using Bray-Curtis. Calculations were obtained from the Primer program (University of Plymouth) and are described in Clarke & Warwick.[31]

Study area

The São Sebastião Channel is a feature located in the inner continental shelf of São Paulo State, south-eastern Brazil (23°43'/23°54'S, 45°20'/45°28'W), with a length of 25km and width of 6, 2 and 7km, in the northern, central and southern areas, respectively. It presents a SW-NE direction, and its higher depths axis is dislocated to the São Sebastião Island side (Figure 1). This bottom morphology is irregular, greater depths (>45m) occurs in the channels' axis central region, where the harbour, submarine sewage outfall and petroleum terminal are adjacently located. The northern and southern mouths have, respectively, isobaths of 20 and 25m, and lower depths occurs in the continental side of the channel, from its central part to north (0 to 7m).[32]

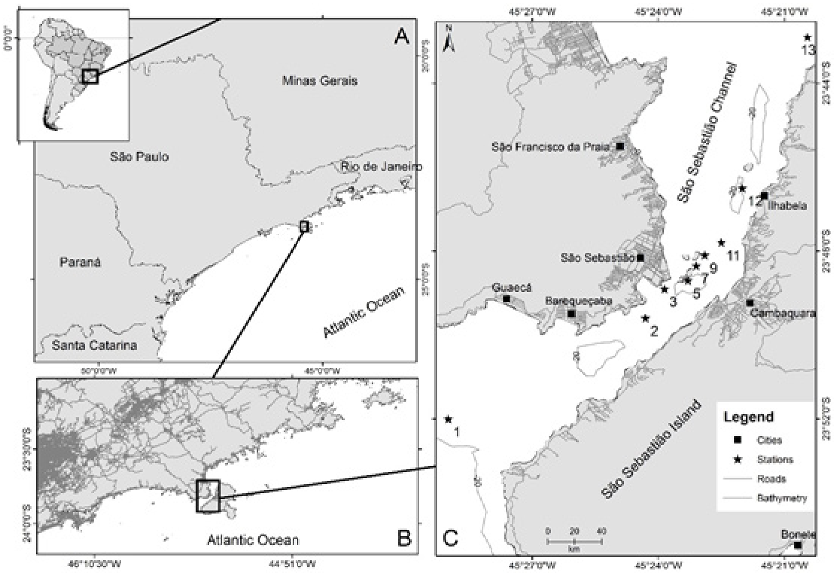

Figure 1 Study area and sampling stations for monitoring.

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The São Sebastião Channel's sediments distribution is heterogeneous, represented by several grain size classes and the modern sedimentary processes are directly related to the hydrodynamic circulation and the bottom topography (Furtado, 1995; Barcellos and Furtado, 2006).[32,33] The wind-generated currents are the most effective hydrodynamic phenomena, responsible for the bottom sedimentary processes.[33] According to Fontes[34] currents greater than 1.0ms^{-1} velocities, are common in its axial central and northern portions, and the predominant current flux presents a northeast direction.

The humid tropical climate associated to the absence of greater river basins draining into the area, give to the rainfall regime a huge importance in the contribution of freshwater from the continent to the ocean, mainly in the rainy season (summer).[35] Since the river input of sediments is limited, the terrestrial and organic matter inputs occur especially through the runoff waters processes, directly dependent on the rainfall regime.[32]

Results

Distribution of species in general

The distribution of the foraminifera, in the São Sebastião channel is characterized by the occurrence of about 8 to 35 species. This variation and the low number of species occurring in this inner shelf area is not the normal expected for this region.

The absolute frequency data of foraminiferal species can be visualized in Appendix 1 (Tables I to IX). It is observed that in the study area inhabit *Ammonia beccarii, Bolivina spp, Bulimella marginata, Buliminella elegantissima, Hanzawaia boueana, Fursenkoina pontoni, Pseudononion atlanticum, Discorbis williamsoni, Discorbis floridana, Hanzawaia spp, Quinqueloculina spp, Pararotalia cananeiaensis. Cassidulina minuta, Cassidulina subglobosa, Elphidium spp, Poroeponides lateralis,* and *Pyrgo* sp.

Individuals of *Ammonia beccarii, Bolivina* spp., *Buliminella elegantissima, Bulimina marginata, Fursenkoina pontoni,* and *Psedononion atlanticum* characteristic of anaerobic environments were found in the central regions of the Channel. In addition to the occurrence of anaerobic species, along the Channel, are also found *Discorbis williamsoni, Discorbis floridana, Hanzawaia spp, Pyrgo* sp., *Cassidulina minuta, Cassidulina subglobosa,* and *Quinqueloculina* spp are indicative species of well-oxygenated environments, reflecting the action of intense currents in the region. The significant occurrence of *Pararotalia cananeiaensis* can also be attributed to the penetration of marine currents in the channel.

Diversity, dominance and fairness

The values of diversity, dominance, and fairness were grouped according to the seasons (spring-summer or autumn-winter) in which samples were collected. The grouping aimed to differentiate patterns and seasonal effects. The diversity (Table 2) is low and relatively constant along the channel, but a significant increase of this variable was observed in the autumn and winter seasons (May/99, May/00, May /01, August/99 and July/02). According to the dominance data, we observed that in the spring and summer (October/98, January/99, November/00, November / 01), dominance values were lower compared to the autumn and winter periods (Table 3). Evenness (Table 4) is high along the Channel, and there is also a significant increase of this variable in the autumn and winter seasons (May / 00, May/01, August/99 and July/02).

Table 1 Number of species occurring in monitored stations

Number of species	Oct-98	Jan-99	May-99	Aug-99	May-00	Nov-00	May-01	Nov-01	Jul-02
1	7	13	22	21	14	14	30	20	34
2	19	17	22	16	11	11	35	21	34
3	29	20	19	23	8	10	31	28	30
4	21	10	20	12	8	9	27	27	35
5	25	14	21	23	10	13	35	30	32
7	27	16	19	27	9	8	34	32	33
11	22	19	14	25	9	9	34	33	33
12	19	24	18	24	12	11	33	32	32
13	21	12	19	22	11	10	35	34	29

Table 2 Diversity related to monitoring (1998, 1999, 2000, 2001, 2002)

Diversity	Spring/Summer				Autunm/Winter				
Samples	Oct-98	Jan-99	Nov-00	Nov-01	May-99	May-00	May-01	Aug-99	Jul-02
1	1.60	1.89	2.36	2.40	2.46	2.37	2.71	2.32	3.26
2	2.53	2.36	1.90	2.30	2.31	2.27	2.64	2.29	3.31
3	2.57	2.24	1.36	1.97	2.18	1.89	2.57	2.78	3.16
4	2.45	1.67	1.36	1.81	2.59	1.82	2.36	1.88	3.32

Table continue

Diversity	Spring/Summer				Autunm/Winter				
Samples	**Oct-98**	**Jan-99**	**Nov-00**	**Nov-01**	**May-99**	**May-00**	**May-01**	**Aug-99**	**Jul-02**
5	2.29	1.93	1.33	2.21	2.28	2.07	2.94	2.80	3.16
6	2.61	1.95			2.34			2.47	
7	2.70	2.09	1.66	2.84	2.44	1.96	2.60	3.11	3.12
8	2.33	1.72			2.43			2.48	
9	2.52	2.42	1.84	2.77	2.38	1.95	3.11	2.64	3.16
10	2.33	2.28			2.17			3.01	
11	2.77	2.66	1.79	2.77	2.15	2.35	2.95	2.89	3.23
12	2.61	2.14	1.98	2.87	2.57	2.22	2.72	2.65	2.96

Table 3 Dominance related to monitoring (1998, 1999, 2000, 2001, 2002)

Dominance	Spring/Summer				Autunm/Winter				
Samples	**Oct-98**	**Jan-99**	**Nov-00**	**Nov-01**	**May-99**	**May-00**	**May-01**	**Aug-99**	**Jul-02**
1	0.79	0.80	0.88	0.84	0.89	0.89	0.92	0.89	0.95
2	0.90	0.88	0.85	0.86	0.89	0.82	0.91	0.87	0.96
3	0.89	0.85	0.80	0.92	0.82	0.69	0.89	0.75	0.95
4	0.85	0.80	0.86	0.92	0.81	0.70	0.86	0.62	0.96
5	0.91	0.82	0.88	0.95	0.85	0.63	0.92	0.79	0.95
7	0.89	0.87	0.89	0.90	0.84	0.76	0.86	0.90	0.94
11	0.86	0.87	0.86	0.94	0.84	0.80	0.94	0.86	0.95
12	0.95	0.91	0.81	0.93	0.90	0.76	0.93	0.88	0.96
13	0.91	0.88	0.91	0.90	0.88	0.83	0.90	0.89	0.93

Table 4 Evenness related to monitoring (1998, 1999, 2000, 2001, 2002)

Evenness	Spring/Summer				Autunm/Winter				
Samples	**Oct-98**	**Jan-99**	**Nov-00**	**Nov-01**	**May-99**	**May-00**	**May-01**	**Aug-99**	**Jul-02**
1	0.82	0.74	0.90	0.80	0.80	0.90	0.80	0.76	0.92
2	0.86	0.83	0.79	0.76	0.75	0.95	0.74	0.83	0.94
3	0.76	0.75	0.59	0.59	0.74	0.91	0.75	0.89	0.93
4	0.71	0.73	0.62	0.55	0.75	0.88	0.72	0.89	0.93
5	0.82	0.75	0.52	0.65	0.83	0.90	0.83	0.94	0.91
7	0.78	0.82	0.80	0.82	0.82	0.89	0.74	0.87	0.89
11	0.75	0.78	0.84	0.79	0.82	0.89	0.88	0.93	0.90
12	0.94	0.84	0.75	0.80	0.74	0.95	0.84	0.91	0.93
13	0.86	0.86	0.86	0.81	0.87	0.93	0.77	0.86	0.88

The variations observed in the indexes of diversity, dominance and equitability along the São Sebastião Channel can be related mainly to seasonality (autumn/winter and spring/summer).

Generally, species diversity is higher in open-ocean and internally open sea environments, in areas with strong salinity oscillations (bays, estuaries, coastal lagoons and mangrove areas). In the case of São Sebastião Channel, since the conditions of temperature and salinity are not limiting, low diversity and low number of species may be the result of the presence of pollutants and contaminants in the environment. It is necessary, therefore, to show that the low number of species recorded along the São Sebastião channel is not normal for inner shelf regions. The number of species present is comparable to estuarine environments where freshwater limits the distribution of organisms. This might reflect the stressful conditions that culminate in disappearance of less resistant species.

Cluster analysis

Cluster analysis (Q Mode) was applied to the biological data during the monitoring months and, except for some exceptions, showed mainly the formation of 2 groups containing different species.

The differences between the groups reside mainly in the opportunistic characteristic of their species. The first group comprises mainly individuals of *Ammonia spp., B. elegantissima, B. marginata, B. striatula* and *F. pontoni,* and the second group includes *Quinqueloculina spp., Elphidium poeyanum, Hanzawaia spp., Discorbis spp., Cassidulina spp.* and *Pararotalia cananeiaensis.*

The species found in the first group are opportunistic, resistant to several types of pollution, and proliferate in places where organic matter contents are high, indicating terrestrial contribution. The second group appear mainly the species associated to high salinity, whose presence indicates oxygenated environments.

Appendix 2 shows dendrograms (a through i) obtained for each monitored month (October/98, January/99, May/99, August/99, May/00, November/00, May/01, November/01 and July/02).

MDS analysis

The analysis of MDS in the monitored stations for each month is represented in figure 2.

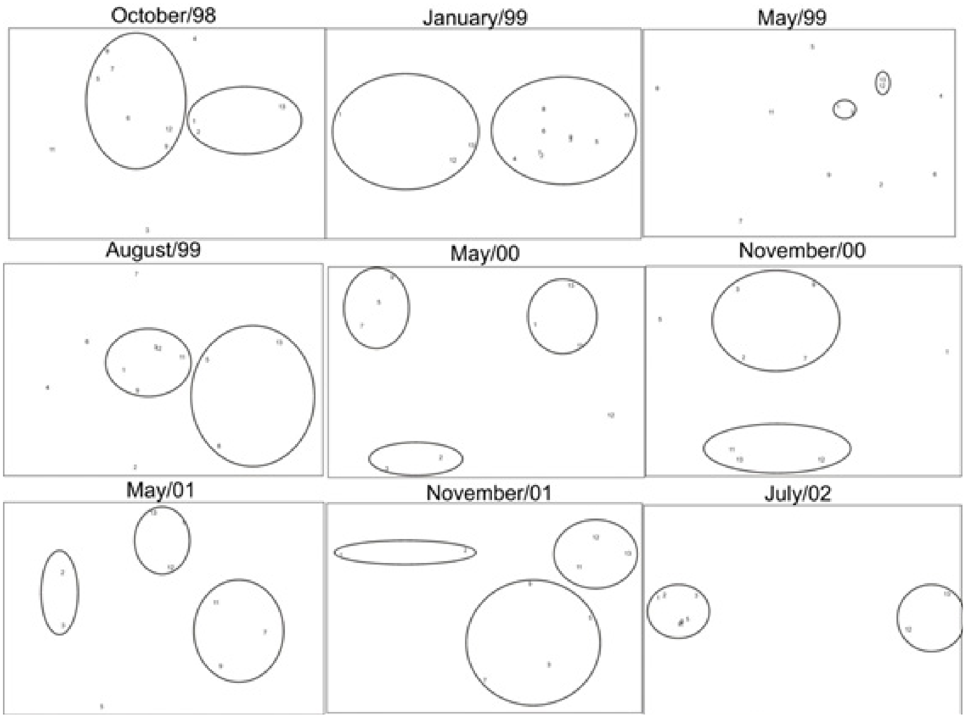

Figure 2 MDS analysis for monitoring stations and monitoring months.

For October/98 and January/99, the analysis revealed the formation of 2 major groups. Stations located at the south and north entrances of the channel (1, 12, 13) are grouped together, while the stations located in the central portion of the channel (2 to 10) are encompassed in a second group. In May/99 it was not possible to observe the formation of clusters. In August /99 it was possible to evidence 2 groups. The first containing stations 1, 3, 9, 11, 12, and the second group, stations 5, 8 and 13.

In May / 2000, it was possible to evidence the formation of three groups of stations: stations located near the TEBAR (7, 8, 9); stations located in the southern part of the São Sebastião Channel (2, 3) and the stations located in the south and north of the Channel (1, 12, 13). This grouping is one of the best that differentiates the existing sub environments in the São Sebastião channel. It was possible to show the main formation of two groups: central Channel (2, 3, 7, 9) and north mouth (11, 12, 13). In May, November 2001 and July 2002, three main groups were formed: South part of the Channel (2, 3), southern and northern parts (1, 12, 13) influence of TEBAR (7, 9, 11).

Discussion

The São Sebastião Channel presents variations in the patterns of diversity, dominance and evenness related mainly to seasonal variations. The spring-summer and autumn-winter variation is characteristic of subtropical environments and is also related to channel oceanography. The waters in the São Sebastião channel are dominated by Coastal Water (CW). In addition, in the spring and summer, the South Atlantic Central Water (SACW), with high salinity and low temperature, enters the bottom through its southern entrance. Therefore, the result

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of mixture between CW, SACW and Tropical Water (TW) occurring in varying proportions on the continental shelf of the region[36] form the waters in the channel. The presence of CW and SACW creates microenvironments along the water column, responsible for the high phytoplankton diversity observed in the Channel. In the specific case of São Sebastião Channel, the very irregular bottom topography, prints deposition of several facies, with sedimentary subenvironments magnified by the seasonal meteoceanographical processes.[35] On the other hand, in the monitoring carried out from 1998 to 2002 along the channel, it is observed an increase in the diversity of foraminiferal species in the autumn and winter periods, suggesting that the increase of the phytoplankton diversity is incorporated into the benthos in 3 to 6 months later. In addition, the last sampling (July / 02) revealed an increase in diversity patterns indicating the trend of environmental recovery.

The distribution of the foraminifera in the central region of the São Sebastião channel near TEBAR is characterized mainly by the presence of *Ammonia beccarii, Bolivina spp, Bulimmina marginata, Buliminella elegantíssima, Fursenkoina pontoni*, sediment characteristics with high organic matter content, mainly anaerobic environments. This area is shallower and with organic matter of continental origin.[36] According to Culver & Buzas,[37] the conspicuous occurrence of *Buliminella elegantissima* in the great majority of the seasons is reflex, of organic contamination.

On the other hand, the occurrence of the robust species characteristic of oxygenated environments, such as *Hanzawaia boueana, Pseudononion atlanticum, Discorbis williamsoni, Discorbis floridana, Quinqueloculina spp, Pararotalia cananeiaensis., Cassidulina minuta, Cassidulina subglobosa, Elphidium spp, Poroeponides lateralis,* and *Pyrgo* sp. reflect the performance of strong currents. According to Debenay et al.[38] the significant occurrence of *Pararotalia cananeiaensis* (marine species of coastal region) can also be attributed to the penetration of marine currents in the Channel, indicating the high hydrodynamics. In fact, gravelly biolithoclastic sediments with low organic matter contents of marine origin corroborate the influence of shelf water masses in the main channel's axis, especially in its southern portion.[35]

Conclusion

We conclude from the associations of foraminifera that occur in the Channel that the conditions of the same, are not totally reducing. In addition, the large number of living organisms, young and adult, reveals that water circulation and dynamics favor the establishment and development of foraminifera, explaining the absence of eutrophication caused by TEBAR and the urban sewage of São Sebastião and Ilhabela.

It is necessary, however, to show that the low number of species recorded along the São Sebastião channel is not normal for inner shelf regions. This number is comparable to estuarine environments where freshwater limits the distribution of organisms. The low number of species found in this region can be attributed to the condition resulting from the effects of sources of contamination in the Channel, such as sewage from municipal sewage, harbor, TEBAR, primary surface runoff, hydrocarbon spills and others. The opportunist group tolerant to this region comprises *Ammonia spp., B. elegantissima, B. marginata, B. striatula* and *F. pontoni,* and the second more oxygenated tolerant group includes *Quinqueloculina spp., Elphidium poeyanum, Hanzawaia spp., Discorbis williamsoni, Discorbis floridana, Discorbis spp., Pyrgo sp Cassidulina minuta, Cassidulina subglobosa Cassidulina spp.* and *Pararotalia cananeiaensis.* The species found in the first group are opportunistic, resistant to several types of pollution, and proliferate in places where the organic matter contents are high, indicating terrestrial contribution, characteristic of anaerobic environments, they were found in the central regions of the Channel. The second group are indicative species of well oxygenated environments, reflecting the action of intense currents in the region. The significant occurrence of *Pararotalia cananeiaensis* can also be attributed to the penetration of marine currents in the channel.[39–45]

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Conflicts of interest

The author declares that there are no conflict of interest.

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