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Meiofauna Spatial-Temporal Distribution in a Subtropical Estuary of Southern Coast Brazil

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ABSTRACT

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The meiofauna spatial-temporal distribution of the Tramandaí-Armazém estuary, RS, Brazil was investigated during two periods: winter 1999 and summer 2000. During the winter, six habitat units were sampled. Two of them situated in the Armazém lagoon (called units 1 and 2), one in an access channel to the Atlantic Ocean (3) and the other three in the Tramandaí lagoon (units 4, 5 and 6). During the summer, besides the aforementioned units, an area of the Armazém lagoon with occurrence of *Ruppia maritima* was also considered (called unit R). Nine samples were collected in each habitat unit using a 2.7 cm inner diameter corer. Environmental factors were measured in the field. The meiofauna dominant group was Nematoda, followed by Copepoda and other groups. Densities ranged from 49 ind.10 cm ^{2} in unit 5 (Tramandaí lagoon) to 3117 ind.10 cm $^{-2}$ in unit 1 (Armazém). The highest densities, in both summer and winter were registered in the units sampled in the Armazém lagoon. The multidimensional scaling analysis applied to winter meiofauna samples pointed to the formation of three different groups comprising Armazém lagoon, Tramandaí lagoon and access channel samples, respectively. In the summer this separation was not so clear. The results lead to the conclusion that the main factors structuring spatial-temporal distribution of meiofauna in the Tramandaí-Armazém estuary were salinity and sediment granulometric characteristics, with variations induced by the hydrodynamics.

ADDITIONAL INDEX WORDS: *Nematoda, benthos, community.*

INTRODUCTION

The estuarine systems are an important habitat for a variety of organisms and a large deposit of both organic and inorganic nutrients, where various chemical and physical interactions occur (DAY *et al.,* 1989).

The Tramandaí-Armazém estuary is an ecosystem of great ecological and economic importance, and is considered an area of natural resources on the north coast of the state of Rio Grande do Sul, Brazil. This system suffers strong anthropic intervention by embankments, discharge of domestic effluents (FABRICIO, 1989; TABAJARA, 1994) and intense fishing activity (FAUSTO, 1999). Transportation and storage of oil in tanks next to the estuary banks also occur in this region.

The importance of meiofauna organisms in an ecosystem is linked to their feeding, excretion and locomotion activities, as well as trophic interactions. They affect the sediment stability by bioturbation (MONTAGNA and YOON, 1991), by mineralization of nutrients (SMOL *et al.,* 1994), and by stimulation of the bacterial growth (ALKEMADE *et al.,* 1992; SMOL *et al.* 1994). Moreover they take part in the energy flow of the estuarine feeding cycle (COULL and BELL, 1979; SIKORA and SIKORA, 1982), directly or indirectly serving as food to higher trophic levels. Studies on contamination biomonitoring using meiofauna organisms are also being developed (AMJAD and GRAY, 1983; ANSARI *et al.,* 1984).

The horizontal distribution of the meiobenthic community is generally associated to an aggregated behaviour which depends of the interaction of abiotic factors (such as size of sediment particle, salinity, hydrodynamics, temperature, among others), biotic factors (such as food availability, reproduction, intra and interspecific relations) and anthropogenic input (such as organic contamination, chemical pollutants) (SANTOS *et al*., 1996; SARMA and WILSANAND, 1996, ALONGI, 1987). Studies that focus on the distribution patterns of organisms are important for further knowledge of the processes that influence the environment (UNDERWOOD *et al*., 2000).

The present study characterises and compares the spatial-temporal distribution of meiofauna in winter and summer in the Tramandaí-Armazém estuary.

METHODS

Study Site: The Tramandaí-Armazém estuary (29º 55 49" and 30º 00 56" S and 050º 06 21 and 050º 11 20" O) is linked to the Atlantic Ocean by a 1.5 Km long channel with average depth of 3.0 m (TABAJARA and DILLENBURG, 1997).

The Tramandaí lagoon is located in the northern section of the estuary and the Armazém lagoon in the southern section, partially separated by a spit of land that outstretches in a NW-SE direction (TOMAZELLI and VILLWOCK, 1991). The Tramandaí lagoon has an area of 12.86Km^2 and average depth of 1.10m (SCHWARZBOLD and SCHÄ FER, 1984); it receives, through the Tramandaí river, water inflow and fine sediments (silt and clay) originated in the rivers and lagoons situated in the north of the system. The Armazém lagoon is between 0.5 and 1.0m deep and presents a surface area of 5.54Km^2 (SCHWARZBOLD and SCHÄ FER, 1984). This lagoon is linked by the Camarão river to Lagoa das Custódias, situated in the south, though this link does not correspond to a high sediment input in the estuary (STROHSCHOEN JR., 1985).

Activity in the Field: Six habitat units were sampled in the winter (June) of 1999 (Figure 1). During the summer, besides the units above, an area with the occurrence of *Ruppia Maritima* was also considered in Armazém lagoon (called R unity). From each unit nine samples were collected for faunal analysis with a sampler of 2.7 cm internal diameter sectioned in 0-2 cm and 2-5 cm strata and fixed in the field with formaldehyde 10%. In order to analyse the response of the meiofauna community to environmental parameters, the following environmental variables were measured simultaneously to the biological

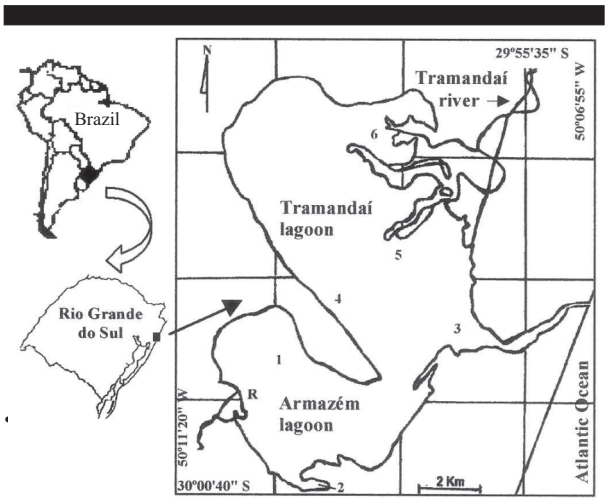

Figure 1. Tramandaí-Armazém estuary showing the position of habitat units.

sampling, in the bottom waters of the units: pH (potentiometer WTW model pH197) and salinity (with refractometer).

Samples for granulometric analysis were taken with a 10cm diameter sampler from each habitat unit. Samples of bottom water were collected and stored for further analysis for nitrate, nitrite, ammoniacal nitrogen, and fecal coliforms.

Meiofauna samples were dyed in the laboratory with Rose Bengal and washed in sieves with 0.500mm and 0.040mm mesh openings. Individuals caught in the 0.500 mm sieve were excluded from the analysis of meiofauna. The organisms were identified and quantified in ind.10cm^{-2}.

The granulometric analysis was carried out according to the methodology suggested by SUGUIO (1973). Results were analysed using SYSGRAN software, which supplied the statistical and granulometric parameters, according to FOLK and WARD (1957). The bottom water analyses were carried out using the methods found in APHA (1995).

Data Analysis: For the statistical analysis, the data was transformed by log (x+1) and used in all analyses.

To characterise and compare the sampled habitat units, Bray-Curtis distance was applied and an analysis of proximity (MDS, Multi-Dimensional Scaling) and similarity (ANOSIM) were performed using PRIMER software version 5.2.9.

In order to verify the influence of environmental parameters in the distribution of meiofauna organisms, an analysis of nonparametric correlation, using Spearman coefficient, between previously transformed biological and abiotic data, was carried out using the software STATISTICA® version 5.0.

RESULTS

Environmental Parameters

The Northeast wind was predominant during the winter of 1999 and the summer of 2000. The month of February, summer, registered higher precipitation (114.5 mm) than June, winter (83.6 mm).

In the winter a decreasing gradient of salinity was observed in unit 3, located near to the entrance of the access channel to the Atlantic Ocean (29.5) towards unit 6, located on the delta of the Tramandaí river, on the northeast bank of the lagoon (0).

In the summer, the salinity for units 3 (channel), 4, 5 and 6 (Tramandaí lagoon) was 0. Salinity and pH values in units R, 1 and 2 (Armazém lagoon) were higher than the values registered in the Tramandaí lagoon, as shown in Table 1.

The granulometric analysis results allowed the identification of two kinds of predominant sediments in the habitat units, those composed by fine sand (units 1, 2 and 4) and by very fine sand (5 and 6). In the winter, unit 3 presented sediment dominated by very fine sand and in the summer by fine sand.

The values of nitrite and nitrate were below detection level in the summer and, due to metodological problems, the analysis of fecal coliforms was not performed during that season.

Meiofauna

Composition

Six taxonomic groups belonging to the permanent meiofauna were identified:

- Turbellaria,
- Nematoda,
- Ostracoda,
- Copepoda,
- Acari,
- Tardigrada
- Nauplii.

Group Tardigrada was registered only in the summer in habitat unit 6.

Nematoda was the most abundant group of the meiofauna, corresponding to 76.5% of the total density followed by Copepoda (10.7%) and Ostracoda (4.2%).

With the exception of what was observed in the channel habitat unit 3 (winter), where the highest abundance of Turbellaria (58%) occurred, in all the other habitat units the dominant taxon was Nematoda.

As temporary meiofauna, it was observed the occurrence of Gastropoda (*Heleobia australis*), Bivalvia (*Erodona mactroides*), Oligochaeta (*Paranais frici*), Polychaeta (*Laeonereis acuta* and *Heteromastus similis*), Isopoda (*Munna peterseni*), Amphipoda, Chironomidae and Hirudinea.

Density

The mean density of meiofauna organisms in the winter ranged between 49 ind.10cm^{-2} in unit 5 (Tramandaí lagoon) and 3117 ind.10cm^{-2} in unit 1 (Armazém lagoon), while in the summer densities fluctuated between 77 ind.10cm^{-2} in unit 6 (Tramandaí) and 2586 ind.10cm^{-2} in unit R, Armazém lagoon (Figure 2).

The highest densities, in both summer and winter were registered in the units sampled in the Armazém lagoon. In the winter, the ANOSIM did not register any significant difference between the densities of units 4 and 5, and 5 and 6 ($p>0.01$). In the summer, there was no significant difference between densities of unit R (vegetated) and unit 1 (non-vegetated). The remaining units presented significant differences between densities.

Spatial Distribution of Meiofauna

Using MDS analysis and ANOSIM, and considering the factor lagoons and the channel during the winter, it was verified the

Table 1. *Physical and chemical parameters collected in the habitat units of the Tramandaí-Armazém estuary in winter (1999) and summer (2000).*

		Habitat Units					
Variables		1	2	3	4	5	6
Winter							
Nitrite (ug/L)		nd	18.3	11.5	2.9	15.1	2.9
Nitrate (mg/L)		0.1	0.17	0.16	0.14	0.04	0.12
NA (mg/L)*		0.69	2.87	2.84	0.64	0.81	0.79
CF **		160	600	20	39	6	112
Sediment+		FS	FS	VFS	FS	VFS	VFS
% silt clay		2.5	14.5	14.2	1.2	37.9	13.8
Salinity		4.5	6	29.5	0.5	1	0
pH		6.6	6.7	8	6.6	6.3	6.6
Summer	R	1	2	3	4	5	6
NA (mg/L)	0.41	0.54	0.68	0.41	0.41	0.54	0.54
Sediment	FS	FS	FS	FS	FS	VFS	VFS
% silt clay	4.4	1.2	13.9	4.8	0.8	10.4	7.6
Salinity	3	3	4	0	0	0	0
pH	8.5	8.5	7.7	7.4	7.4	6.8	6.7

* ammoniacal nitrogen **fecal coliforms, + FS=fine sand, VFS=very fine sand

Table 2. *Results of the analysis of similarity (ANOSIM) between the lagoons and the channel in each sampling season and between winter and summer.*

ANOSIM	R	p
Winter Armazém x Channel	0.86	0.001
Winter Armazém x Tramandaí	0.611	0.001
Winter Channel x Tramandaí	0.493	0.001
Summer Armazém x Channel	0.179	0.07
Summer Armazém x Tramandaí	0.182	0.001
Summer Channel x Tramandaí	-0.001	0.46
Winter x summer	0.23	0.001
Armazém winter x summer	0.133	0.006
Tramandaí winter x summer	0.515	0.001
Channel winter x summer	0.82	0.001

formation of three groups: Armazém lagoon, Tramandaí lagoon and channel (Figure 3, Table 2).

Group 1, formed by samples collected in habitat units 1 e 2, situated in the Armazém lagoon, and characterised by fine sand sediment, presented the highest mean densities of meiofauna (3117 ind.10cm^{-2} and 537 ind.10cm^{-2}, respectively). The dominant group was Nematoda, with a relative participation of 86% and 83% in units 1 and 2, respectively. Groups Copepoda, Nauplii and Ostracoda also collaborated to the higher density numbers.

The group 2 was composed by the units collected in the Tramandaí lagoon and characterised by fine and very fine sand sediments and low salinity, not surpassing 1. The mean density of organisms was low if compared to the Armazém lagoon and the channel, while the most representative groups in these units were Nematoda, Ostracoda, Nauplii, temporary meiofauna and Copepoda.

Finally, the group 3 was formed by samples collected next to the channel link to the sea, unit 3, with very fine sand sediment. This location presented the highest percentage of sand (98.86%), and the highest salinity (29.5). The mean density in this group was 213 ind.10cm^{-2}, intermediate between Tramandaí and Armazém lagoons. Turbellaria was the most representative group (58%), followed by Nematoda (21%) and Ostracoda (10%).

This separation was not so clear during the summer (Figure 3, Table 2), when only the separation between Armazém and Tramandaí lagoons (p=0.001) did occur. It should be emphasised that in this situation the R value was low (R=0.182).

Seasonality

The comparison between winter and summer through ANOSIM showed that the Tramandaí lagoon and the channel presented significant difference between the sampling seasons, the channel registering the highest R value (R=0.82). In the aforementioned sites the highest densities were registered in the summer. No significant difference between seasons was observed in the Armazém lagoon (Table 2).

Meiofauna and Environmental Parameters

The correlation analysis between the total density of the meiofauna (ind.10cm^{-2}) and the environmental parameters, carried out using the coefficient of Spearman, showed a positive correlation between meiofauna, salinity and pH. Otherwise, a negative correlation occurred between the density of meiofauna and the percentage of fines (silt and clay).

DISCUSSION

The results found for Nematoda in the present study indicate a predominance of this group in all habitat units, with the exception of the channel (winter). This predominance has been registered by different authors for estuarine environments (OZÓRIO *et al.,* 1999; DALTO and ALBUQUERQUE, 2000, FONSECA 2003).

The ability of nematodes to colonise different habitat units is mainly due to their body characteristics, such as the elongated cylindrical body (BARNES, 1990), allowing a greater penetration in the sediment (BELL and SHERMAN, 1980). Moreover, many of its species are adapted to live in anaerobic conditions (HENDELBERG and JENSEN, 1993).

In this study, during the winter, nematodes presented a positive correlation with salinity and a negative correlation with percentage of fines. In the summer it showed a positive correlation with salinity, pH and sand percentage.

Copepoda, the second most abundant group, presented a negative correlation with silt and clay percentage and a positive correlation with sand percentage in the summer. Similar results were verified by SMOL *et al.* (1994) in the Oosterschelde estuary (Netherlands). According to MCLACHLAN *et al.* (1977), copepods present a greater mobility in sediments of coarser granulometry, also being more sensitive to anoxic conditions common in very fine sediments.

The total mean density of organisms presented a large variation between the habitat units, situation also registered by Pinto (2003) in the Lagoa dos Patos estuary (RS) and by FONSECA (2003) in Laguna (SC).

The texture characteristics of the sediment found in the Tramandaí-Armazém estuary agree with the results obtained by TABAJARA and DILLENBURG (1997) in studies developed in the same estuary. The authors found sediments composed of fine and very fine sands in depths below one metre, and in sheltered or deeper locations the authors registered muddy-sand and sandy-mud textures. The authors mention that the general pattern of sediment distribution results mainly from hydrodynamics, established by the action of waves and currents, produced by local winds, mainly the northeast wind. The northeast wind was predominant in both sampling seasons in this study. Rainfall, another active factor in the hydrodynamics, was higher in the summer (February 2000), affecting the Tramandaí lagoon and the Channel, sites where salinity was found to be 0. Although the salinity of the Armazém lagoon was low in the summer, it was still higher than in the Tramandaí lagoon, during winter and summer. The statistical analysis showed that characteristic factors of the substrate and salinity affected the benthic meiofauna of this estuary. In the winter, when precipitation was lower, there was a clear separation of the habitat units collected in the two lagoons, Tramandaí and Armazém, and the channel.

The density value found in the channel was intermediate

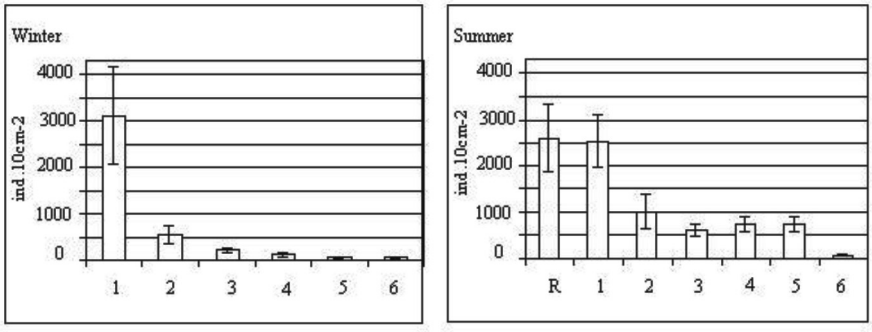

Figure 2 Total meiofauna mean density on each habitat unity, Tramandaí-Armazém estuary, RS, Brazil.

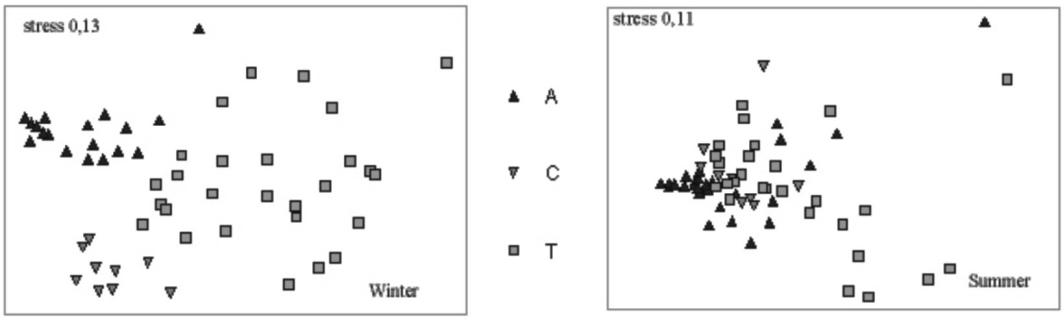

Figure 3. Multidimensional Scaling applied to total meiofauna density, Armazém lagoon (A), Channel (C), Tramandaí lagoon (T), in winter (1999) and summer (2000).

between the values found in Tramandaí and Armazém lagoons, considering that the active factor in this site would be the wide salinity variations provoked by saline wedges and high hydrodynamics. ROSA-FILHO and BEMVENUTI (1998), using the abundance/biomass comparison method for macrozoobenthos, to identify environments under stress, classified this area as highly stressed. According to the authors, the high chemical instability caused by saline wedge intrusion; wind; rainfall; and hydrodynamics are the main sources of stress. Turbellaria (58%) was the predominant group in this unit; these individuals are probably associated with saline wedge intrusion, once it was in this site that the highest salinity was registered (29.5). J.G. GOMES-FILHO (personal communication, Benthic Laboratory, FURG), while studying benthic macrofauna associated to artificial substrates in the Lagoa dos Patos estuary, registered an increased density of Turbellarians due to saline wedge intrusion.

The Armazém lagoon presents the highest densities of organisms. Sediments, predominantly fine sand, form its substrate, and salinity is higher, if compared to the Tramandaí lagoon. ROSA-FILHO and BEMVENUTI (1998) classified the area vegetated by *R. maritima* in the Armazém lagoon as undisturbed, and the adjacent non-vegetated area, as moderately stressed. The result found by the authors can also be confirmed by the high occurrence of Ostracoda *Perissocytheridea kroemmelbeini* found during this study, which, according to WÜRDIG (1988), would be better adapted to areas towards inland, with lower hydrodynamics and less abrupt salinity fluctuations.

A probable organic contamination revealed by a high concentration of ammoniacal nitrogen and the presence of fecal coliforms may be influencing the high density of meiofauna registered in the Armazém lagoon. According to GEE and WARWICK (1985), a moderate level of organic matter induces an increase in density of organisms, while the diversity diminishes with the increase of organic matter.

ANSARI *et al.* (1984), while studying meiofauna along a transversal section with domestic sewage influence, in the Mandovi estuary, India, registered low density of organisms next to the mouth of the emissary and higher densities at farther distances. The present study has not analysed this situation.

Environments with low hydrodynamics and consequently less water renovation suffer greater impact by organic contamination than areas with higher hydrodynamics (MCLUSKY, 1989). The consequences of the contamination of the Armazém lagoon are possibly not worst due to the moderate hydrodynamics of that site (TABAJARA and DILLENBURG, 1997).

The Tramandaí lagoon registered the lowest meiofauna densities, mainly in units 5 and 6, situated on the delta of the Tramandaí river. This result is probably due to the influx of fine sediments by the river and to the intense influence of fresh waters. This result was confirmed by the correlation analysis, which emphasised that the organisms present a positive correlation with salinity and a negative with the fraction of the sediment's fine particles. ANSARI *et al*. (1980) studying Mandovi estuary of Goa, in India, found higher densities of meiofauna organisms in fine sand sediments and lower densities in fine sediments. SMOL *et al*. (1994), studying the Oosterschelde estuary (Netherlands), found positive correlation of the total meiofauna with the percentage of fines, but the content of fine fractions in the author's samples was lower than the registered in the present study. MONTAGNA and YOON (1991) studied the effects of freshwater inflow into San Antonio Bay (Texas) and verified that the lower densities occurred in lower salinities. The present study also registered this result.

The clear separation between the lagoons and the channel did not occur in the summer, due probably to the influence of low salinity, however, the habitat units in the Armazém lagoon (R and 1) showed densities significantly higher than the other units. It was verified that the density of organisms in the Tramandaí lagoon and in the channel, was significantly higher in the summer than in the winter, probably due to the temperature. Despite the higher density in the summer, it was still lower than densities registered in the Armazém lagoon.

Vegetated areas are used for breeding, feeding and as shelter against predators by different species of invertebrates and fish and are considered sites of ecological and economic importance (GARCIA *et al*., 1996; KAPUSTA and BEMVENUTI, 1998). OZÓRIO *et al.* (1999) while comparing a non-vegetated submerged area to a marsh area colonised by *Spartina alterniflora* in the Lagoa dos Patos (Brazil) estuary, found density of meiofauna significantly higher in the non-vegetated area. The authors associated this result to the less favourable conditions of the sediment inside the marsh, such as lack of O_2 and low pH, since this site is immersed at periods. Besides, the organisms movement would become difficult due to the large number of roots.

Comparing the area vegetated by *Ruppia maritima* (unit R) to the non-vegetated adjacent area (unit 1) in the Tramandaí-Armazém estuary, no significant differences were found between densities of meiofauna organisms. Vegetation attraction does not seem to have a direct influence on the total density of meiofauna, but seem to favour nematodes, since they presented higher abundance inside the bank of *R. maritima*. The groups Ostracoda, Copepoda and Nauplii presented higher densities in the non-vegetated area probably due to a greater ease of movement outside the vegetated area.

CONCLUSION

The present study showed evidence that the spatial-temporal distribution of meiofauna in the Tramandaí-Armazém estuary has been influenced mainly by salinity and substrate characteristics, with variations induced by the hydrodynamics caused by the northeast wind; rainfall and by the saline wedge intrusion into this system.

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