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Foraminifera and Thecamoebians as Indicator of Hydrodynamic Process in a Choked Coastal Lagoon, Laguna Estuarine System, SC, Brazil

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ABSTRACT

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The aim is to describe the indicator species that provides proxy information on hydrodynamic energy and circulation patterns in the Laguna estuarine system (SC). The area is a choked coastal lagoon connected to the ocean via a single narrow channel. Sediment samples for foraminifera and thecamoebians analysis were collected in 25 stations in summer time as well as hydrographical data on fixed station. Sampling started in the entrance, close to the ocean and extended inward to the inner parts of the system. In the fixed station, surface and bottom temperature varies between 24 e 26ºC; surface salinity varied between 0 and 30, while in the bottom values are between 30 a 35. In relation to the fauna distribution, the entrance of the lagoon presents higher number of species, followed by the central part. Toward inner parts diversity values reaches its minimum. MDS analysis revealed that group I presents lower density of foraminifera and thecamoebians from all over the region. Group II presents *Ammobaculites exigus*, *Gaudryina exillis* and *Ammotium salsum* as indicators of low freshwater input. The group III located in the entrance of the lagoon presents the highest diversity of species and *Buccella peruviana*, *Bolivina striatula*, *Cassidulina subglobosa*, *Pseudononion atlanticum*, *Saccamina sphaera*, *Quinqueloculina miletti*, *Q. patagonica*, *Ammonia tepida* and *Elphidium poeyanum* as indicators of marine water intrusion. Group IV located in Mirim lagoon, Tubarão and D'Una rivers present *Miliamina fusca* and thecamoebians species as indicators of the strongest freshwater input.

ADDITIONAL INDEX WORDS: *Freshwater input, marine water, indicator species.*

INTRODUCTION

Foraminifera and thecamoebians have been used as reliable bioindicators of environmental conditions (YANKO *et. al*, 1999). They have been used in oceanography and environmental monitoring because they occur in all aquatic environments, are easy to sample, and to handle (SELLIER DE CIVRIEUX, 1968; SUGUIO *et al*., 1975; MURRAY, 1987). They are able to synthetisize principal environmental characteristics enhancing environmental changes and to sensibly react to seasonal variations and anthropic effects.

The Laguna estuarine system is ecologically very rich and productive and presents economic importance on fisheries and marine culture and touristy attractive but remains incompletely studied.

The use of foraminifera and thecamoebians correlated to physical parameters as indicators is very useful information to be monitor and plan the lagoon exploration used. The aims of this study are to present ecological and physical data related to Laguna estuarine system, Laguna, SC, Brazil (Figure 1) and to describe the principal species that provides proxy information on hydrodynamic energy and circulation patterns in the region.

STUDY AREA

It is located 130 km south of Florianópolis, between Imbituba and Laguna city and includes Santo Antônio, Imaruí e Mirim lagoons making up 40 km of extension (Figure 1). In according to KJERFVE (1994) and MIRANDA *et al* (2002) the studied area is classified as a choked coastal lagoon with elliptical cells connected to the ocean via a single long and narrow channel, which serves as a hydraulic filter in reducing tidal effects inside the lagoon. Shallow depths and limited tidal water exchange characterize it, with the coastal ocean presenting high-energy wave energy, active littoral drift. The area is subjected to micro tidal and the wind plays an important role. Moreover choked lagoons are particularly susceptible to eutrophication, pollution, and sediment infilling and restrict water exchange due to long water residence times.

METHODS

As a component of a comprehensive ecological study sediment samples for foraminiferal and thecamoebians analysis were collected in 25 stations (Figure 1) in summer time (march/02) using a Van Veen grab sampler. Sampling started in the entrance (close to the ocean) and extended inward to D'Una

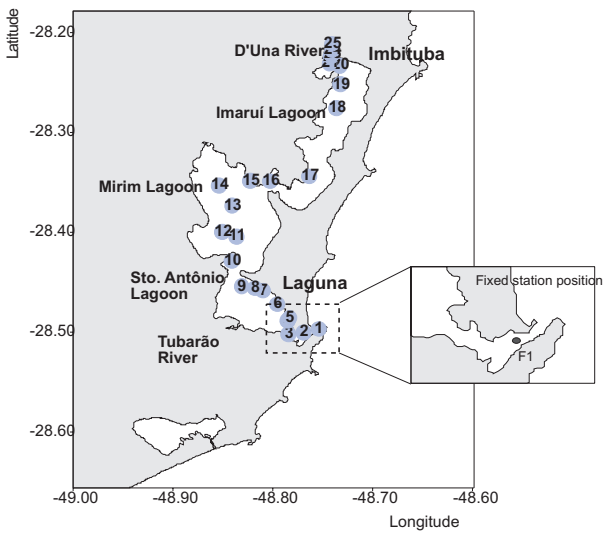

Figure 1. Sampling biological stations (1 to 25) and fixed station position (F1).

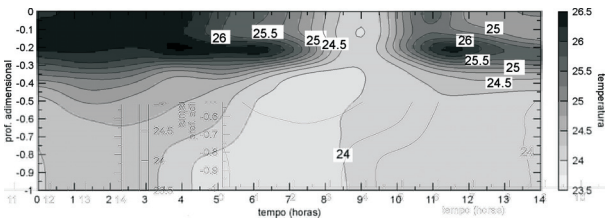

Figure 2. Temperature values in the fixed station (F1).

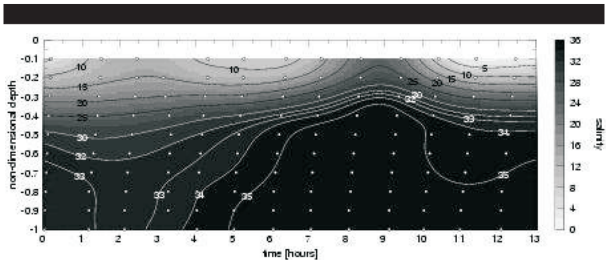

Figure 3. Salinity values in the fixed station (F1).

River in the inner parts of the Laguna estuarine system. Survey of hydrographic (salinity, temperature, current velocity and direction) data measures was made during 13 hours in a fixed station (F1), (detail on Figure 1) using a CTD Falmouth instrument connected to a current meter. The lagoon entrance (F1) was classified with Estratification-Circulation parameter proposed by HANSEN and RATTRAY (1966).

RESULTS

Physical Parameters

Surface and bottom temperature varies between 24 e 26ºC. Bottom temperature presents low values if compared to surface temperature. In figure 2 it can be observed that vertical salinity variation was intense. In surface salinity values varied between 0 and 15, while in the bottom values are between 15 a 35.

Temperature and salinity variation in water column is mainly related to the pressure gradient difference formed by the mixing between the high salinity and cold-water penetration from the ocean and river runoff (Tubarão River) in the studied area.

The non-dimensional depth facilitates the time series analysis due to the cancel effect of depth variation along tidal cycle. Considering that inward flux from tide occurs after outward in a tidal cycle, the time-space average of along estuary velocity is a good approximation of velocity due the river-flow u_f. A negative average velocity was found, therefore determining a mean inflow into estuary during experiment period. For that reason was not possible to estimate the u_f. The on-board logbook registries a strong SW wind, that is parallel to the coastal line. Due to the Ekman integrated transport that wind conduct to a sea level increase near coast, and therefore a flow inward estuary. The figure 2 shows the salinity time series in non-dimensional depth. A substantial salinity difference between surface and bottom could be observed all time, suggesting a bi-directional flow: freshwater at top flowing outward and saltwater at bottom flowing inward. In despite of that difference, only during a short period, near 9-experiment hour, a strong salinity gradient is observed approximately at depth 0.3. Without knowing u_f values it were not possible to determine the circulation parameter, the \h parameter and Hansen-Rattray diagram. But analyzing the salinity data the estuary show a partially mixed structure during the experiment period. The turbulent diffusion, characteristic process of that type of estuary, is extremely important to local community as it consider improve the circulation in estuary and also the water renovation.

Species Distribution

A total of 24 foraminifera species and 8 thecamoebians species were found in the study area. The number of tests in 50 cm3 of sediment was 36881, distributed in 12 Rotaliina species, 2 Milioliina species, 10 Textulariina species and the thecamoebians. Very few living specimens were present and it was impossible to use them for a statistical analysis. Thus, the following study is based on total assemblages. In the stations 1 e 2, located in the laguna channel entrance (closer to the ocean) occurs *Buccella peruviana*, *Bolivina striatula* and *Cassidulina subglobosa*. Toward stations 6 e 7, it also occurs *Pseudononion atlanticum*, *Saccamina sphaera*, *Quinqueloculina miletti* and *Q. patagonica*. Especimens of *Ammonia tepida* and *Elphidium poeyanum* were found from station 1 to 10 and 1 to 13, respectively. Rotaliina is absent in the stations 14, 15, 16, 18, 20 to 25. The agglutinated foraminifera *Miliammina fusca* was dominant mainly from station 17 to 25. In the other hand *Haplophragmoides wilberti* and *Arenoparrela mexicana* are nearly absent restricted only to stations 3 to 8. *Ammotium cassis, Ammotium salsum, Ammobaculites exigus* and *Gaudriyna exillis* are dominant in stations 5 to 21, presenting different spatial distributions in the study area. In stations 10 to 16, *A cassis* is dominant while *A. salsum* is widely distributed in stations 6 to 21. *A. exigus* and *Gaudyina exillis* are dominant closer to entrance (5 to 14) and (4 to 14), respectively. Thecamoebian principal species found in the study area were *Difflugia oblonga, D. tricuspis, D. urceolata* e *Centropyxis constricta*. They were found mainly in stations 3 to 9 and 18 to 25, indicating local strong freshwater influence. Table 1 shows the following foraminifera and thecamoebians fauna parameters: species number (S) of, specimens number (N), eveness (J´), diversity (H´) and dominance (S') in the summer.

In table 1 it is observed a decrease in species total number forward inner parts of the system. The entrance of the lagoon (1 to 6) presents higher number of species and diversity, followed by the stations 7 to 13. Toward inner parts in stations 14 to 19 number of specimens and diversity values decreases. From station 20 to 23, it was observed increase in species and specimens number while stations 23 and 24 presents decreased values. It is noted that station 13 to 19 present the lowest specimens number. It was seen a diversity gradient where higher values occur in the entrance of lagoon while values are decreasing up to station 15 showing the lowest diversity value in the study area. The MDS analysis allows the recognition of

Table 1. *Species number (S), specimens number (N), eveness (J´), diversity (H´) and dominance (S') in the summer.*

Stations	S	N	J'	H'	S'
1	9	242	0,64	1,41	0,33
2	11	126	0,74	1,77	0,23
3	13	507	0,85	2,17	0,14
4	12	202	0,86	2,13	0,15
5	14	389	0,81	2,15	0,15
6	17	996	0,65	1,85	0,23
7	6	704	0,72	1,30	0,32
8	7	226	0,86	1,68	0,22
9	7	864	0,81	1,58	0,24
10	6	120	0,91	1,62	0,24
11	7	558	0,79	1,53	0,24
12	6	1616	0,74	1,33	0,29
13	6	29	0,91	1,64	0,21
14	3	20	0,73	0,80	0,54
15	2	8	0,54	0,38	0,78
16	2	12	0,81	0,56	0,63
17	3	55	0,63	0,69	0,59
18	2	76	0,77	0,53	0,65
19	3	246	0,50	0,55	0,66
20	6	9792	0,31	0,56	0,74
21	7	2856	0,39	0,76	0,67
22	8	14208	0,36	0,76	0,69
23	9	1588	0,79	1,74	0,26
24	4	536	0,91	1,26	0,30
25	3	886	0,28	0,31	0,86

4groups. The group I representing the north of Imaruí lagoon and south of Mirim lagoon, composed by stations 14, 15, 16 and 17 is related to the lowest density of foraminifera and thecamoebians. The group II formed by stations 7, 8, 9, 10, 11, 12 and 13 presents *Ammobaculites exiguus, Gaudryina exillis* and *Ammotium salsum* as indicators of lower freshwater input. This group can also be indicator of large grain size of sediment, but this assumption needs further studies. This group represents the north of Santo Antonio lagoon and south part of Imaruí lagoon. The group III includes stations from the entrance (1, 2, 4, 5 and 6) of the lagoon and reflects the dominance of *Buccella peruviana, Bolivina striatula, Cassidulina subglobosa, Pseudononion atlanticum, Saccamina sphaera, Quinqueloculina miletti* and *Q. patagonica.* These species are indicative of marine influence (MURRAY, 1991). The group IV includes most of the samples from D'Una River (24, 25), station in the estuary of Tubarão River (3) and Mirim lagoon (18, 19, 20, 21, 22, 23). These environments present the agglutinated species *Miliamina fusca* and *thecamoebians species*, (genera *Difflugia* and *Centropyxis*) as indicators of the strongest freshwater input in the region. Principal species found in the study area can be seen in figures 5 and 6.

DISCUSSION AND CONCLUSIONS

Hydrodynamic and Water Oxygenation

The foraminiferal assemblages show that marine influence is noticeable only in the lagoon entrance, because the choked channel restricts tidal water exchange with the coastal ocean (MIRANDA *et al*., 2002) inside the lagoon. Similar observations were made in two Brazilian choked lagoon, Lagoa da Conceição (SC) (DEBENAY *et al.*, 1997) and Araruama lagoon (RJ) (DEBENAY *et al.*, 2001) where the marine influence is limited to the entrance of the channel, characterizing the system as having low water renewal in the inner parts of the lagoon.

The entrance of the estuarine system presents high freshwater input resulting in noticeable saline stratification in the fixed station. The influence is noted mainly in stations 2 and 3. In such places, salinity decreases showing that the circulation pattern is also influenced by freshwater from Tubarão River. Salinity values showed horizontal gradient where higher values were found in the entrance and lower values in the inner parts. In spite of the small tide range, the resulting salinity gradient is a balance between tides and freshwater from Tubarão and D'Una River, that controls mixing characteristics in the lagoon. Tubarão and D'Una River are of large economic importance of 21 districts in the study area because the coal industry and agricultural production (rice, potatoes, tobacco, manioc, and cattle and pig raising) throws up in the lagoons' water the residue of its activities. Tubarão River is located in the south of the lagoon, closer to the ocean. Their water is well renewal if compared to D'Una River, once D'Una River is located far from the ocean and its water is not well renewable. Moreover, the highest depth of the D'Una River (5 and 7m) if compared to the lagoon itself (less than 3,6m) restricts the circulation and oxygenation of deeper waters. Dissolved oxygen values in surface and bottom of the most satations are usually high (5-7mg/l), which decreases mainly in D'Una River where surface dissolved oxygen reaches 4mg/l, and bottom reaches (less than 2 mg/l). The decrease in oxygen values shows that mixing is not

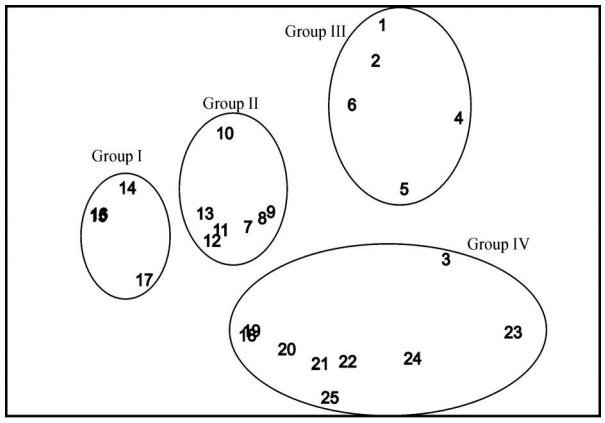

Figure 4. MDS analysis of biological data.

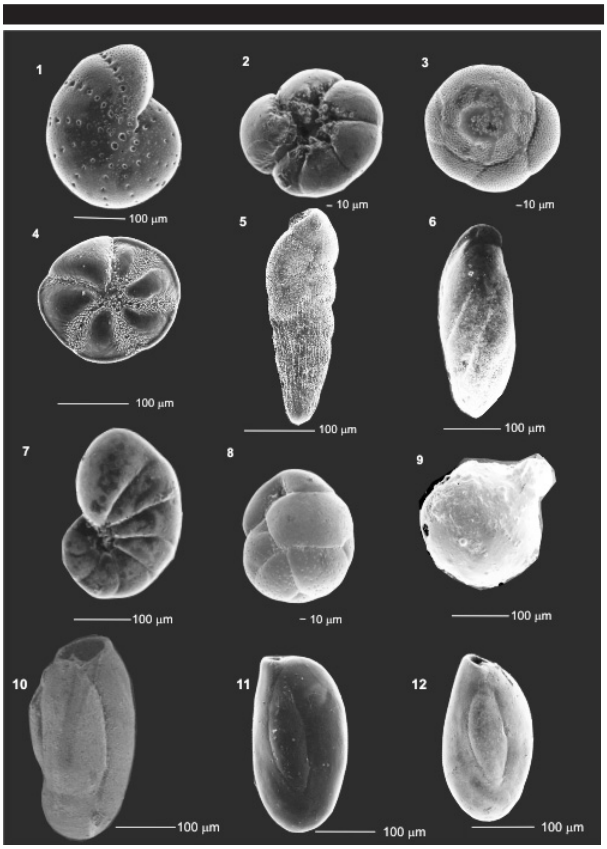

Figure 5. *E. poeyanum*. 2-3 *A. tepida.* Aperture and dorsal view. *4 B. peruviana. 5 B. striatula. 6 B. elegantissima. 7 P. atlanticum. 8 C. subglobosa. 9 Diatrona sp. 10 Q. miletti. 11-12 Q. patagonica.*

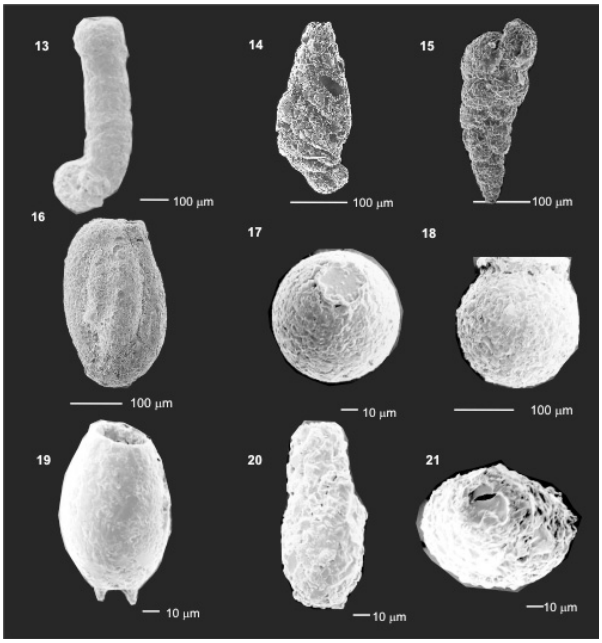

Figure 6. *13 A. exiguus. 14 A. salsum. 15 G. exillis. 16 M. fusca. 17 D. tricuspis. 18 D. urceolata. 19 C. constricta. 20 D. oblonga. 21 P. Compressa.*

complete and the part north of the lagoon presents higher tendency of endanger the system owing to human activities.

Species Distribution

The assemblages observed in the entrance of the Laguna estuarine system are very similar to those reported by EICHLER *et al* (2001) in the entrance of the Guanabara Bay (RJ, Brazil) where *Ammonia tepida, Elphidium poeyanum, Buccella peruviana, Pseudononion atlanticum, Bulimina marginata* and *Buliminella elegantissima Saccamina sphaera, Quinqueloculina miletti* and *Q. Patagonica* were dominant. Similar kind of assemblage has also been reported from intertidal zones from temperate regions (SCOTT and MEDIOLI, 1980; PATTERSON, 1990; HORTON *et al.*, 1999) and from tropical and subtropical mangroves (DEBENAY *et al.*, 2000; EICHLER, 2001).

It is worthy noted that A. tepida and E. poeyanum distribution occurs from station 1 to 13, tolerating wide environmental variation (MURRAY, 1991; LINKE and LUTZE, 1993) confirming its euryhaline characteristics. By the other hand, the stenohaline species *Buccella peruviana, Pseudononion atlanticum Bulimina marginata* e *Buliminella elegantíssima* were found only in the stations 1 to 6, revealing less capacity of dealing with salinity and temperature alterations.

In the Mirim lagoon, D'Una and Tubarão River the proportion of calcareous species decreased and *Ammotium cassis, Ammotium salsum, Ammobaculites exigus, Gaudriyna exillis* and *Miliammina fusca* became dominant sometimes associated with thecamoebians. This assemblage occurs in environments dominated by freshwater and it was also possible to observe a faunal gradient related to diversity, where lower values occur toward north being dominated by *Miliammina fusca* associated with the thecamoebians *Difflugia oblonga, D. tricuspis, D. urceolata* e *Centropyxis constricta*. This assemblage occurs mainly from station 20, and in the anoxic stations located in D'Una River, revealing that these species besides being characteristics of very low salinities in temperate mangroves (SCOTT and MEDIOLI, 1980; JENNINGS *et al*. 1995) and tropical and subtropical mangroves (DEBENAY, *et al*., 1998, 2000; WANG and CHAPPELL, 2001; DULEBA and DEBENAY, 2003), they are also indicative of low oxygenation environments.

MDS analysis showed that species distribution experienced both the influence of marine and fresh water, as indicated by the formed groups related to salinity and distance from the ocean. This double influence has been described in other places under influence of tide (HAYWARD and TRIGGS, 1994; DE RIJK, 1995), and it looks like it is the most important feature of Brazilian coastal zones (MADEIRA FALCETTA, 1974; EICHLER, 2001; DULEBA and DEBENAY, 2003). Foraminífera and thecamoebian assemblage presents spatial distribution well defined where mixohaline calcareous species *A. tepida, E. poeyanum, B. peruviana, P. atlanticum, B. marginata* and *B. elegantíssima, S. sphaera, Q. miletti* and *Q. patagonica* dominate in environment under higher marine influence followed by mixohaline calcareous and agglutinated species changing gradually to assemblages dominated by agglutinated species *A. salsum, A. exigus* and *G. exillis,* and ending in monospecific of *M. fusca* associated with thecamoebians in strongly hyposaline water. These assemblages were very similar to those reported from estuaries and lagoons (BOLTOVSKOY and BOSTOVSKOY, 1968; DEBENAY *et al.*, 2000; EICHLER, 2001 and DULEBA and DEBENAY, 2003) and show a succession of marine and mixohaline calcareous species (near the mouth) that changes to mixohaline calcareous and agglutinated species, then to agglutinated species alone, and finally to M. fusca and thecamoebians in the inner parts, indicating that fresh water influence is intense, and that water renewal is less efficient.

Based on foraminifera and thecamoebian distribution it was possible to identify the extension of fresh water and marine influence verifying that the distribution were a function of the natural characteristics of the environment, not showing signs of anthropogenic activities in the area, in spite of the existence of some activities related to coal industry and agricultural production.

The urban development that leads to endanger the environment has not been felt yet, but if there is no plans of coastal management that includes zone limitation of throwing municipal and industrial wastes, the environment will be showing degradation signs mainly in the north of the Laguna estuarine system where water renewal is less efficient.

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