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Assessment and diagnostics of the Pium river estuary and the coastal zone adjacent to the Pirangi beach reef area (RN)

Abstract

The work examined sediments from the adjacent area to the Pium estuary (Pirangi Beach), in the municipality Parnamirim - RN. The main objective of the study was to assess the degree of pollution of the regions, bases upon foraminiferal associations and their responses to abiotic factors (temperature, depth, salinity, and sediment characteristics including grain size, % calcium carbonate and % organic matter). Abiotic parameters were measured and 12 sediment samples were collected from the coastal zone, adjacent to Pirangi Beach. Areas closer to Pium estuary were more affected by anthropogenic. The dominant species in this area is Quinqueloculina lamarckiana.

Keywords: Foraminifera, environmrntal indicators, abiotic data, sedimentology

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Introduction

Foraminifera are widely used in oceanography and environmental monitoring because they occur in all aquatic environments and are easy to sample.[1-3] Their assemblages reflect characteristics of the environment in which they occur, reacting to seasonal variations and changes caused by anthropogenic action.[4]

Many authors have been studying foraminifera and their relationship with sediment dynamics, transport and hydrodynamics.[5-8] The distribution of species and their diversity can reflect different hydrodynamic patterns in coastal regions[9-13] and water bodies.[14] Araújo & Machado (2008) also reported that the distribution of assemblages is strongly related to grain size. Araújo & Machado[12] also reported that the distribution of assemblages is strongly related to grain size.

Our study characterizes and monitor the quality of sediments in the coastal zone of the Pium River Estuary and the internal platform adjacent to the Pirangi reef area, through the study of bottom sediments and foraminifera associations as bioindicators. We examined the interactions of the sedimentological characteristics with the foraminiferal assemblage using univariate and multivariate statistical analyses.

The responses of foraminifera to the physical water and sedimentological parameters of the study area for future environmental preservation projects.

Characterization of the study area

The study area was off Pirangi Beach, located on the East Coast of the Brazilian Continental Margin, in the municipality of Parnamirim - RN, 21 km away from the capital Natal[15] (Figure 1).

The East Potiguar Platform is narrow (between 15 and 35km), shallow (average depth of 13-25m) and relatively flat (with slopes ~ 0.2° to 0.5°) inshore of the shelf break.[16-20] Johnson & Boldwin's[21] classify this type of platform as mixed the hydrodynamic energy regimes, dominated by ocean currents.

Material and methods

Twelve surface sediment samples were collected on 24 of January of 2013, using a Van Veen type grab or by scientific diving (Figure 2).

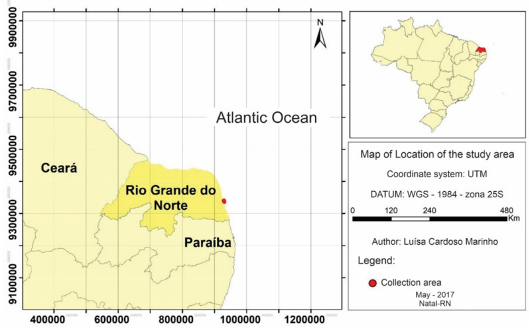

Figure 1 Map of Location of the study area.

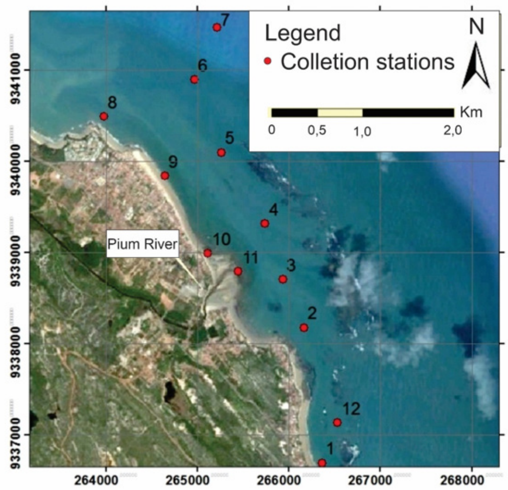

Figure 2 Location of the sampled stations.

These samples were sub-sampled, the first two centimeters of the sediment were transferred to flasks containing rose Bengal stain dissolved in 70% ethanol, and the rest was used for sedimentological analyses. Hydrographic parameters (salinity, temperature and oxygen content) as well as the depth of the collection points were acquired using the Castaway brand CTD (conductivity, temperature and depth) device. The hydrographic parameters were illustrated using contour maps created using ArcGIS 10.2.

Biological parameters

In the laboratory, the rose Bengal stained subsamples were transferred to successive sieves of 0.500 and 0.0062 mm, for the process of wet sieving, aiming to remove silt and clay. Then the material was dried in an oven at 50° C for 72 hours.

Next, the samples were floated in trichloroethylene, to separate the foraminiferal tests from the sediment. After that, the samples, again, dried in an oven, now at 70°C, until total dryness.

In the Laboratory of Marine Geology and Geophysics and Environmental Monitoring (GGEMMA), the all foraminiferal tests were sorted, a fine brush, moved to micropaleontological faunal slides, and tests were identified to species based on the bibliographic material of Boltovskoy et al.

Sedimentological parameters

Sedimentological processing was carried out in the Laboratory of Geological Oceanography - LABOGEO of the Federal University of Pernambuco - UFPE, by the Elemental Analysis - Isotope Ratio Mass Spectrometry (EA-IRMS, with the COSTECH ECS 4010 analyzer, coupled with the Delta V Advantage from Thermo Scientific).

After the sedimentological data were obtained, they were applied to the program Granulometric Analysis System (SAG), and the sedimentological classification was assigned based upon Folk and Larsonneur (1977)[22] for each sample.

Species – based indices

The foraminiferal assemblages from each sample were identified, as noted above, and number of individuals found of each species were recorded to provide data to calculate species-based indices and subsequently for statistical analyses. The indices calculated were the Shannon – Wiener diversity index,[23] Pielou's equitability index, both in base 10, and Simpson's dominance index,[23] using the PRIMER software of Plymouth University, described by Clarke & Warwick,[25] based on the absolute frequency table of foraminifera species of the study area.

Shannon's index measures the degree of uncertainty in which an individual belongs to a given species, out of a sample of S species with N individuals. This degree of uncertainty is calculated using the equation:

$$H' = -\sum_{s}^{i}(p_i \times \ln p_i)$$

Where: H' = diversity;

S = number of species;

pi = frequency of each species, for i ranging from 1 to S.

Meaning that diversity increases with increasing Shannon Index, that is, with increasing degree of uncertainty.

According to Clarke and Warwick,[25] equitability refers to the homogeneity of the distribution of individuals among different species. This index demonstrates the stability of the system.

Pielou's equitability index (J') ranges from 0 to 1, in which the minimum value is obtained when a single species dominates the community; and maximum when all species present are equally abundant.[26]

Simpson's index (D), on the other hand, means the probability that n random individuals in a community are of the same species, given by the equation for a finite population:[27]

$$D = \sum_{i=1}^{s}[\frac{n_i(n_i-1)}{N(N-1)}$$

Where: n_i is the number of individuals of species I and;

n is the total number of individuals.

Relating these three ecological indices, low equitability values are accompanied by low diversity and high dominance.

Multivariate analyses

The descriptive procedures of Cluster Analysis, Multi-Dimensional Scaling (MDS), Principal Component Analysis (PCA), and BEST were also carried out using in PRIMER sotfware.

Cluster analysis produces dendograms of station similarity, relating biotic and abiotic data, exposing the environmental parameter with the greatest influence on species dynamics.[28]

The MDS statistical technique has produces a map in which the stations are arranged, not taking into consideration the geographical location, but rather their biological and abiotic similarities.[28]

The Principal Component Analysis (PCA), allows graphic grouping based upon abiotic characteristics, through the sum of the principal components (PC), selecting those with higher percentages of variations, evaluating the abiotic values resulting in the distribution of similar stations into distinct groups.

And finally, the BEST analysis[29] combines the data sets in order to find the best match for the multivariate parameters of the foraminiferal associations.

Results

Hydrographic parameters

The hydrographic aspects of the water at each station (depth, surface and bottom temperature, salinity, surface and bottom oxygen concentrations) are provided in Table 1.

The station depths range from 2m (station 10) to 11m (station 7). The northernmost stations (stations 5 - 8) were slightly deeper, while the stations closest to the Pium River estuary were shallower (stations 4, 10 and 11), reflecting discharge of sediments from the estuary onto the shelf.

Surface temperature varied minimally, from 28,2°C to 29,3°C, with a standard deviation of only 0.36. The stations further from the Pium River estuary were warmest, (29.1 - 29.3°C), (Figure 3A). It bottom temperatures (Figure 3B) were similar to surface temperature.

Table 1 Abiotic data from Pirangi stations, highlighting the maximum, minimum, mean, and standard deviation values for each parameter collected

Stations	Depth (m)	Surface Temperature(°C)	Core Temperature(°C)	Surface Salinity (dimensionless)	Oxygen Surface(ppm)	Oxygen Bottom(ppm)
1	6	29,2	29,2	35	5,65	5,5
2	4,22	29,1	29,1	36	5,57	5,33
3	5,54	29,1	29,1	36	5,74	5,1
4	5	28,2	28,2	36	5,45	5,28
5	7	29	29	36	5,41	5,09
6	9,5	29,1	29,1	36	5,8	5,66
7	11	29,1	29,1	37	5,79	5,66
8	5,45	29,1	29,1	36	5,88	5,51
9	4,4	28,8	29,1	34	5,73	5,44
10	2	28,4	28,5	21	5,83	5,5
11	3	29,2	29	35	5,74	5,5
12	2,72	29,3	29,3	36	6,03	5,61
Maximum	**11,00**	**29,30**	**29,30**	**37,00**	**6,03**	**5,66**
Minimum	**2,00**	**28,20**	**28,20**	**21,00**	**5,41**	**5,09**
Average	**5,06**	**26,300**	**26,318**	**31,182**	**5,218**	**4,941**
Standard Deviation	**2,909**	**0,359**	**0,334**	**4,739**	**0,186**	**0,211**

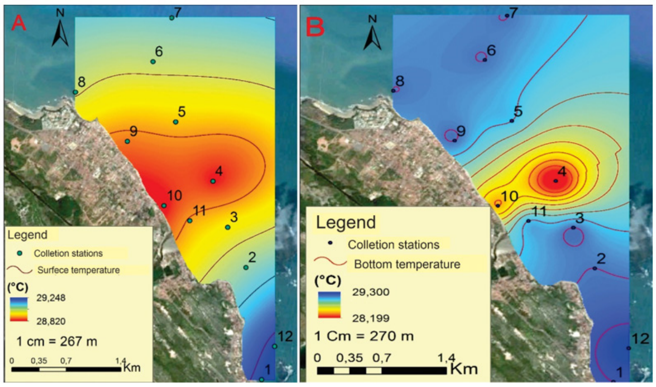

Figure 3 Contour Map referring to the Pirangi campaign: (A) Surface Temperature; (B) Bottom Temperature.

Surface salinities ranged between 34 and 37, except o a low of 2 at station 10, near the outflow of the estuary (Figure 4). Overall, salinities were lowest near the coastline and increased offshore.

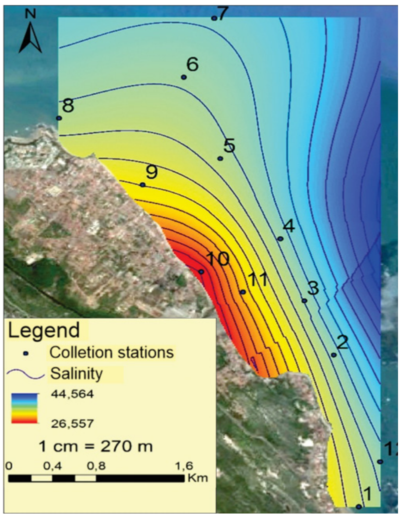

Figure 4 Salinity contour map for the Pirangi campaign.

Both surface and bottom oxygen concentrations show the opposite behavior to salinity, with the stations closer to the coastline having the higher levels (Figure 5). Similarly bottom and surface oxygenation, also trend opposite to temperatures.

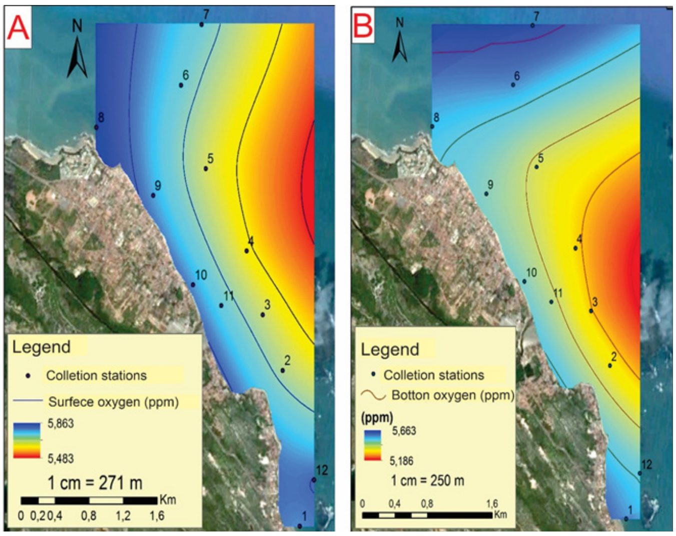

Figure 5 Contour maps for the Pirangi campaign, surface oxygen; (B) bottom oxygen.

Sediment textures

Sand dominated at all sites (minimum 63% at station 8), with medium sands to the south and offshore, fining northward and inshore (Table 2, Figure 6). Higher proportions of carbonate components (shells and fragments) were also found offshore (>40%). Inshore stations 8–10 were the finest and included the most silt. The northern offshore stations 6 and 7 were also predominantly fine sand, with some silt and the highest concentrations of organic matter (8–9%).

Station 1 had the highest gravel content, while no gravel was recorded in sediments from stations 7 – 11. A small amount of clay (1.5%) was recorded only at station 6.

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Table 2 Sedimentological data from Pirangi stations, highlighting the maximum, minimum, mean and standard deviation values for each parameter collected

Stations	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Organic Matter	CaCO content3 (%)	Larsounner(1977)	Average Rating
1	6,48	92,47	1,05	0,00	1,70	45,3	Lithobioclastic	Medium Sand
2	0,24	99,52	0,24	0,00	2,23	40,6	Lithobioclastic	Medium Sand
3	0,04	98,98	0,98	0,00	4,87	58,7	Biolithoclastic	Medium Sand
4	0,28	98,21	1,52	0,00	3,23	70,6	Bioclastic	Medium Sand
5	1,13	98,22	0,65	0,00	2,50	56,3	Biolithoclastic	Medium Sand
6	0,26	91,24	7,04	1,47	9,03	52,8	Biolithoclastic	Very fine sand
7	0,00	92,16	7,84	0,00	8,20	59	Biolithoclastic	Very fine sand
8	0,00	63,19	36,81	0,00	5,83	29,1	Lithoclastic	Very fine sand
9	0,00	83,67	16,33	0,00	4,77	37,3	Lithobioclastic	Very fine sand
10	0,00	84,00	16,00	0,00	1,63	11,7	Lithoclastic	Very fine sand
11	0,00	98,27	1,73	0,00	1,83	7	Lithoclastic	Very fine sand
12	0,07	94,43	5,50	0,00	2,30	11,7	Lithoclastic	Very fine sand
Maximum	**6,48**	**99,52**	**36,81**	**1,47**	**9,03**	**70,60**		
Minimum	**0,00**	**63,19**	**0,24**	**0,00**	**1,63**	**7,00**		
Average	**0,71**	**91,20**	**7,97**	**0,12**	**4,01**	**40,01**		
StandardDeviation	**1,778**	**27,174**	**10,498**	**0,408**	**2,692**	**23,093**		

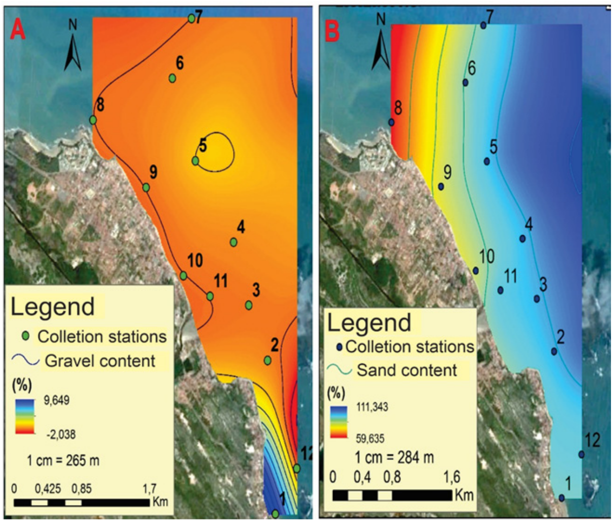

Figure 6 Contour maps of the sedimentological data of the Pirangi samples. A - Gravel; B - Sand.

The percentages of carbonate in the sediments varied widely, from medium bioclastic sand at station 4 (70.6% $CaCO_3$) to very fine lithoclastic sand with only 7% CaCO3 at station 11.

Lower percentages of $CaCO_3$ were found at most inshore stations. However, for the organic matter content, the lowest percentages were recorded at stations near the mouth of the estuary (10 and 11), as well as station 1 further south. In contrast, stations 6 and 7, further north and offshore, have the highest levels.

Biological Parameters

Overal, the 12 sediment samples analyzed produced 8579 foraminiferal tests distributed among 45 species (Table 3).

The most abundant species found were: Quinqueloculina lamarckiana (3653 individuals), Q. patagonica (2230), together making up more than two thirds of the specimens ad counted. Other species making up more than 2% of the assemblage overall were Discorbis valvulatus (586), Ammonia tepida (357), Pyrgo rigens (267), D. williamsoni (176), Miliolinella subrotunda (153), Elphidium articulatum (137 individuals).

Table 3 Absolute number of foraminifera found in Pirangi

Pirangi/2013	1	2	3	4	5	6	7	8	9	10	11	12	Total
Ammonia rolshauseni	0	0	52	0	0	0	3	0	0	0	0	0	55
Ammonia sp	0	0	26	0	0	0	0	0	0	0	0	0	26
Ammonia tepid	3	0	104	9	0	3	6	14	26	64	108	20	357
bn	0	0	0	0	0	0	0	0	0	8	0	0	8
Bolivina sp	0	0	26	0	0	0	0	0	0	0	0	0	26
Bolivina striatula	0	0	0	0	0	0	0	0	0	0	6	0	6
Discorbis sp	21	0	0	0	0	0	0	0	0	0	3	0	24
Discorbis valvulatus	0	0	312	36	0	57	3	0	0	36	6	136	586
Discorbis williamsoni	0	0	78	9	5	0	0	7	0	44	9	24	176
Elphidium articulatum	0	0	26	30	5	24	27	7	14	4	0	0	137
Elphidium discoidale	0	0	0	0	30	0	0	0	0	0	0	4	34
Elphidium galvestones	0	0	0	0	5	0	3	0	0	0	0	0	8
Elphidium sp	21	0	0	0	5	0	0	0	0	0	0	0	26

Table 3 Continued...

Fissurina sp	0	0	0	0	0	0	0	0	0	0	3	0	3
Young benthic foraminifera	6	0	0	0	75	9	0	0	0	0	0	0	90
Globulin ovulates	0	0	0	0	0	0	3	0	0	0	0	0	3
Marginulinopsis sp	0	0	0	0	0	0	0	0	0	0	0	16	16
Massilina secans	0	3	0	0	0	0	0	0	0	0	0	0	3
Massilina sp	0	0	0	0	0	0	3	0	0	0	0	0	3
Miliolinella suborbicularis	0	0	0	0	0	0	0	7	0	0	0	0	7
Milliolinella subrotunda	0	3	26	18	0	12	0	56	10	20	0	8	153
Ooline hexagon	0	0	0	0	0	0	0	0	2	0	0	0	2
Oolina melo	0	0	0	0	0	0	0	0	2	0	0	0	2
Poroeponides lateralis	15	0	52	6	0	6	0	0	0	0	0	0	79
Pseudononium atlanticum	0	0	0	0	5	3	0	0	4	4	9	12	37
Pyrgo nasuta	3	3	26	0	10	0	0	0	0	0	0	0	42
Pyrgo rigens	0	6	104	90	35	6	6	14	6	0	0	0	267
Quinqueloculina atlantica	0	6	52	21	10	3	0	0	0	0	0	0	92
Quinqueloculina gregaria	0	9	0	0	0	0	0	0	0	0	0	0	9
Quinqueloculina intricata	0	15	52	75	0	0	6	0	2	0	0	0	150
Quinqueloculina lamarckiana	42	360	1690	345	465	213	63	14	62	112	111	176	3653
Quinqueloculina milletti	0	0	104	0	0	0	0	0	0	0	0	0	104
Quinqueloculina patagonica	75	177	832	105	405	189	123	56	38	56	102	72	2230
Quinqueloculina seminulun	0	6	0	0	0	3	0	0	0	0	0	0	9
Quinqueloculina sp	0	0	0	3	0	0	0	7	0	0	0	0	10
Quinqueloculina sp cf Chipolensis	0	0	0	3	0	0	0	0	0	0	0	0	3
Recuvoides sp	0	0	0	6	0	0	0	0	0	0	0	0	6
Siphonira sp	0	0	0	0	0	0	0	0	0	0	0	12	12
Spiroculina planulata	48	3	0	0	5	24	0	0	0	0	0	0	80
Spiroculin sp	0	0	0	9	0	9	0	0	0	0	0	0	18
Tentalin/Enantiodentalin sp	0	6	0	3	0	0	0	0	0	0	0	0	9
Textularia agglutinans	3	0	0	0	0	0	0	0	0	0	0	0	3
Textularia gramen	15	0	0	0	0	0	0	0	0	0	0	0	15
Textularia sp	0	24	0	0	0	0	0	0	0	0	0	0	24
Triloculina baldai	0	51	0	0	0	0	0	0	0	0	0	0	51
Total	252	597	3562	768	1060	561	246	182	166	348	357	480	8579

Before getting into these species characterize three biofacies (Figures 7-10). Biofacies 1 (station 1) dominated by Q. patagonica and Spiroculina planulata; biofacies 2 (offshore stations 2 – 7 and 12) dominated by exceptionally abundant Q. lamarckiana and Q. patagonica; and biofacies 3 (stations 8 – 11) marked by lower abundances of Quinqueloculina and with higher proportions of Ammonia tepida and M. subrotunda (Figure 11).

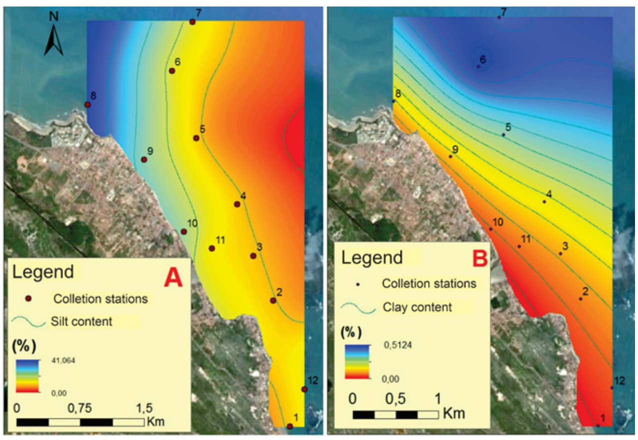

Figure 7 Contour maps of the sedimentological data of the Pirangi samples. A - Silt; B - Clay.

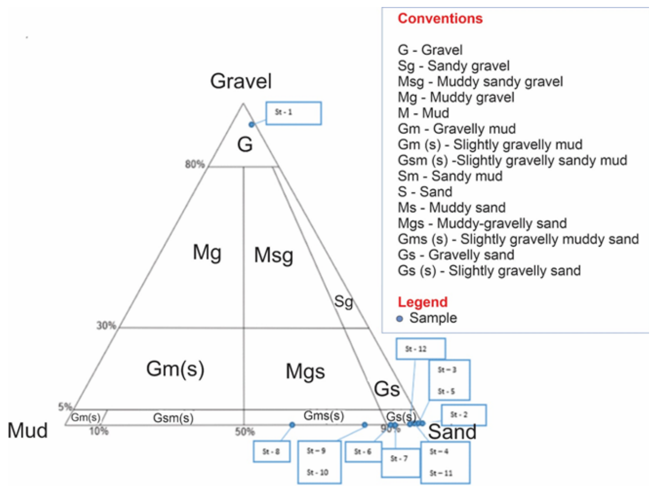

Figure 8 Ternary diagram for particle size analysis of the Pirangi (st) stations.

The genus Quinqueloculina is exceptionally diverse in coastal and shelf regions worldwide. Some species are opportunistic and tolerant of polluted and stressed environments and can be found in coastal lagoons, salt marshes, estuaries, and bays.[30] This genus was described as typical of hydrodynamic inner shelf environments.[31,32]

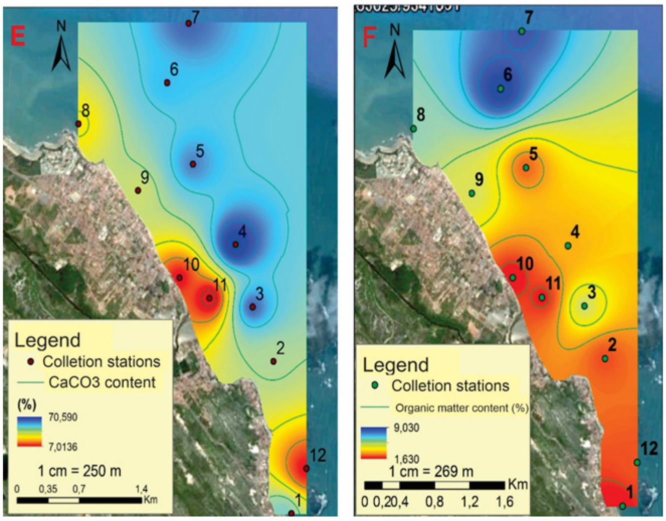

Figure 9 Contour maps of sedimentological data from Pirangi samples. A - CaCO3 content; B - Organic matter content.

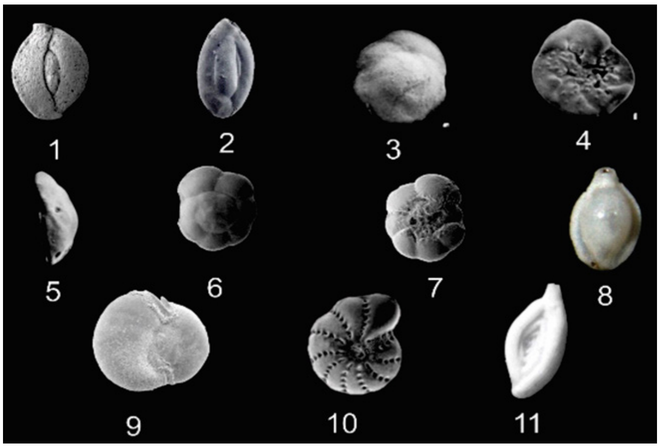

Figure 10 Plate with the main foraminifera species found at Pirangi beach. (1) Quinqueloculina lamarckiana, (2) Quinqueloculina patagonica, (3 - 5) Discorbis valvulatus, (6 - 7) Ammonia tepida, (8) Pyrgo rigens, (9) Miliolinella sub-rotunda, (10) Elphidium articulatum and (11) and Spiroculina planulata.

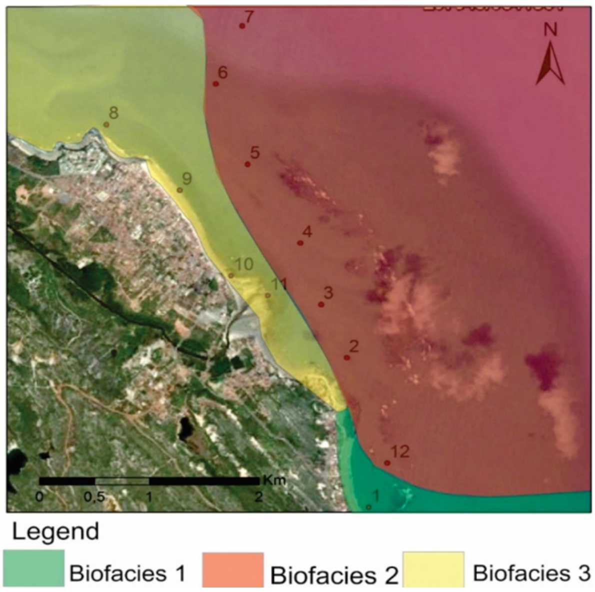

Figure 11 Map of the biofacies of Pirangi Beach.

More specifically Quinqueloculina patagonica is a species that prefers mixohaline environment,[33] such as estuaries, characterizing biofacies 1 as influenced by the Pium River estuary, with waters of lower salinity and temperatures and higher oxygen content.

Biofacies 2 can be characterized as an environment influenced by the estuary, with high hydrodynamics and tolerant to physical variables. Since Quinqueloculina lamarckiana, characterized by a resistant carapace and cosmopolitan character, tolerant to physical variables such as high hydrodynamics, for being exposed to wave action.[33]

The Eastern Platform presented as dominant species the Quinqueloculina lamarckiana, in which foreheads with occurrence of tafonomic processes such as wear and dark coloration were found. This may also be associated with erosion as it almost absolutely dominates the stations.

The species Ammonia tepida indicates the influence of coastal waters because it is able to withstand large variations in salinity, being typical of estuarine regions and coastal waters influenced by fluvial environments.[3,34] It is also characterized as an infaunal genus, typical of muddy sediments and high organic content,[3,35] thus characterizing biofacies 3.

Univariate analysis

Table 4 presents univariate analysis data, where we observe that the number of species (S) of foraminifera ranges from 10 species in sample 8 to 17 in samples 3 and 4, which can be related to the samples farthest from the shoreline, which presented the highest values of species numbers.

Table 4 Statistical data concerning biotic parameters, in which the number of species (S), the number of foraminifera individuals (N), the equitability (J'), the diversity (H') and the dominance (Lambda or D) areanalyzed

Stations	S	N	J'	H'(loge)	Lambda (D)
1	12	504	0,675827	1,679368	0,293651
2	15	1344	0,515969	1,397269	0,341119
3	17	7124	0,549305	1,556298	0,322873
4	17	1536	0,573532	1,624937	0,31234
5	14	2120	0,52213	1,377932	0,336408
6	15	1122	0,562456	1,52316	0,318239
7	12	492	0,576411	1,432328	0,33254
8	10	364	0,695909	1,602389	0,303254
9	11	332	0,652513	1,564658	0,307374
10	10	696	0,696235	1,60314	0,29852
11	10	714	0,62373	1,436191	0,317951
12	11	960	0,643109	1,542109	0,311042
Maximum	**17**	**7124**	**0,696235**	**1,679368**	**0,341119**
Minimum	**10**	**332**	**0,515969**	**1,377932**	**0,293651**
Average	**12,83333**	**1442,333**	**0,607261**	**1,528315**	**0,316276**
Standard Deviation	**2,65718**	**1867,448**	**0,065448**	**0,096788**	**0,014942**

As for the number of individuals (N), sample 9 presents the lowest number (332 individuals) and the highest number (7124 individuals) was found in sample 3. The lowest values were found near the continent, with the exception in both parameters for station 7, which even though it is the farthest from the coastline, presents similar behavior, and may relate this lower number of individuals with lower concentrations of nutrients and salinity.

Analyzing the equitability (J'), which refers to the distribution mode of the number of individuals among the different species, station 10 had the highest stability (69%) and the lowest stability in station 2 (52%).

The diversity index (H') was highest at station 1, with 504 individuals distributed among 12 species; and lowest at station 5, with 2120 individuals divided among 14 species.

Finally, analysing the dominance (D' or Lambda) of the samples, it is observed higher in sample 2, with 1344 individuals distributed among 15 species and sample 1 lower values, with 504 individuals divided among 12 species. Observed that, generally, the behavior of diversity is inverse to that of dominance.

It can be seen from Table 3 that the dominant species was Q. lamarckiana, followed by Q. patagonica.

Multivariate analysis

MDS

The MDS reveals the distinction of six groups, which are arranged (Figure 12), reflecting their similarities in biotic and abiotic parameters. They are:

I. Group I (sample 1), characterized by presenting the highest percentage of the gravel fraction, shows an oscillation in dominance between the species Q. patagonica and Q. lamarckiana and presents a higher diversity of species;

II. Group II (Sample 2) presents almost all of its granulometry in the sand fraction (99.52%, being the sample that obtained the highest value for the parameter), dominance of the species Q. lamarckiana and lower equitability and with higher dominance;

III. Group III (samples 3 and 4) characterized by being poorly sorted, with dominance of the species Q. lamarckiana and still being the stations with the highest number of species;

IV. Group IV (samples 5, 6 and 7) refers to stations with greater depths and with dominance of the species Q. lamarckiana and Q. patagonica;

V. Group V (samples 8, 9 and 10) has the highest amounts of sand, and also has high diversity rates and the lowest numbers of species;

VI. Group VI (samples 11 and 12) shows low Calcium Carbonate concentrations and dominance of the species Q. lamarckiana.

It was also possible to locate the groups spatially (Figure 13).

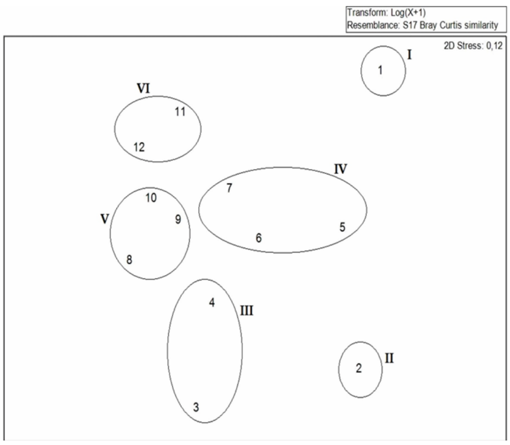

Figure 12 MDS analysis for the Pirangi campaign.

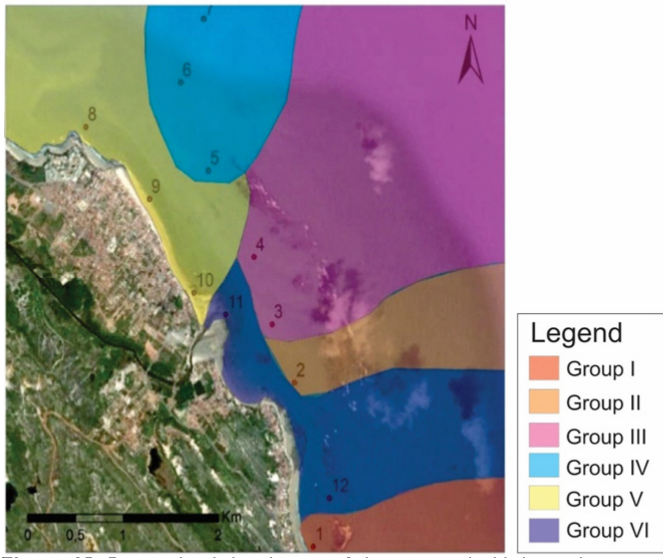

Figure 13 Geographical distribution of the stations highlighting the groups of the MDS analysis.

PCA

The Principal Component Analysis employed to the abiotic parameters reveals five groups, evidenced in Figure 14 and Table 5, which indicates that the abiotic parameters explain 55.4 of the foraminifera distributions and Table 6, the data obtained, inform that the PC1 and PC2 values are the most important for the study (configuring a total of 52.3%). Table 6 presents data that allow the construction of Figure 14, with the values of PC1 referring to the X axis and PC2 referring to the Y axis of the Cartesian plane. According to Table 6 it is observed that 4 groups were formed: group P1, with samples 6 and 7, in which depth (m), salinity, organic matter content (%), clay content (%), bottom temperature (ºC) and surface temperature (ºC) are similar.

Table 5 Product generated by Principal Component Analysis (PCA) for Pirangi Beach

Principal Components (PC)	Eigenvalue	Variation (%)	Variation (%)
1	3,44	28,6	28,6
2	3,21	23,7	55,4
3	2,17	18,0	73,4
4	1,15	9,6	83,0
5	1,00	8,3	91,3

Table 6 PC1 to PC5 values for the abiotic data applied in Principal Component Analysis (PCA).

Variable	PC1	PC2
Gravel (%)	0,102	0,104
Sand (%)	0,362	0,209
Silt (%)	-0,360	-0,231
Clay (%)	-0,199	0,262
Organic Matter (%)	-0,305	0,338
CaCO3 content (%)	0,222	0,409
Depth (m)	-0,114	0,475
Surface Temperature (°C)	-0,263	0,238
Bottom temperature (°C)	-0,299	0,219
Surface Salinity	-0,021	0,430
Surface Oxygen	-0,453	-0,160
Bottom Oxygen	-0,411	-0,032

Citation: Marinho LC, Eichler PPB, Gomes MP, et al. Assessment and diagnostics of the Pium river estuary and the coastal zone adjacent to the Pirangi beach reef area (RN). *J Aquac Mar Biol.* 2025;14(2):83‒92. DOI: 10.15406/jamb.2025.14.00419

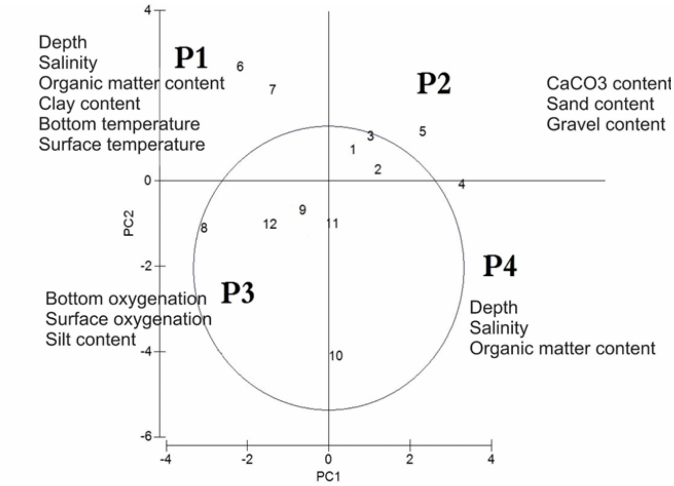

Figure 14 Product plot of the PCA analysis for Pirangi area showing the groupings of the stations for the PC1and PC2 values, with the arrangement of the abiotic parameters for each quadrant.

Group P2, shows similarity of Calcium Carbonate content (%), sand content (%), and gravel content (%), and is formed by samples 1, 2, 3, and 5.

Group P3, is characterized by the similarity of samples 8, 9 and 12 in bottom and surface oxygen content (%) and silt content (%). And the P4 group, composed of samples 4, 10 and 11, similar as to depth, salinity and organic matter content. It was also possible to locate the groups geographically (Figure 15).

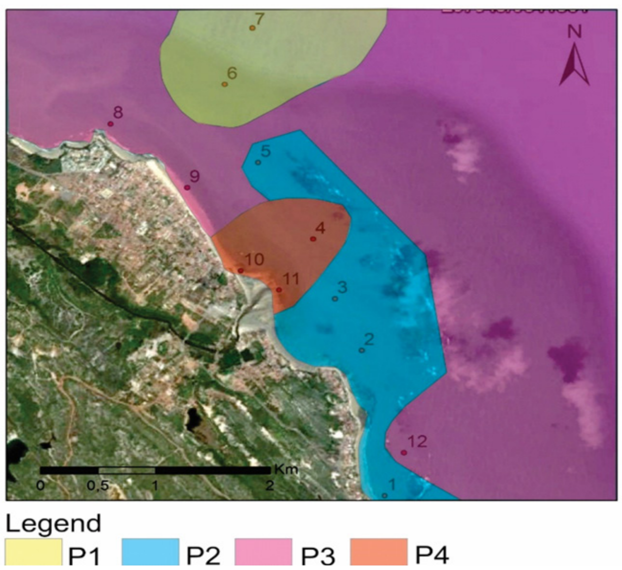

Figure 15 Geographical distribution of the stations highlighting the groups from the PCA analysis.

Cluster

The CLUSTER analysis based on the biological table between the stations (Mode Q) points to the dendogram (Figure 16) with differentiation into five groups, with emphasis on the biological similarities and relating them to the abiotic characteristics of the stations. The groups are:

I. Group I (sample 1), identical to group I from the MDS analysis. The dominant species of this group are Q. patagonica, Spiroloculina planulata, and Q. lamarckiana, which also showed the highest amounts of the gravel fraction;

II. Group II (Samples 10, 11 and 12), presents as dominant species the species Q. lamarckiana and Q. patagonica; related to this, these are stations characterized by having the lowest percentages of calcium carbonete and for being better selected;

III. Group III (samples 7, 8 and 9) with the species Q. patagonica and Q. lamarckiana as dominant, shows lower values of these species. In sample 7, Elphidum articulatum, is also dominant. Ammonia tepida is dominant in samples 8 and 9. And sample 8, also presents as dominant species the species Milliolinela subrotunda and Pyrgo rigens. This group is characterized by a great diversity and by presenting all the abiotic parameters very similar;

IV. Group IV (samples 3, 4 and 6): the dominant species in this group are Q. lamarckiana, Q. patagonica, and Discorbis valvulatus. It is also important to note that sample 3 is the only station where the species Q. miletti is dominant in the area. These stations are still poorly selected;

V. Group V (samples 2 and 5) is the most diverse group, with Q. patagonica and Q. lamarckiana as the dominant species and stations in which the sand fraction predominates.

VI. And so, as for the other multivariate analyses, it was also possible to locate the groups geographically (Figure 17).

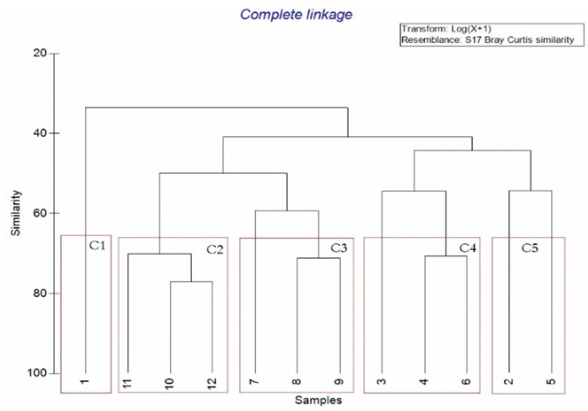

Figure 16 Dendogram of Pirangi stations according to the similarity of dominant foraminifera species.

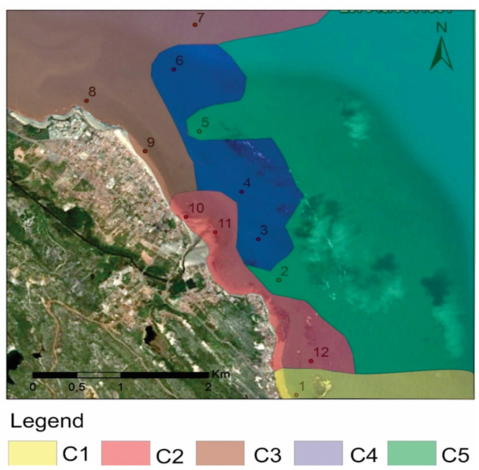

Figure 17 Geographical distribution of the stations showing the groups of the CLUSTER analysis.

Best

The variables that most influenced the abundance of foraminifera were the gravel content, followed by the sand content. The parameter which is least related to foraminifera abundance was bottom oxygen.

Discussion

From the physical-chemical parameters it was noted that the stations closest to the river estuary (mainly stations 10 and 11) presented different values from the other stations, which may be a product of the influence of continental waters and urban waste from the localities near the Pium River.

In addition, at stations 10 and 11 there are fewer species and low numbers of individuals, characterizing it as a region with low nutrient concentrations and salinity (with salinity measuring 21 at station 10).

In contrast, it was observed that the samples with the highest numbers of species were also the samples with the highest numbers of individuals (stations 2, 3, 4, 5, and 6), possibly signifying higher concentrations of nutrients and salinity, and also being the stations farthest from the shoreline.

Looking at the multivariate statistics, Sample 1, characterized by the highest percentage of the gravel fraction and the highest diversity of species, also shows dominance of Quinqueloculina patagonica, followed by Spiroculina planulata, the latter only influencing this station, characterizing the station as the most different from the others. This led us to consider it a biofacies different from the other stations.

Biofacies 1, with a higher gravel value and dominance of Quinqueloculina patagonica evidences the influence of the Pium River estuary and southward wind flows.

Biofacies 2 is characterized by a high concentration of sand fraction, low $CaCO_3$ and as an estuarine influenced, high hydrodynamic environment.

Finally, biofacies 3 composed of the stations classified by the average as very fine sand besides presenting high concentrations of $CaCO_3$, with the dominance of Ammonia tepida means estuary influence indicating a northward flow of the Pium River.

Environmental stress and foraminiferal indicators in the Pirangi beach reef

The Pirangi Beach Reef system reveals significant environmental heterogeneity influenced by the proximity to the Pium River estuary. Stations located closer to the estuarine input (especially 10 and 11) exhibit altered physicochemical parameters—most notably reduced salinity (as low as 21) and low nutrient availability—conditions that correspond with low foraminiferal diversity and abundance. These patterns point to the influence of continental waters and untreated urban waste, underscoring anthropogenic pressure on the reef ecosystem. In contrast, stations farther from the estuary (e.g., stations 2–6) show a higher richness and abundance of benthic foraminifera, correlating with increased salinity and nutrient levels, and suggesting relatively healthier environmental conditions. The multivariate analysis identified distinct biofacies based on species dominance and sediment composition, particularly Quinqueloculina patagonica and Ammonia tepida, which are known indicators of high-energy or stressed environments. The presence and dominance of opportunistic and stress-tolerant taxa like Ammonia tepida, combined with taphonomic evidence of test alteration, highlight the utility of foraminiferal assemblages as bioindicators. This suggests a clear potential for implementing the FoRAM Index (Foraminiferal Index) in future monitoring efforts. The index, especially when integrated with taphonomic assessments, can offer quantitative evaluations of water quality and reef health, particularly in systems subject to strong hydrodynamics and pollution gradients like Pirangi. These findings reinforce the value of benthic foraminifera in long-term biomonitoring programs, while also demonstrating how community shifts reflect ecological degradation linked to estuarine discharge. Such insights are crucial for guiding conservation strategies and for supporting the designation of environmentally sensitive areas.[36,37]

Concluding remarks

We thus conclude that both Quinqueloculina lamarckiana and the other three dominant species characterize this region of Pirangi Beach as a high hydrodynamic environment, stressful to the attachment of organisms. The present study can be used for monitoring activities and for future environmental preservation projects. It is also suggested that studies with the application of the Foram Index (IF) to provide a numerical classification for the area to evaluate the water quality in the environment are adequate to support myxotrophy as the dominant nutritional mode in the ecosystem associated or not with the analysis of the tafonomy of the species, since especially in the Pirangi region the shells have shown to be very altered.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

References

1. Sellier De Civrieux JM. Un Metodo De Observaciones Y Representaciones Graficas Del Metabolismo (Foraminifera) With Application to the Study of Ecology in Highly Variable Salinity Biotopes. *Boletin Del Instituto Oceanográfico, Universidad De Oriente*. 1968;7(2):99–109.

2. Suguio K, Vieira EM, Barcelos J H. Ecological Interpretation of the Foraminifera from the Santos Estuary Zone, State Of São Paulo, Brazil. *Proceedings Annals*. 1975.
3. Murray JW. Ecology And Palaeoecology of Benthic Foraminifera. *Longman Scientific Andtechinical. Harlow*. 1991;397.
4. Figueredo SMC, Machado AJ, Araújo TMF, et al. Bathymetric Zonation of Foraminiferal Assemblages of the Continental Shelf and Slope of Conde Municipality, Bahia. *Porto Alegre*. 2011;9(1):1–10.
5. Martin RE. Taphonomy and Temporal Resolution of Foraminiferal Assemblages. In: Sen Gupta, B.K. (Ed.) Modern Foraminifera. *Dordrecht, The Netherlands: Kluwer Academic Press*. 1999;281–298.
6. Yordanova EK, Hohenegger J. Taphonomy of Larger Foraminifera: Relationships Between Living and Empty Tests On Apartment Reef Slopes (Sesoko Island, Japan). *Facies*. 2002;46:169–204.
7. Lançone RB, Duleba W, Mahiques MM. Bottom Dynamics of Flamengo Inlet, Ubatuba, Brazil, Inferred from the Spatial Distribution, Morphometry and Tafonomy of Foraminifera. *Revista Brasileira De Paleontologia*. 2005;8(3):181–92.
8. Távora VA, Coelho JA. Foraminiferal Taphonomy of the Pirabas Formation (Lower Miocene), State of Pará. *Geosciences*. 2006;25(2):197–204.
9. Moraes SS. Interpretations of Hydrodynamics and Transport Types from The Study of Recent Foraminifera from the Coastal Reefs of Praia Do Forte and Itacimirim, *Northern Coast of Bahia State. Dissertation, Institute of Geosciences, Federal University of Bahia*. 2001.
10. Moraes SS, Machado AJ. Avaliação Das Condições Hidrodinâmicas De Dois Reifes Costeiros Do Litoral Norte Do Estado Da Bahia. *Revista Brasileira De Geociências*. 2003;33(2):201–210.
11. Bruno RLM, Araújo HAB, Machado AJ. Impact Of Hydrodynamic Energy on Foraminiferal Tests Present in the Surface Sediment of Recife De Fora, Porto Seguro, Bahia, Brazil. *Annals Xii Congresso Latino–Americano De Ciências Do Mar – Colacmar*. 2007.
12. Araújo HCB, Machado AJ. Benthic Foraminifera Associated with the South Hia Coral Reefs, Brazil. *Journal of Foraminiferal Research*. 2008;38(1):23–38.
13. Araújo HCB. *Foraminiferal Assemblages Indicative of Environmental Changes in the Abrolhos Reef Complex, Bahia.* Thesis, Institute of Geosciences, Federal University of Bahia. 2009.
14. Eichler PPB, Eichler BB, Miranda L B, et al. Modern Foraminiferal Facies In A Subtropical Estuarine Channel, Bertioga, São Paulo, Brazil. *Journal of Foraminiferal Research*. 2007;37:234–247.
15. Moura DS De. Foraminifera From Marine Sediments and Their Use in the Assessment of Dynamics and Environmental Quality in Reef Areas of Rio Grande Do Norte. *Master's Thesis. Graduate Program in Geodynamics and Geophysics (Ppgg) – Federal University of Rio Grande Do Norte – Ufrn, Brazil*. 2016;62.
16. Knoppers B, Ekau W, Figueiredo AG. The Coast and Shelf of East and Northeast Brazil and Material Transport. *Geo–Marine Letters*. 1999;19(3):171–178.
17. Manso VDAV, Correa ICS, Guerra NC. Morphology And Sedimentology of the Internal Continental Shelf Between Porto De Galinhas and Campos Beaches–Southern Coast of Pernambuco, Brazil. *Geosciences Research. Porto Alegre, Rs, Brazil*. 2003;30(2):17–25.
18. Araújo TD, Seoane JCS, Coutinho PDN, et al. Geomorphology of the Continental Shelf of Pernambuco. Oceanography: A Tropical Setting. *Recife, Edições Bagaço*. 2004;39–57.
19. Vital H, Furtado SFL, Gomes MP. Response of the Apodi – Mossoró Estuary–Incised Valley System (Ne Brazil) To Sea–Level Fluctuations. *Brazilian Journal of Oceanography*. 2010;58(Spe2):13–24.
20. Monteiro PG. Geophysical Methods Applied to the Location of Biodetrital Granulate Deposits and Paleochannels in the Coast of Paraíba, Brazil. *Master's Dissertation. Programa De Pós–Graduação Em Geociências – Universidade De Brasília – Unb, Brazil*. 2011;117.
21. Johnson HD, Baldwin CT. *Shallow Clastic Seas*. In: Reading HG, Editor. *Sedimentary Environments: Processes*. Facies and Stratigraphy. 1996;232–280.
22. Dias GTM. *Classification Of Marine Sediments, Proposal for Representation in Sedimentological Charts*. In: Congresso Brasileiro De Geologia, 39; Salvador. Anais... Salvador: Sbg. 1996;3:423–426.
23. Newman MC. Quantitative Methods in Aquatic Ecotoxicology. *Lewis Publisher*. 1995.
24. Zar JH. *Biostatistical Analysis*. 2 Ed. Englewood Cliffs. New Jersey. 1984;718.
25. Clarke KR, Warwick RM. Changes in Marine Communities: An Approach to Statistical Analyses and Interpretation. *Natural Environment Research Council, Plymouth*. 1994;144.
26. Magurran AE. *Diversidad Ecológica Y Su Medición.* Barcelona: Vedra. 1989;200.
27. Barros RSM. *Measures of Biological Diversity*. Graduate Program in Ecology Applied to the Management and Conservation of Natural Resources – Pgecol. Federal University Of Juiz De Fora – Ufjf. Juiz De Fora, Mg, Brazil. 2007.
28. Eichler PPB, Eichler BB, Sen Gupta, et al. Foraminifera As Indicators of Marine Pollutant Contamination on the Inner Continental Shelf of Southern Brazil. *Marine Pollution Bullentin*. 2012;64:22–30.
29. Clarke KR. Non Pararmetric Multivariate Analyses of Changes in Community Structure. *Aust J Ecol*. 1993;18:117–143.
30. Debenay JP. *A Guide To 1,000 Foraminifera from Southwestern Pacifc New Caledonia*. Ird Éditions, Publications Scientifiques Du Muséum, Paris. 2012;385.
31. Eichler BB, Eichler PPB, Miranda LB, et al. Using Foraminifera as Indicators of Marine Influence in Guanabara Bay, Rj, Brazil. *Porto Alegre*. 2001;251–262.
32. Wang P, Chappell J. Foraminifera as Holocene Enviromental in the South Alligatir River, Northen Australia. *Quaternary Interncational*. 2001;83(85):47–62.
33. Cordeiro CL. Foraminifera as a Study Tool in the Environmental Geology of the Potengi River Estuary of the Internal Platform, Rn, Brazil. 2015.
34. Moraes SS. Spatial Distribution And Tafonomy Of Foraminifera In The Continental Shelf of The Northern Region of The Dendê Coast (Foz Do Rio Jequiriça To Ponta Dos Castelhanos) – Bahia. *Phd Thesis. Institute of Geosciences of the Federal University of Bahia*. 2006;102.
35. Gooday AJ. The Biology of Deep–Sea Foraminifera: A Review of Some Advances and Their Applications in Paleoceanography. *Palaios*. 1994;9:14–31.
36. Testa V, Bosence DWJ. Physical And Biological Controls on the Formation of Carbonate and Siliciclastic Bedforms on the Northeast Brazilian: Shelf. *Sedimentology*. 1999;46:279–301.
37. Vital H. *The North and Northeast Brazilian Tropical Shelves*. In: Chiocci FL, Chivas AR, Editors. Continental Shelves of the World: Their Evolution During the Last Glacio–Eustatic Cycle. Geological Society, London, Memoirs. 2014;41:35–46.