Benthic Foraminifera and Thecamoebians of Godineau River Estuary, Gulf of Paria, Trinidad Island
Foraminíferos e Tecamebas Bentônicos do Estuário do Rio Godineau, Golfo de Paria, Ilha de Trinidad

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Abstract

In the Godineau River Estuary, located in Trinidad Island (off the northeast coast of Venezuela), were found 114 taxa of foraminifera and 17 of thecamoebians in the dead fauna. Most of the identified foraminiferal species were rare because they were transported from the Gulf of Paria to this estuary. The autochthonous foraminiferal assemblage was represented by several tropical estuarine species such as Ammonia tepida, Ammotium salsum, Arenoparrella mexicana, Cribroelphidium excavatum, Ammonia parkinsoniana, Haplophragmoides wilberti, Miliammina fisca and Ammotium cassis. The thecamoebians assemblages, found in the inner part of this estuary, were dominated by Cyclopyxis spp., Centropyxis spp., Diffugia corona and Diffugia urceolata. The relative abundance of the main species of foraminifera and thecamoebians were analyzed through Q-mode and R-mode cluster analyses. Statistical results revealed the presence of three different environments in the Godineau River Estuary related to different hydrodynamic conditions and more or less oceanic or fluvial influence. The first sector represents the most confined region of the estuary and was mainly composed by agglutinated foraminifera together with thecamoebians. The second sector was located in the middle part of the estuary and was associated with the presence of brackish waters. The third sector denotes the outermost part of the estuary characterized by the greatest hydrodynamic activity and highest oceanic influence within the estuary. This sector was marked by the occurrence of a large number typical-marine foraminifera species.

Keywords: Estuarine compartments; Foraminifera; thecamoebians; microtidal estuary; tropical coastal environment

Resumo

No estuário do Godineau localizado na ilha de Trinidad (ao noroeste da costa de Venezuela) foram identificados 114 táxons de foraminíferos e 17 de tecamebas da fauna morta. Muitas das espécies de foraminíferos identificadas são raras e pequenas indicando transporte do Golfo de Paria para dentro do estuário. Os foraminíferos autóctones foram representados por espécies típicas de estuários tropicais como Ammonia tepida, Ammotium salsum, Arenoparrella mexicana, Cribroelphidium excavatum, Ammonia parkinsoniana, Haplophragmoides wilberti, Miliammina fisca e Ammotium cassis. As tecamebas eram abundantes na região mais interna do estuário. As espécies dominantes foram Cyclopyxis spp., Centropyxis spp., Diffugia corona e Diffugia urceolata. A abundância relativa das principais espécies foi analisada através da análise de agrupamento em modo Q e R. As análises estatísticas revelaram a existência de três ambientes distintos no estuário que são relacionados a diferentes condições hidrodinâmicas de maior ou menor influência marinha ou fluvial. O primeiro setor representou a região mais confinada do estuário composta por foraminíferos aglutinantes junto com tecamebas O segundo setor foi localizado na região intermediária do estuário e era tipicamente um ambiente salobro (mixohalino). O terceiro setor, situado na parte mais externa do estuário, estava associado a maior atividade hidrodinâmica e maior influência oceânica, claramente marcada pela ocorrência de espécies de foraminíferos típicas de ambiente marinho.

Palavras-chaves: Compartimentos estuarinos; foraminíferos; tecamebas; estuário de micromaré; ambiente costeiro tropical
1 Introduction

Tropical regions are geographically comprehended between the tropics of Cancer (23°27'N) and Capricorn (23°27'S). These parts of the globe receive solar radiation at a steep angle what climatically results in mild winters. According to Latrubesse et al. (2005), solar energy influences the hydrological cycles more directly in the tropics than in other areas of the planet. The rain regime is the factor that determines the seasons and consequently, the amount and distribution of rain is an important criterion to distinguish subclimatic zones such as humid (> 1800 mm/year), humid-dry (700-1800 mm/year) and dry (<700 mm/year).

The large tropical rivers in different parts of the world have attracted the attention of researchers and a great variety of subjects has been studied including geomorphology, sedimentology, hydrology, flooding and paleoflooding events and associated tectonic processes. The understanding and analogy of current fluvial models are essential to understand the sedimentary sequences of these regions which are in general poor or incomplete, showing the need for more detailed studies of these environments (Miall, 1996). The processes that took place in tropical environments may be very different from those operating in polar and temperate regions (Nittouer et al., 1995) requiring much more detailed studies.

Several aspects including morphology, circulation and biota can be used to characterize an estuary (Kennish, 1992). Benthic foraminifera have been widely employed as a tool for reconstructing marine environments from the Cambrian to the Recent. They are present in all marine and transitional environments, from hypersaline lagoons along the coast to deep sea (Murray, 2006).

The composition of a benthic foraminiferal assemblage is directly influenced by a wide variability of water physicochemical parameters (i.e., salinity, dissolved oxygen), substrates characteristics as well as sedimentary organic matter quantity and quality (Leipnitz et al., 2014). Similarly thecamoebians are related to the water physicochemical properties and hydrodynamics of river water (Laut et al., 2010, 2011a). The use of foraminiferal and thecamoebian assemblages has been considered useful in ecological, paleoecological, hydrodynamics and environmental monitoring analyses. These organisms are highly sensitive to changes of physicochemical parameters which may be directly reflected on population composition (Scott & Medioli, 1980).

Each estuary presents particular characteristics resulting from local tide, wave and wind conditions and geomorphology. All these characteristics as well as the adjacent shelf morphology and dynamics influence the composition of foraminiferal and thecamoebian assemblages and their distribution in this type of transitional environment. In this way, each estuary may possess typical assemblages of these protozoans. These studies make possible to: find similarities and differences between several worldwide estuaries and; give contributions to establish models useful in paleoecological reconstructions and monitoring studies.

Trinidad Island (Republic of Trinidad and Tobago) has a long history of foraminiferal investigations particularly from the fossil records (Wall & Sawkins, 1860). The Cenozoic foraminifera species in Trinidad Island were initially studied by Guppy (1863, 1873). In the southern region of the island, 144 taxa were described in a stratigraphic Oligo-Miocene sequence (Cushman & Jarvis, 1929).

In Trinidad Island the taxonomic investigations of recent microfauna were started by Cushman & Brönnimann (1948a, 1948b). These authors studied small estuaries located between the Caroni River at north and Oropouche River in the southern region and reported an unusual brackish water foraminiferal fauna composed by three genera: Ammobaculites, Trochammina and Cribroelphidium.

The first ecology investigation preformed in the region of Gulf of Paria was carried out in 1952 by the Dutch Orinoco Shelf Expedition (Andel & Postma, 1954). This work reported: results of the taxonomy and distribution of foraminifera and ostracoda species; their relationship to the physical properties of the environment and; the absence of benthic foraminifera in the nearshore and tidal zones along the western coast of Trinidad Island.

Todd & Brönnimann (1957) described the recent foraminifera and thecamoebians assemblages in mangrove swamps and tidal mudflats, river mouth and deltas along the western coast of Trinidad Island, and also in the deeper part of the eastern Gulf of Paria. In this study about 200 taxa of benthic
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Foraminifera and 9 thecamoebians were recognized, including ten new species and 39 considered then indeterminate taxa.

A comparison of Miocene and Pliocene foraminifera with recent fauna from brackish water environments of west and east coast of Trinidad Island was proposed by Saunders (1958). In this study, was not possible to define an accurate analogy between the fossil and recent depositional environment, because *Miliammina telemaquensis* was the only specie well represented in the Miocene brackish waters (Cruse Formation) and was not found in recent fauna.

This paper aims to study the distribution of recent foraminifera and thecamoebians on the sediment of the Godineau River estuary in Trinidad Island. It also provides a taxonomic review of tropical species and applies statistical tools to identify estuarine gradients.

1.1 Regional Setting

The Godineau River Estuary is located in the SW coast of Trinidad Island (Republic of Trinidad and Tobago; 0°14’ N latitude and 61°31’ W longitude) and is associated with the Paria Gulf, a semi-enclosed sea located between the Trinidad Island and the east coast of Venezuela (Figure 1). This transitional system was recently referred as the Godineau Swamp by James et al. (1986) considering the occurrence of a coastal lagoon behind a sandbar with mangroves and a tidal mudflat, and environments varying from freshwater to brackish marshes at the landward side with rice paddies.

This choked lagoonal system is aligned perpendicularly to the coastline, extends approximately over an area of 56 km² and has salt water influence mostly up to its middle parts (Barnes, 1980). Moving inland from the lagoon west coast, there are pronounced changes in the ecosystem; evolving from marine and brackish environments to freshwater toward the mainland (Ramnath et al., 1997).

The saltwater penetrates further inland during the dry season (January - May) when the freshwater runoff is reduced. The lagoon barrier is interrupted by two channels, which connect the lagoon to the sea, to the Godineau River and to Mosquito Creek. The tidal regime is microtidal with a spring tide range of 97 cm, neap tide range of 44 cm and a mean semidiurnal range of 77 cm. The average temperature is 27°C, and salinity ranges between 0.10 and 34.3 (Norville & Banjoo, 2006).

The major types of vegetation in the lagoon are mangrove forest, tidal marsh, swamp forest, and grasses (*Eleocharis mutata* and *Cyperus articulatus*). Presently, there is no more rice cultivation due to the intrusion of saltwater and changes in government policies (Juman & Ransewak, 2013). Some abandoned fields are used for grazing of cattle, goats and sheep, and are referred to as wet pastures. There are, however, small areas of vegetable farming, mainly for the production of the short-term traditional crops (Juman & Ransewak, 2013).

The lagoon is extensively used as an area of nursery and feeding for many species of commercially important fishes, and it supports an extensive bank (Oropouche Bank) offshore, which is the focus of a thriving fishing industry (Chan A Shing, 2002).

At present, the governance and management of the lagoon is poorly regulated. There are polices and legislations governing the use and aiming to protect the lagoon, but it is suffering with poaching, pollution and cutting of the mangrove. Part of the lagoon such as the mangrove swamp area is managed and protected by the Forestry Act that prohibits hunting and fishing in closed seasons, and cutting of the mangrove. The Environmental Management Authority has presently the empowerment to govern this lagoon, avoiding for example pollution inputs, but there is no monitoring of this system.

2 Material and Methods

Sediment samples (50 ml) were collected with a van Veen Grab in 24 stations in the Godineau River Estuary, Trinidad Island (Republic of Trinidad and Tobago), in 1984, for foraminiferal and thecamoebians analyses (Figure 1). The sediment was stored in plastic containers filled with alcohol 70% stained with Bengal Rose (2g L⁻¹), in order to avoid the tests degradation by bacterial activity and for the identification of living organisms during sampling event. The physicochemical parameters were not measured in this fieldwork because the sampling...
was collected only to recognize the foraminifera and thecamoebians species in the region.

The samples for the protozoans’ analyses were processed following the methodology described in Boltovskoy (1965). The sediment (50 ml) was washed through sieves of 500 µm and 62 µm. The fractions greater than 500 µm and smaller than 62 µm were discarded. After drying, the sedimentary particles with low density, including foraminifera and thecamoebians of each sample were separated by flotation on trichloroethylene (C₂HCl₃). The specimens counting were carried out under stereoscopic microscope. The living and dead individuals were separately counted to provide information both on living and dead microfauna.
However only the dead assemblages were analyzed in this study due to: (1) the low abundance of living benthic foraminifera; (2) the seasonal variability is smoothed when dead assemblages are used and; (3) the dead assemblages can give a much clearer relationship not only of the physicochemical parameters but also of the hydrodynamical influence in the study area.

Classification of benthic foraminifera was based for the: suprageneric taxa on World Foraminifera Database (Hayward et al., 2017); genus level on Loeblich & Tappan (1987) and; species level on several authors (e.g. Cushman & Bronniman, 1948a, 1948b; Todd & Bronnimann, 1957; Boltovskoy et al., 1980). The species synonymy was revised considering the World Foraminifera Database (Hayward et al., 2017).

The thecamoebian classification was based on Kumar & Dalby (1998) and Scott et al. (2001). Considering the small number of specimens of thecamoebians (testate rhizopods), which prevents a separated statistical analysis and considering the importance of this group of protozoans, they were analyzed together with foraminifera.

The species with tests in good state of preservation were picked out from the samples and were mounted on stubs using a carbon conductive adhesive tape. The stubs were then coated with two layers of palladium and gold and examined with the Scanning Electronic Microscope ZEISS DMS 960 (Plates 1-6).

Only the samples with the number of foraminifera and thecamoebians more than 100 specimens were considered for the statistical analyses. Assemblages’ indexes such as the relative abundance of species, species richness (S), Shannon Index ($H'$), equitability ($J'$) were used in data interpretation. All these indexes were calculated with the MVSP 3.1 Software.

Cluster analysis in Q-mode (Euclidean distance and Ward linkage method) and R-mode (r-Pearson’s linear correlation coefficient and Ward linkage method) cluster analyses (CA) were used to define assemblages of foraminifera and thecamoebians in the estuary. PCord 5.0 Software was used to perform these analyses. Only were used in these analyses the species that occurred in more than one station or with a relative abundance of more than 4% in one sample.

3 Results

One hundred and sixteen species of foraminifera and seventeen of thecamoebians were identified in the Godineau River Estuary, Gulf of Paria, Trinidad Island (Appendices 1 and 2). SEM photos of the most common species are illustrated in the Plates 1-6. The stations with the lowest foraminifera density (<100/50 ml of sediment) are OR06 (28 tests/50 ml), OR09 (43 tests/50 ml), OR10 (50 tests/50 ml), OR13 (20 tests/50 ml), OR15 (22 tests/50 ml), OR16 (19 tests/50 ml), OR19 (4 tests/50 ml), OR23 (35 tests/50 ml) and OR24 (21 tests/50 ml). At the other stations, the tests density ranged from 1,332 tests/50ml, in the inner portion of Compère Channel (OR18), and 106 tests/50 ml in the middle portion of Godineau River (OR20) (Appendix 2).

The station OR03 presented the lowest S (4 species) and OR18 the highest one with 80 species (Appendix 2). The largest number of foraminifera species (82 species) was found in station OR18. In this station most of the species were rare in the study area (restricted to only one site) and displayed low relative abundance, including for instance Fissurina spp., Lagena spp., Nodosaria spp., Oolina spp., Uvigerina spp. (Appendix 2).

Ammonia tepida reached the highest relative abundance (38.8 – 83.7%) in the outer estuary area (stations OR01, OR02, OR03, OR04, OR05, OR07, OR08, OR12 and OR14). The percentage of this species decreased considerably (0.4 – 9.3%) in the innermost region of the estuary (stations OR11, OR14, OR17, OR18, OR20 and OR21).

Otherwise in the inner estuary region (stations OR14, OR18, OR20 and OR21), Ammotium salsum was the most dominant species (30.2 – 74.8 %). Arenoparrella mexicana was the second most abundant species (15.1 – 25%) in this part of the estuary and was particularly abundant in stations OR14, OR17 and OR20 (Appendix 2).

The most frequent species was A. tepida (87% of stations) followed by A. salsum (67% of stations), Cribroelphidium excavatum (62%...
of stations) and *Ammonia parkinsoniana* (62% of stations). *Haplophragmoides wilberti* (58% of stations), *Milliammina fusca* (54% of stations) and *Ammotium cassis* (50% of stations) were the most represented accessory species. The only agglutinated foraminifera with rare occurrences in the estuary were the species (Appendix 2): *Acupeina trirerforata* (in station OR18), *Paratrochammina closii* (in station OR18), *Saccammina sphaericus* (in station OR17) and *Tritaxis squamata* (in station OR21).

Some extinct foraminifera species from Miocene (*Siphonodosaria consobrina*, *Siphonodosaria bradyi* and *Stilostomella antillea*) were identified in station OR18 with low relative abundance (<1%; Appendix 2). The only extinct species identified in several stations was *Siphonodosaria jacksonensis* (in stations: OR01 – 0,4%; OR02 – 0,6%; OR04 – 0,4%; OR14 – 0,9%; OR17 – 1%; OR18 – 14,1%).

The thecamoebians were absent in ten stations. The station OR22 presented the highest $S$ value (9 species). *Cyclopyxis* spp., *Centropyxis* spp. and *Difflugia corona* were the most constant thecamoebian species in the estuary occurring with low relative abundance (<5%) in 25%, 20% and 16% of the stations respectively (Appendix 2). The species *Difflugia urceolata* (reaching 9% in station OR21) and *Difflugia viscidula* (reaching 7% in station OR09) had the highest relative abundance in the estuary.

The average $H'$ in the estuary was 1.56, the highest value was found at the station OR18 (3.2) and the lowest one was found in the stations OR04 (0.86), OR03 (0.91) and OR21 (0.95). The average $J'$ was 0.57. The highest $J'$ value was 0.91 in the station OR18 and the lowest value was 0.29 in station OR07 (Appendix 2).

Cluster analysis in R-mode using the similarity of 50%, showed the existence of four subclusters representing four distinct assemblages in the Godinneau River Estuary (Figure 2). These assemblages are composed by the following species: A – *Ammoastuta inepta*, *Siphotrochammina lobata*, *Trochammina inflata*, *A. mexicana*, *Centropyxis* spp., *Ammotium cassis*, *Haplophragmoides manilaensis*, *D. corona*, *Difflugia globulus*, *M. fusca*, *Ammoastuta salsa* and *Ammobaculites dilatatus*; B – *H. wilberti*, *Trochammina* spp., *Difflugia oblonga*, *Trochamminita salsa*, *Textularia earlandi*, *Jadammina macrescens*, *Ammobaculites exiguos*, *Cyclopyxis* spp., *Lagenodiffugia vas*, *A. tepida*, *D. viscida*, *A. salsum* and *D. urceolata*; C – *Caribeana polystoma*, *Cornuspira incerta*, *A. tepida*, *C. excavatum*, *Elphidium gunteri*, *Caronia exilis*, *Cucurbitella tricuspis*, *Entzia polystoma*, *Ammonia parkinsoniana*; D – *Siphonodosaria jacksonensis*, *Cibicides refugels*, *Uvigerina peregrina*, *Haynesina depressula*, *Globocassidulina subglobosa*, *Neoponides antillarum*, *Bolivina translucens*, *Quinqueloculina polystoma*, *Quinqueloculina seminula* and *Rosalina bradyi*.

The Q-mode cluster analysis identified four groups of stations in the estuary considering 85% of similarity (Figure 2): Group I composed by the stations OR17, OR18, and OR20; Group II including the stations OR11, OR21 and OR22; Group III encompassing the stations OR04, OR05, OR07, OR08, OR12 and OR14 and; Group IV comprising the stations of the river mouth (OR01, OR02 and OR03).

On the basis of the combination of Q-mode and R-mode cluster analyses, it is possible to verify that the stations of: Group I are mainly represented by taxa of Assemblage B and at some extent by those of Assemblage A; Group II are mostly composed by taxa of Assemblage B and include some species of Assemblages A and C; Group III are dominantly represented by taxa of Assemblage C with some species of Assemblages A and B and; Group IV are mainly composed by taxa of Assemblage C with some species of Assemblages A and D (Figure 2).

### 4 Discussion

The coastal zone of the western coast of Trinidad Island is characterized by some microtidal estuaries with a tidal range of less than 50 cm (Todd & Brönnimann, 1957). In this coastal zone there are favorable conditions for the formation of mangroves swamps and mud flats and to the occurrence of environments evolving from very low salinity to marine and hypersaline conditions. In such conditions only euryhaline foraminifera species are able to survive (Todd & Brönnimann, 1957).

In microtidal estuaries associated with mangrove forests, the physicochemical parameters
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Figure 2 Q and R-mode cluster analyses based on relative abundance of benthic foraminiferal and thecamoebians species in the Godineau River Estuary.
are more stable than in meso-macro tidal and because of this, the number of foraminifera species can be more than forty (Laut et al., 2007).

On the contrary, the microtidal estuaries associated with mangroves in South America have a low number of species due to the rainfall intensity in the tropical and intertropical zone (Laut et al., 2007). Santa-Cruz & Dias-Brito (2006) identified 24 species in Bertioga Channels in São Paulo coast (23°58’S – 46°17’W) and Laut et al. (2007) identified 28 foraminiferal species in Itacorubi estuary (27°34’S - 48°32’W), in Brazil. At the mouth of Paraíba do Sul River estuary (21°28’S – 41°02’W), in Rio de Janeiro State (southeast Brazil), a large hydrographic basin, Laut et al. (2011a) found only 15 foraminiferal species.

A review of foraminifera species from the estuarine areas and tidal channels in Guaratiba (23°02’S – 43°33’W), Rio de Janeiro State (sotheast Brazil) performed by Laut et al. (2012) revealed an occurrence of 58 foraminiferal species. These authors noticed that this region is the one with the greatest foraminiferal richness in mangrove species of Rio de Janeiro State. Later on, Leipnitz et al. (2014) recognized over one hundred benthic foraminiferal species in the Tramandai Basin (Rio Grande do Sul, south Brazil).

This study documents the occurrence of 114 species of protozoans (including foraminifera and thecamoebians) in a typical microtidal estuary of Godineau River. About 65% of these species were typical of marine environments and were never been identified in the estuaries of Trinidad Island.

Todd & Brönnimann (1957) studied the estuaries of Guacara and St. Jean located at northern of the Godineau River estuary, in Tarouba Bay. In both estuaries, the number of species (living + dead specimens) was very low. In the estuary of Guacara River the authors identified 11 foraminiferal species and 1 thecamoebian species; and in St. Jean Estuary, 16 species of foraminifera and 2 thecamoebians species. In the tidal Swamp of Caroni River, Wilson et al. (2008) identified 17 species of foraminifera with a mean of 198 tests/75 cm$^3$ per sample (transect C1A).

Probably, the inflow through the bottom of oceanic water from Paria Gulf in the Godineau River mouth is the cause of the marine species increment in this region. Species such as Globocassidulina subglobosa, Cornuspira incerta, Dentalina sp., Rosalina williamsoni, Ellipsoidella spp., Neoeponides antillarum, Reussoolina laevis, Nonionella opima, Nonionella atlantica, Pullenia quinqueloba, Quinqueloculina laevigata, Quinqueloculina polygona, Quinqueloculina lamarkiana and Quinqueloculina seminula were found at the Godineau River mouth (stations OR01 and OR02).

Only 76% of the samples collected in the Godineau Estuary encompassed more than 100 protozoan tests. In most of the stations located in the lower and middle part of the channels only a few tests were found. Such a distribution might be related to the impact of the hydrodynamism caused by the presence of the port jetties, as observed by Wilson et al. (2008) in Caroni Swamp, at north of Trinidad Island. In undisturbed mangrove, the waves and tides energy is largely dissipated (Hong Phuoc & Massel, 2006). However the asymmetrical ebb and flood tidal currents may cause erosion and transport off organic detritus, such as fallen leaves (Wlanski et al., 1980).

The building of structures in tidal regions, even small jetties, into mangrove can interfere with the local dissipation of tidal current energy and prompt erosion and transport of material (Wilson et al., 2008). Although the jetties, being an open framework of beam overlain to a floor, allow the unimpeded passage of water and sediment, they affect considerably the local geomorphology. This dissipation of tidal current energy can have created a depositional site at station OR18, located in the inner portion of the estuary, in which 80 species and a density of 1,332 tests/50 ml were found.

The common dark grey and black mud accumulation between the roots of mangrove plants presumably under reducing conditions seems to offer excellent living conditions for certain agglutinated foraminifera species (Order Textulariida) such as Ammoastutusspp., Ammobaculites ssp., Arenoparrella mexicana, Entzia polystoma, Haplophragmoides spp. and Jadamina macrescens (Suter 1954; Todd & Brönniman 1957).

Several tropical estuarine systems from the western Atlantic coast have similar composition
of foraminifera and thecamoebians assemblages to those found in Godineau River Estuary (Todd & Brönnimann, 1957; Brönnimann & Zaninetti, 1965; Madeira-Falcetta, 1974; Zaninetti et al., 1979; Brönnimann et al., 1981a, 1981b, 1981c; Bonetti & Eichler, 1997; Barbosa & Suguio, 1999; Debenay et al., 2002; Duleba & Debenay, 2003; Debenay & Guillou, 2002; Laut et al., 2010, 2011a, 2012).

Among the dominant species of foraminifera in the Godineau River Estuary, *A. tepida* is considered one of the most resistant ones to environmental stress (Boltovskoy, 1965) and pollutants (Laut et al., 2007). It frequently occurs in shallow water environments such as lagoons, deltas and estuaries (Coccioni, 2000). *Ammonia tepida* proliferation is favored by the reduced competition in hypoxic and hypersaline environments since it is an euryhaline species (Murray, 1991).

*Cribroelphidium excavatum* has been also reported in mangrove swamps in Florida (Phleger, 1956), Puerto Rico (Culver, 1990), New Zealand (Hayward & Hollis, 1994), French Guiana (Debenay et al., 2002) and Brazil (Brönniman et al., 1981a, 1981b, 1981c; Debenay et al., 1996; Laut et al., 2012). This benthic foraminifera species is commonly restricted to outer mangrove swamps, to recently regenerated or aged forests of mangrove, where mangrove trees are small and/or sparse, but where marine influence is noticeable (Debenay et al., 1996).

The *Ammotium* spp. co-dominate frequently with *A. tepida* and *A. parkinsoniana* in estuarine regions with low salinity and sandy sediments (Laut et al., 2011b). In many Brazilian estuaries, the *Ammotium* genus is associated with thecamoebians in areas with strong influence of freshwater and with substrates of muddy sediment (Laut et al., 2011a, 2011b; 2012).

*Haplophragmoides wilberti* is a dominant species in most of the Western Atlantic estuaries in different biotopes (Todd & Brönnimann, 1957; Brönnimann et al., 1981a; Debenay et al., 1996; Laut et al., 2010; 2011a, 2011b, 2012). Hayward et al. (1996) related the occurrence of *H. wilberti* to extreme high-tide level in assemblages including mostly trochaminids species and *Miliammina fusca*, in different types of sediment. Laut & Barbosa (1999) associated this species to subaerial regions in Jaboatão Estuary (Pernambuco, northeastern Brazil). In the Amazon region (Laut el al., 2010) and in Delta of Paraíba do Sul (Laut et al., 2011a), this species occurred in areas with high levels of water turbidity.

*Arenoparrella mexicana* is dominant in anthropic impacted regions of Brazilian coast, such as tidal channels (Brönnimann et al., 1981), estuaries (Laut et al., 2010; 2011b; 2012), and mangroves swamps (Zaninetti et al., 1979). Laut et al. (2007) suggested that *A. mexicana* displays a symbiotic relationship with sulphate reducing bacteria in Itacorubi River Estuary, at south of Brazil. However, Laut et al. (2016) observed the abundance of this species declines with the increase of bacterial carbon and total organic matter content in other Brazilian estuaries. In the study area, *A. mexicana* is one of the most frequent species but it has low relative abundance along the stations.

Species such as *Adelosina laevigata*, *Cornsipira incerta*, *Miliolinella subrotunda*, *Quinqueloculina lamarckiana*, *Quinqueloculina polygona*, *Quinqueloculina seminula* and *Spirosigmoilina asperula* (belonging to *Miliolida* Order) are stenohaline and have low resistance to low concentrations of oxygen (Boltovskoy, 1965; Todd & Brönnimann, 1957). They are therefore normally restricted to the outer region of the estuaries (Brönnimann et al., 1981a). In the Godineau River Estuary, these species were found in the station OR01, located at the mouth, where there is greater marine influence and in the station OR18, situated in a protected area of the inner region, as the result of transport and deposition of sedimentary material (including protozoans tests) by tidal currents.

Some species were described as geographically close to the Gulf of Paria (Todd & Brönnimann, 1957). The species *Neoeponides antillarum* (as *Eponides antillarum*) occurred only in the eastern part of Gulf of Paria (Andel & Postma, 1954; Todd & Brönnimann, 1957). This species is ecologically associated with marine conditions and relatively stable salinity and continental shelf environments (Andel & Postma, 1954; Todd & Brönnimann, 1957). However, it was found in stations OR01 and OR05 next to the mouth of the estuary. This fact indicated a great transport from Gulf of Paria to the Godineau River Estuary.
Saline water in estuaries is not the preferred habitat of thecamoebians. Their occurrence in marine environments suggests that these tests have been remobilized and transported seaward from the freshwater areas (Saunders, 1958). As expected, in the Godineau River Estuary the number of thecamoebian specimens is much reduced compared with the foraminifera abundance. In lotic environments, like estuaries, the density of thecamoebians is low (Leipnitz et al., 2006) and according to Scott & Medioli (1983) and Patterson et al. (1985) the density and species richness of thecamoebians is usually higher in lentic environments.

However, the number of thecamoebians species in the Godineau River Estuary is higher than in other estuaries of Trinidad Island. In Guaracara River (Trinidad Island) Todd & Brönnimann (1957) identified only two species of thecamoebians, Difflugia urceolata and Centropyxis sp. The inner part of the Guaracara River Estuary was characterized by the dominance of D. urceolata. The fresh water zone of the St. Jean Estuary was demarcated by the dominance of D. urceolata too (Todd & Brönnimann, 1957). Thus, the relatively high richness and abundance of thecamoebians identified in the Godineau Estuary possibly reflects the transport of tests of the adjacent river areas to the channel mouth.

The species of thecamoebians identified in the Godineau River Estuary are comparable to other large Brazilian estuarine systems such as from Araguari River in Amazon (Laut et al., 2010), San Francisco River in the northeastern coast (Semensatto Jr. & Dias-Brito, 2006), Paraíba do Sul River (Laut et al., 2011a) and Suruí River (Laut et al., 2011b) in the southeastern coast.

In the Araguari River Estuary, the genus Centropyxis was dominant in all stations (Laut et al., 2010). Here it was associated with low organic matter content and relatively high salinities (Laut et al., 2010; Patterson et al., 2013).

The genus Difflugia was the most frequent thecamoebian in the Godineau Estuary. However, its relative abundance increases mostly in the inner estuary area. In other estuaries, this genus is commonly found associated with high organic matter content. In most of the estuaries, D. oblonga was described as a common bioindicator of the upper estuarine zone (Kliza & Schröder-Adams, 1999; Laut et al., 2010).

The abundance of C. tricuspis is a proxy for diatoms productivity and is an excellent indicator of a healthy trophic status of an ecosystem (Patterson et al., 2013). In the Godineau River Estuary, the abundance of C. tricuspis increased close to the mouth, in the stations OR09, OR11 and OR12.

Centropyxis constricta and D. corona have been reported as tolerating low pH and metal contamination (Patterson & Kumar, 2000; Boudreau et al., 2005; Patterson et al., 2013). The sediments collected in 1984 in the Godineau River Estuary were not analyzed for metals concentration. But the results of this work suggest that these species tolerate acidic conditions of the sediment in the estuarine inner sector.

The $H'$ values in the Godineau River Estuary were much higher than those identified in other estuaries associated with mangroves (Laut et al., 2007, 2010, 2011a, 2011b; Souza et al., 2010). According to Semensatto Jr & Dias-Brito (2004, 2006) values of $H'$ ranging from 0.4 to 0.8 are typical of tropical estuarine regions.

Laut et al. (2011b) only found in the Suruí Estuary agglutinated foraminifera and thecamoebians, but the assemblages (living + dead) diversity and equitability were relatively high in the middle estuarine zone than in the Godineau River Estuary: $H'$ (2.5) and $J'$ (0.7). The authors related these values to low hydrodynamic conditions in this estuarine sector. In the Godineau River Estuary, the highest $H'$ values were found at the stations next to the mouth and in the inner sector of the Compère Channel. The highest values of $H'$ and $J'$ found in this region should be related to the transport and deposition of marine species, and fossil reworked tests due to the tidal currents activity. The marine influence in the middle region of the estuary is traced by the presence of a few exotic species relatively high values of $H'$ (~1.0) and low values of $J'$ (~0.4).

On the basis of the Q-mode cluster analysis, it was possible to distinguish three distinct sectors in the estuary, each one representing different hydrodynamic conditions. The first sector (stations of groups I and II) represents the most confined region in the estuary whose taxa are those of the assemblages A and B and it includes species typical of paralic environments (Debenay et al., 2002; Debenay & Guillou, 2002; Wilson et al., 2008; Laut et al., 2005).
et al., 2011b, 2012). The largest freshwater input is evident in the main channel (stations of Group II), due to its highest richness of thecamoebians species (Assemblage B).

The second sector is located at the middle part of the estuary (stations of Group III) that would be related to environments characterized by a reduced freshwater input. This sector integrates predominantly the Assemblage C which is composed typically by estuarine species (Laut et al., 2007, 2014, 2016a, 2016b; Souza et al., 2010, Clemente et al., 2014). The third sector (stations of Group IV) represents the outer part of the estuary with the strongest marine influence as pointed out by the Assemblage D. This assemblage is characterized by foraminiferal taxa characteristic of marine settings and the absence of thecamoebians (Todd & Brönnimann, 1957) transported from the Gulf of Paria to the estuary mouth by tidal currents.

5 Conclusions

The biodiversity of foraminifera and thecamoebians found in the estuary of the Godineau River, a microtidal environment, seems to be higher than that in mangroves of the Eastern Atlantic coast. The inflow of marine water from the Paria Gulf through the bottom of the Godineau Estuary mouth causes the increase in number of marine species in the estuarine main channel. In this region, typical marine species represent about 65% of the protozoan assemblages.

Statistical analyses based on the most abundant and frequent species of foraminifera and thecamoebians allowed the identification of three estuarine sectors characterized by different conditions. The first sector comprising the most confined estuarine region where an assemblage typical of paralic environment can be found characterized by the predominance of agglutinated foraminifera and thecamoebian species. Relatively high abundance of thecamoebians species were also found in the main channel of the estuary, corresponding to material transported and deposited from the innermost estuarine regions. The second sector, located at the northern part of the estuary, is affected by lesser impact of freshwater. This sector is composed predominantly by typical estuarine foraminiferal species. The third sector includes the region with largest marine influence in the estuary. In the area, an important contribution of shelf species transported from the Gulf of Paria and deposited into the estuary mouth was observed.

This work evidences that studies based on foraminifera and thecamoebians assemblages using multivariate analyses can provide important information for defining zonation and environmental diagnoses of coastal areas.

6 Acknowledgments

The authors would like to thank to: the Geologist Joel Moura for providing the samples collected in Trinidad Island; CNPq (Universal 445830/2014-0) for the financial support and Scientific Initiation fellowship to Débora S. Raposo and Renan Habib; Dr. João Graciano de Mendonça Filho and Dr. Frederico Sobrinho da Silva from the “Laboratório de Palinofácies & Fácies Orgânicas” of Universidade Federal do Rio de Janeiro (UFRJ) for providing the Scanning Electronic Microscope photos used in this work.

7 References


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Plate V Legend: A – Oolina globosa, B – Paratrochammina classi, C – Polysaccammina ipohalina, 
D – Pullenia bulloides, E – Pullenia quinqueloba, F – Pyramidulina catesbyi, G – Quinqueloculina lamarckiana, 
H – Quinqueloculina polygona, I – Quinqueloculina seminula, J – Reophax nana, K – Reussoolina apiculate, L – Reussoolina laevis, 
M – Rosalina bradyi, N – Rosalina williamsoni, O – Saccammina sphaerica, P – Siphogenerina costata, Q – Siphogenerina raphana, 
Appendix 1 – List of benthic foraminiferal and thecamoebians of species recognized in the Godineau estuary.

**CLASSIFICATION**

**Order Arcellinida**
- *Arcella discoides* Ehrenberg, 1847

**Order Diffugina**
- *Diffugia globula* Dujardin, 1837
- *Diffugia oblonga* Ehrenberg 1832
- *Diffugia urceolata* Carter, 1864
- *Diffugia viscidula* Perrad, 1902
- *Lagenodiffugia vasa* (Leidy, 1874)
- *Pontiguldia compressa* (Carter, 1864)

**Family Trigonopyxidae**
- *Trigonopyxis arcula* Penard, 1910

**Family Trinematidae**
- *Trinema lineare* Penard 1890

**Order Astrorhizida**

**Family Polysaccaminidae**
- *Polysaccammina ipohalina* Scott, 1976

**Family Rhabdamminidae**
- *Bahianotubus salvadorensis* Brönnimann et al. 1979

**Family Saccaminidae**
- *Saccammina sphaerica* Brady, 1871
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*
- *Spirosgmoilina asperula* (Karrer, 1868)

**Order Lagenida**

**Family Nodosariidae**
- *Laevidentalina communis* (d'Orbigny, 1826)
- *Siphonodosaria consobrina* (d'Orbigny, 1846)
- *Siphonodosaria fascia* (Brady, 1870)

**Family Nodosariinae**
- *Miliolinella subrotunda* (Montagu, 1803)
- *Quinqueloculina lamarckiana* d'Orbigny, 1839
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*

**Family Stilostomellidae**
- *Siphonodosaria consobrina* (d'Orbigny, 1846)

**Family Epistominidae**
- *Laevidentalina communis* (d'Orbigny, 1826)
- *Miliolinella subrotunda* (Montagu, 1803)
- *Quinqueloculina lamarckiana* d'Orbigny, 1839
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*

**Family Miliamminidae**
- *Miliammina fusca* Brady, 1870

**Family Nodosariidae**
- *Laevidentalina communis* (d'Orbigny, 1826)
- *Miliolinella subrotunda* (Montagu, 1803)
- *Quinqueloculina lamarckiana* d'Orbigny, 1839
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*

**Family Miliamminidae**
- *Miliammina fusca* Brady, 1870

**Family Stilostomellidae**
- *Siphonodosaria consobrina* (d'Orbigny, 1846)

**Family Nodosariidae**
- *Miliolinella subrotunda* (Montagu, 1803)
- *Quinqueloculina lamarckiana* d'Orbigny, 1839
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*

**Family Miliamminidae**
- *Miliammina fusca* Brady, 1870

**Family Robertinida**

**Family Haplophragmoididae**
- *Haplophragmoides manilaensis* Andersen, 1952
- *Haplophragmoides wilberti* Andersen, 1953
- *Trochamminita irregularis* Cushman and Brönnimann, 1948
- *Trochamminita salsa* (Cushman and Brönnimann, 1948)

**Family Trochamminidae**
- *Arenoparella mexicana* (Kornfeld, 1931)
- *Entzia polystoma* (Bartenstein and Brand, 1938)
- *Entzia macrescens* (Brady, 1870)
- *Lepidodeuterammina ochracea* (Williamson, 1858)
- *Paratrochammina glossi* Brönnimann, 1979
- *Paratrochammina spp.*
- *Siphrotrochammina lobata* Saunders, 1957
- *Tiphrotricha comprimita* (Cushman and Brönnimann, 1948)
- *Tritaxis squamata* (Jones and Parker, 1860)
- *Trochammina inflata* (Montagu, 1808)
- *Trochammina spp.*

**Family Hormosinidae**
- *Acostata mariae* (Acosta, 1940)
- *Warrenita palustris* (Warren, 1957)

**Family Reophacidae**
- *Reophax nana* Rhumbler, 1913

**Order Miliolida**

**Family Cornuspiridae**
- *Cornuspira incerta* (d'Orbigny, 1839)

**Family Cribrulinoididae**
- *Adelosina laevigata* (d'Orbigny, 1826)

**Family Hauerinidae**

**Family Rhabdamminidae**
- *Bahianotubus salvadorensis* Brönnimann et al. 1979

**Family Saccamminidae**
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*

**Family Nodosariidae**
- *Miliolinella subrotunda* (Montagu, 1803)
- *Quinqueloculina lamarckiana* d'Orbigny, 1839
- *Quinqueloculina polygona* d'Orbigny, 1839
- *Quinqueloculina seminula* (Linnaeus, 1758)
- *Quinqueloculina spp*

**Family Miliamminidae**
- *Miliammina fusca* Brady, 1870

**Family Robertinida**
Benthic Foraminifera and Thecamoebians of Godineau River Estuary, Gulf of Paria, Trinidad Island

Lazaro Laut; Iara Clemente; Maria Virginia Alves Martins; Fabrizio Frontalini; Débora Raposo; Pierre Belart; Renan Habib; Rafael Fortes & Maria Lucia Lorini

Dentalina sp. A
Dentalina sp. B

Family Ellipsolagenidae
Fissurina agassizi Todd and Bronnimann, 1957
Fissurina flintiana Cushman, 1923
Fissurina semimarginata Boomgaard, 1949
Fissurina sequenziana (Fornasini, 1887)

Family Glandulinidae
Glandulina ovoida d'Orbigny, 1846

Family Lagenidae
Lagena perlucida (Montagu, 1803)
Lagena semilineata Wright, 1886
Lagena striata (d'Orbigny, 1839)
Reussoolina apicalata (Reuss, 1851)
Reussoolina laevis (Montagu, 1803)

Family Stilostomellidae
Siphonodosaria bradyi (Cushman, 1927)

Family Nodosariidae
Lagenomodosaria candei d'Orbigny, 1839
Pyramidulina catesbyi (d'Orbigny, 1839)
Nodosaria spp.
Nodosaria glans d'Orbigny, 1826
Oolina globosa (Montagu, 1803)

Family Vaginulinidae
Lenticulina occidentalis (Cushman, 1923)

Family Stilostomellidae
Stilostomella antillea (Cushman, 1923)
Siphonodosaria jacksonensis (Cushman and Applin, 1926)

Order Lituolida
Family Acupeinidae
Acupeina tripertorata (Millett, 1899)

Family Lituolidae
Ammoastuta inepta (Cushman and McCulloch, 1939)
Ammoastuta salsa Cushmanand Brönnimann, 1948
Ammobaculites dilatatus Cushmanand Brönnimann, 1948
Ammobaculites exigus Cushmanand Brönnimann, 1948
Ammotium cassis (Parker, 1870)
Ammotium salnum (Cushman and Brönnimann, 1948)

Family Discorbinellidae
Discorbinella sp. A

Order Rotaliida
Family Acervulinidae
Acervulina inhaerens Schulze, 1854

Family Amphisteginidae
Amphisteginula sp. A

Family Anomaliniidae
Anomaliniella glabrata (Cushman, 1924)

Family Bolivilinidae
Bolivina barbata Phlegerand Parker, 1951
Bolivina inflata Heron-Allen and Earland, 1913
Bolivina sp. A
Bolivina sp. B
Bolivina spathulata (Williamson, 1858)
Bolivina striatula Cushman, 1922
Bolivina subaenariensis Cushman, 1922
Bolivinellina translucens (Phleger and Parker, 1951)
Fursenkiolina pontoni (Cushman, 1932)

Family Buliminidae
Bulimina marginata d'Orbigny, 1826
Bulimina pseudosaffinis Kleinpell, 1938
Bulimina striata d'Orbigny, in Guérin-Méneville, 1843
Buliminella subfastiformis Cushman, 1925
Buliminella elegantissima (d'Orbigny, 1839)

Family Cassidulinidae
Globocassidulina subglobosa (Brady, 1881)

Family Cibicididae
Cibicides dispar (d'Orbigny, 1839)
Cibicides fletcheri Gallowayand Wissler, 1927
Cibicides refugens de Montfort, 1808

Family Discorbinidae
Discorbinella bertheloti (d'Orbigny, 1839)
Neopontonis antillarum (d'Orbigny, 1839)

Family Uvigerinidae
Uvigerina auberiana d'Orbigny, 1839
Uvigerina flintii Cushman, 1923
Uvigerina peregrina Cushman, 1923

Order Spirillinida
Family Ammodiscidae
Ammodiscus sp. A
### Family Ellipsoidinidae
*Ellipsoidinidae* spp.

*Ellipsoidina ellipsoides* Seguenza, 1859

### Family Elphidiidae

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<td><strong>Family</strong> Elphidiidae</td>
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</tbody>
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*Cribroelphidium excavatum* (Terquem, 1875)

*Elphidium discoidale* (d'Orbigny, 1839)

*Elphidium gunteri* Cole, 1931

### Family Heleninidae

*Helenina anderseni* (Warren, 1957)

### Family Nonionidae

*Haynesina depressula* (Walker and Jacob, 1798)

*Nonion* spp.

*Nonionella atlantica* Cushman, 1936

*Nonionella aurist* (d'Orbigny, 1839)

*Nonionella opima* Cushman, 1947

*Pullenia bulloides* (d'Orbigny, 1846)

*Pullenia quinqueloba* (Reuss, 1851)

*Pullenia nipposa* A

### Family Planorbulinidae

*Caribecancilla polystoma* Bermúdez, 1952

### Family Rosalinidae

*Rosalina bradyi* (Cushman, 1915)

*Rosalina williamsoni* (Chapman and Parr, 1932)

### Family Rotaliidae

*Ammonia parkinsoniana* (d'Orbigny, 1839)

*Ammonia rolshauseni* (Cushman and Bermúdez, 1946)

*Ammonia tepida* (Cushman, 1926)

### Family Siphogenerinoididae

*Siphogenerina costata* Schlumberger, 1883

*Siphogenerina raphana* (Parker and Jones, 1865)

### Family Reophacellidae

*Caronia exilis* (Cushman and Brönnimann, 1948)
Appendix 02 – Ecological indexes (density, relative abundance, richness, evenness) of Godineau Estuary.

<table>
<thead>
<tr>
<th>OR01</th>
<th>OR02</th>
<th>OR03</th>
<th>OR04</th>
<th>OR05</th>
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<th>OR08</th>
<th>OR11</th>
<th>OR12</th>
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<tbody>
<tr>
<td>Density (tests in 50 ml)</td>
<td>479</td>
<td>488</td>
<td>165</td>
<td>285</td>
<td>193</td>
<td>172</td>
<td>586</td>
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<td>119</td>
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<tr>
<td>Richness</td>
<td>36</td>
<td>30</td>
<td>4</td>
<td>19</td>
<td>21</td>
<td>9</td>
<td>22</td>
<td>21</td>
<td>24</td>
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<td>22</td>
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<tr>
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<td>0.86</td>
<td>1.24</td>
<td>0.73</td>
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<td>1.29</td>
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<td>0.95</td>
<td>1.27</td>
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<tr>
<td>Evenness (J')</td>
<td>0.71</td>
<td>0.80</td>
<td>0.55</td>
<td>0.30</td>
<td>0.44</td>
<td>0.29</td>
<td>0.52</td>
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<td>0.62</td>
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<td>0.91</td>
<td>0.75</td>
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<td>Acostata mariae</td>
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<td>0.1</td>
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<td>Acutepina tripleforata</td>
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<td>Ammobaculites dilatatus</td>
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### Benthic Foraminifera and Thecamoebians of Godineau River Estuary, Gulf of Paria, Trinidad Island

Lazaro Laut; Iara Clemente; Maria Virginia Alves Martins; Fabrizio Frontalini; Débora Raposo; Pierre Belart; Renan Habib; Rafael Fortes & Maria Lucia Lorini

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**Benthic Foraminifera and Thecamoebians of Godineau River Estuary, Gulf of Paria, Trinidad Island**

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