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COLLEMBOLA PODUROMORPHA AS BIOINDICATOR OF ANTHROPOGENIC IMPACT ON "RESTINGA" AREAS IN THE STATE OF RIO DE JANEIRO, BRAZIL [1]

(With 7 figures)

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ABSTRACT: Representatives of Order Poduromorpha were studied under taxonomic and ecological view in halophyte-psammophyte vegetation as well as in foredune zone environments in preserved and impacted areas of "Restinga de Maricá". Throughout 2003, 128 sampling events were carried out in January, June, July and December, which totalized 8,125 springtails, among which 4,264 were representatives of Order Poduromorpha, distributed through 5 families, 16 genera and 23 species. In the preserved areas, a pattern of species distribution was noticed for each environment. Through the species indicator test, two indicator species of impacted areas were pointed out as well as one species of preserved area, three species of halophyte-psammophyte vegetation and four species of foredune zone; *Austrogastrura travassosi* was highlighted as indicator of halophyte-psammophyte vegetation environment in impacted areas. The highest diversity, richness and equitability values were observed in the foredune zone environment of Itaipuaçu impacted area. The Canonical Correspondence Analysis showed that the most important elements in space-temporal species distribution were pH, soil humidity and organic matter content. The faunal variability was kept in the preserved areas of each sampled environment.

Key words: Collembola. Ecology. Indicator species. Littoral. Taxonomy.

RESUMO: Collembola Poduromorpha como bioindicador de impacto antrópico em áreas de restinga no litoral do Estado do Rio de Janeiro, Brasil.

Representantes da Ordem Poduromorpha foram estudados do ponto de vista taxonômico e ecológico nos ambiente de vegetação halófila psamófila reptante e de primeiro cordão arenoso em áreas preservadas e impactadas da Restinga de Maricá. Durante o ano de 2003 foram realizadas 128 amostras nos meses de janeiro, junho, julho e dezembro, que totalizaram 8.125 colêmbolos, dos quais 4.264 eram representantes da Ordem Poduromorpha, distribuídos em 5 famílias, 16 gêneros e 23 espécies. Nas áreas preservadas, para cada ambiente, verificou-se um padrão de distribuição das espécies. Através do teste de espécies indicadoras foram apontadas duas espécies indicadoras de área impactada, uma de área preservada, três de ambiente da vegetação halófila psamófila reptante e quatro de primeiro cordão arenoso, destacando-se *Austrogastrura travassosi* como indicadora de ambiente de vegetação halófila psamófila reptante em áreas impactadas. Os maiores valores de diversidade, riqueza e equitabilidade foram observados no ambiente de primeiro cordão arenoso da área impactada de Itaipuaçu. A Análise de Correspondência Canônica mostrou que os fatores mais importantes na distribuição espaço-temporal das espécies foram o pH, a umidade do solo e o conteúdo de matéria orgânica. A variabilidade da fauna foi mantida nas áreas preservadas em cada um dos ambientes amostrados.

Palavras-chave: Collembola. Ecologia. Espécies Indicadoras. Litoral. Taxonomia.

INTRODUCTION

There are numerous springtails in most soils, especially in the disturbed and at initial stage of succession ones, where the community structure has changed along a pollution gradient (PETERSEN, 2002). Their sensibility and perception to environmental changes enabled them to be bioindicators in many types of edaphic systems (PRAT & MASSOUD, 1980; PINTO *et al.*, 1997; GREENSLADE, 1997; GOMEZ-ANAYA & PALACIOS-VARGAS, 2004). This bioindicator activity has been used for conservation and monitoring strategies in natural ecosystems as well as in the ones disturbed by pollution and by other anthropogenic impacts (KOPESKI, 1997; CULIK & ZEPPELINI-FILHO, 2003). The presence of abundant and diversified interstitial

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collembolan fauna in sandy sediments, found by Thibaud & Christian (1997), allows interesting comparisons of the group in its several communities, which confirms its position as ecological indicator.

Several researchers have been using certain genera of Order Poduromorpha (e.g. *Mesaphorura* Borner, 1901) as ecological indicators (Rusek, 1979) and in biocenotic studies on verification of soil acidification (Hagvar, 1990; Ponge, 2000). The species *Mesaphorura krausbaueri* Borner, 1901 has been considered indicator of soil fertility and a pioneer in secondary succession of cultivated soils (Dunger, 1986) as well as indicator of soils compacted by agricultural machines (Heisler, 1995). Other species, such as *Protaphorura armata* (Tullberg, 1869), have been used for the study of the effects of pollution and human activities on reproduction, mortality and population growth (Bengtsson *et al.*, 1983, 1985) as well as the impact of compaction on agricultural soils (Larsen *et al.*, 2004). Studies concerning adaptation of cuticle (King *et al.*, 1990), growth, reproduction, mortality (Witteven & Joosse, 1987), ionic and osmotic regulation (Witteven *et al.*, 1987) and the ability of survival to marine transport conditions (Coulson *et al.*, 2002) have been carried out with some littoral species.

The "restingas" located between the marine and continental ecosystems present complexity and diversity only surpassed by rainforests. This ecosystem consists of sandy soils, generally poor in clay and organic matter, with low capacity of water and nutrient retention, despite the large proportion of annual nutrient input as salt spray (Hay & Lacerda, 1984; Menezes & Araujo, 2000). According to Weiner & Thibaud (1991), Oliveira *et al.* (1994) and Thibaud & Christian (1995), the beach sand seems to constitute a biotope that is less rich in individuals as well as in species. Besides that, it is considered to be trophicly very poor and to have extreme prevailing life conditions.

Thus, Itaipuaçu and Maricá "restingas" areas were chosen as the object of this study, not only due to the reduced number of known species, but also to the quick deterioration this ecosystem has been suffering , mainly caused by real state speculation, for the last years. Other equally harmful events, such as removal of sand and decorative plants, lumber extraction, forest fires and litter deposit, have turned a large part of its area into fragments of original vegetation. The damage to the biological and landscape components is irreversible and puts a valuable genetic patrimony at risk.

The present article aimed to check the responses of Collembolan Poduromorpha community to the environmental degradation caused by anthropogenic action. It also aimed to relate the structure of Collembolan Poduromorpha community to the variation in environmental features in preserved as well as degraded areas and to determine indicator species of anthropogenic impact on "Restinga de Maricá".

MATERIAL AND METHODS

The present project was carried out in "Restinga de Maricá" which is located on the "fluminense" coast east of Rio de Janeiro city (22°57'50''S and 42°50'44"W). In the Municipality of Maricá, two protected areas under legislation and two areas impacted by anthropogenic action were chosen; each area is situated between Itaipuaçu and Barra de Maricá beaches in the districts of Itaipuaçu and Maricá, respectively. The preserved areas are situated at the "Área de Proteção Ambiental (APA) de Maricá" which occupies a total area of 8, 3 km^2 between the coordinates of 22°52' to 22°54'S and 42°48' to 42°54'W. The studied areas were divided into two environmental types: the first one comprises the halophyte-psammophyte vegetation and the second one, the foredune zone; both are based on the classification of Araújo & Henriques (1984). The sampling sites are showed in figure 1.

Samples were performed during the two typical seasons of the region: dry (winter) and rainy (summer) in January, June, July and December 2003. In each environmental area previously determined, four soil/ litter samples were carried out. Further information on the study area, sampled environments and sampling methods can be obtained from Fernandes & Mendonça (2007).

The analyses of organic matter content, Carbon, Nitrogen, pH in water and in KCl, available phosphorus and base content (Ca, Mg, K, Na, Al, H) were performed by the Laboratório de Água, Solos e Plantas (LASP) da Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA- SOLOS) in each collected sample.

Information about maximum, mean and minimum temperatures, precipitation, relative humidity and solar radiation concerning the Meteorological Station of Maricá (at the geographical coordinates of 22º55'S and 42º49'W) was obtained from the 6º Distrito de Meteorologia do Instituto Nacional de Meteorologia (INMET).

Statistical analyses were performed from the frequency values obtained for each area in order to check similarities among the sampling sites, relationships of species with environmental factors and space-temporal variations.

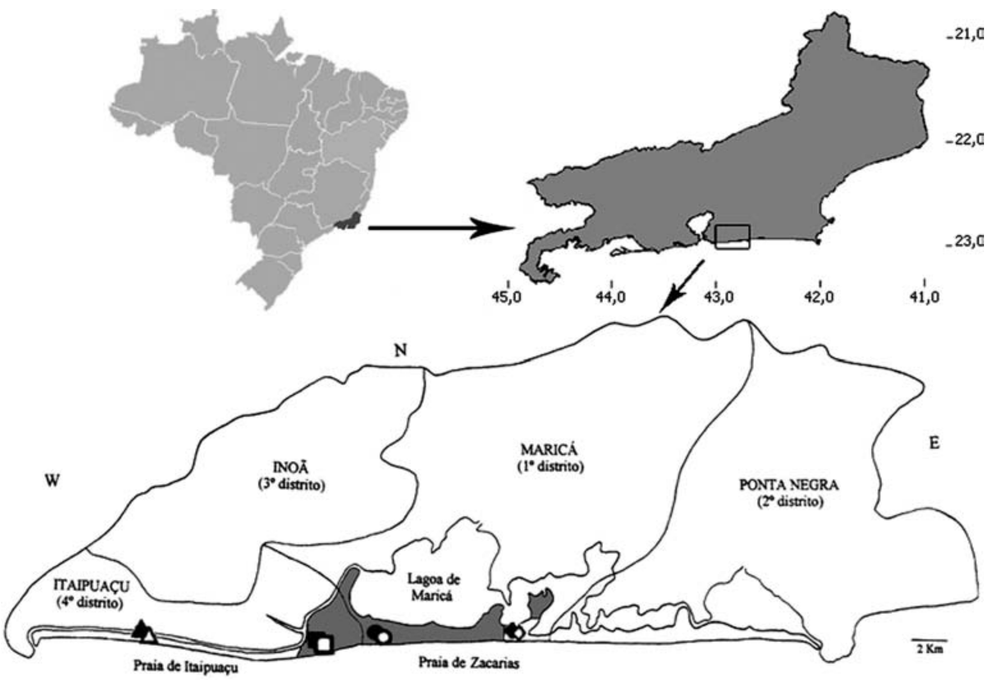

Figure 1. Maps of the Brazil, Rio de Janeiro State, showing the city of Maricá (RJ) detached and the District delimited, the APA of Maricá (in gray) and the sampling sites (△) IPA- Itaipuaçu (impacted area), halophyte-psammophyte vegetation; (▲) IPB- Itaipuaçu (impacted area), foredune zone; (☐) IAA- Itaipuaçu- APA (preserved area), halophyte-psammophyte vegetation; (■) IAB- Itaipuaçu - APA (preserved area), foredune zone; (❍) MAA- Maricá - APA (preserved area), halophyte-psammophyte vegetation; (●) MAB- Maricá- APA (preserved area), foredune zone; (✧) MPA- Maricá (impacted area), halophyte-psammophyte vegetation; (✦) MPB- Maricá (impacted area), foredune zone).

The Tukey Honest test was performed to verify the relationship of abiotic factors with both preserved and impacted areas and the environments of halophyte-psammophyte vegetation and foredune zone.

Diversity (Shannon-Weaver), Richness (Margalef) and Equitability (Hill) indexes (Ludwig & Reynolds, 1988) were used for checking differences in the community composition of each area. Differences between sampled areas and environments were verified by the Student's *t* test.

The percentage of species abundance was also calculated in both studied environments in each sampled site. Species with # 1% of abundance were excluded.

The indicator species test (Dufrene & Legendre, 1997) was used for verifying the characteristic species of preserved and impacted areas as well as halophyte-psammophyte vegetation and foredune zone. The results were submitted to Monte Carlo test with 1000 permutations in order to check their importance (accepted values: $p<0.05$).

The Canonical Correspondence Analysis (Ludwig & Reynolds, 1988) was used as arrangement method to detect and visualize the relationship between taxa and abiotic parameters as well as to calculate the factors that determine species distribution. In this analysis, two matrixes of data were used: sampling points versus taxa and sampling points versus abiotic parameters. The first matrix data were turned into log *(X+1)* and the second matrix data into $xi - \bar{x} / \sigma$, where xi = observed value; $\bar{x}$ = mean and σ = standard deviation.

The statistics software PC-ORD for Windows (McCune & Mefford, 1999), STATISTICA for Windows (StatSoft, 1997) and DivEs – Species Diversity (Rodrigues, 2005) were used for the analyses.

Categorization of the study area

Climate

According to data obtained from the Meteorological Station of Maricá, from January to December 2003, the Municipality of Maricá presented annual mean temperature of 23.7°C, minimum mean varying between 15.8°C and 22.9°C in July and January, respectively; and maximum mean varying between 33.8ºC and 25.2ºC in February and August. The coldest months were verified from May to September and the hottest ones from October to December. The total annual rainfall level was of 1,612mm and the mean monthly one was of 134mm with 105 rainy days in the year; the rainiest months were March, August and October while the driest ones were February and July. The monthly mean relative humidity values varied between 70% and 83%, and the lowest relative humidity occurred in February together with the highest solar radiation incidence (Tab.1).

In "Restinga de Maricá", the pluviometric precipitation verified during the present study was concentrated in the summer and reduced in the winter, which was similar to the pattern found for other "restingas" of the Southeast region of Brazil (Araujo & Henriques, 1984). However, this pattern has not always been repeated for the last years, since the months with high rainfall levels in the winter and low rainfall levels in the summer, as it happened during the present research, had already been evidenced by Mantovani & Iglesias (2001) for the year 1994. The average data of temperature, relative humidity, pluviometric precipitation, evaporation and solar radiation incidence, evidenced by the referred authors for the years between 1989 and 2000, mostly corresponded to the data observed for the year 2003.

Soil

The physicochemical analyses of 128 samples collected and synthesized in table 2 showed that the halophyte-psammophyte vegetation and foredune zone environments were mainly separated by pH both in water and in KCl. According to studies of Hay & Lacerda (1984) in "Restinga de Barra de Maricá", the soil becomes more acid in the horizontal direction and there is an increase in the organic matter content as well as in the cation exchange capacity until it becomes constant at about 100m far from the bank of the beach; coincidently, the same happened to the data here observed in relation to the sampled environments. The data analysis also revealed high cation exchange capacity in the impacted areas, which was due to a higher organic matter content and high aluminum saturation; it was also evidenced by Hay &

TABLE 1. Data obtained from the Meteorological Station of Maricá, from January to December 2003.

Months	Compensated Mean Temperature °C	Mean Temperature °C		Insulation (hs)	Relative Humidity (%)	Precipitation (mm)
		Max.	Min.			
January	**26,7**	**31,1**	**22,9**	**5,8**	**82**	**168,2**
February	28,1	33,8	22,8	10,0	70	34,4
March	26,5	31,3	22,5	6,3	76	221,2
April	24,7	29,7	20,4	7,4	80	72,7
May	21,9	27,3	17,5	6,4	80	88,9
June	**21,9**	**27,4**	**17,2**	**7,3**	**83**	**59,0**
July	**20,8**	**26,8**	**15,8**	**6,6**	**79**	**71,8**
August	20,2	25,2	16,0	5,9	79	246,8
September	21,5	26,3	17,3	5,3	79	67,0
October	22,9	27,6	18,7	6,5	79	230,0
November	24,5	29,1	20,4	5,4	79	195,5
December	**25,5**	**30,2**	**21,9**	**4,9**	**83**	**156,5**

Obs.: Sampled months in bold.

Lacerda (1984) on nutrient cycling studies in "restinga" and by Reis-Duarte *et al.* (2002) when they were doing research on soil fertility in "Restinga da Ilha Anchieta" (SP). Yet, according to these authors, high aluminum levels may represent a serious obstacle to the recovery of degraded areas in "restinga" forests, as the presence of iron and aluminum oxide shows that an impoverishment of soil is about to happen (Setzer, 194?). In relation to organic matter, the largest amount found in impacted areas was probably due to a larger amount of litter deposit in these regions or, like the impacted area of Itaipuaçu (IPB), to the predominant presence of *Allagoptera arenaria* (Arecacea). According to Menezes & Araújo (2000), dense populations of *A. arenaria* enrich the soil, once the organic matter is developed under its senescent leaves, which, consequently, achieves the accumulation of nutrients. Besides that, its system of thin and ramified roots allows the plant to reduce the loss of lixiviate nutrients in the soil, which favors the success of this plant species in "restinga" environments impacted by fire.

It is know that animals' defecation takes nitrogen and phosphorus compounds to the soil, which is important to a suitable functioning of organic matter decomposition chain (Miranda-Rangel & Palacios-Vargas, 1992). Therefore, it specifies limits to the growth of microbial populations when in high concentrations (Hasegawa & Takeda, 1996). However, in "restinga" environments, phosphorus input occurs through salt spray deposition (Hay & Lacerda, 1984). The analysis of phosphorus found in the studied areas showed higher content of this element in halophyte-psammophyte vegetation of impacted areas. Thus, we can also attribute its retention either to litter accumulation in the border or to the presence of clay deposited in this environment for the construction of roads.

Analyzing the abiotic parameters related to soil humidity and soil temperature in preserved as well as impacted areas, we noticed that soil humidity was higher during the summer months in the impacted areas, mainly in the foredune zone of Itaipuaçu (IPB). In this areas, as it was evidenced in relation to the high organic matter content, the presence of accumulated litter and A. *arenaria* (with its system of thin and intricate roots) would protect the soil against the high evapotranspiration, keeping the soil temperature lower in this area than in the others. The highest soil temperature recorded from halophyte-psammophyte vegetation in Praia de Barra de Maricá (MPA) might have been influenced by heat accumulation, as it was always the last sampling point.

In preserved areas, the highest soil humidity and temperature evidenced during the summer months were due to the high temperature and rainfall period which is typical during this season.

RESULTS AND DISCUSSION

Relationship of preserved and impacted areas with soil parameters

There were significant differences in relation to the following parameters Ca, Mg, K, Na, Al, H, available P, organic matter and soil humidity between preserved and impacted areas (Tab.3). The maximum, mean and minimum values and standard deviation can be verified in figure 2 (A-1).

Relationship between sampled environments and soil parameters

There were statistical significant differences between halophyte-psammophyte vegetation and foredune zone environments in relation to Ca, K, Al, H, pH in water, organic matter and soil humidity (Tab.3). The maximum, minimum and mean values as well as standard deviation can be verified in figure 3.

From these results, we can affirm that soil humidity, organic matter content and base content were the parameters that significantly influenced the distinction between the sampled environments and the type of impact. Another primordial element for separation of halophyte-psammophyte vegetation and foredune zone was pH. So, there was clear separation between the sampled environments and preserved as well as impacted areas, which enables the use of species obtained from the "restinga" ecosystem as indicators of plant communities and the impact they are submitted to.

Spatial and temporal distribution of Poduromorpha fauna

The colleted samples (128) totalized 8,125 springtails among which 4,264 correspond to Order Poduromorpha, distributed through 5 families, 16 genera and 23 species (Tab.4).

The highest values of diversity, richness and equitability observed in the foredune zone of Praia de Itaipuaçu (IPB) were probably due to the highest organic matter concentration and soil humidity, which assures a higher productivity and, consequently, favors the faunal composition and structure.

Comparing the diversity and richness indexes of both studied environments, we could observe that the foredune zone presented the highest values in all the four study areas. Considering that diversity

TABLE 2. Mean values and Standard deviation (in parentheses) of soil physic-chemical factors of the sampled areas.

	Impacted				Preserved			
	Itaipuaçu		Maricá		Itaipuaçu		Maricá	
	HP	FD	HP	FD	HP	FD	HP	FD
Ca^{++}	0,09 (0,3)	**2,01 (1,4)**	0,84 (1,2)	**1,34 (1,4)**	0,53 (2,1)	0,56 (1,1)	0,00 (0,0)	0,16 (0,3)
Mg^{++}	0,51 (0,1)	**1,55 (1,0)**	0,88 (0,8)	**1,07 (1,2)**	0,80 (1,4)	0,58 (0,4)	0,48 (0,2)	0,56 (0,2)
K^{+}	0,02 (0,0)	**0,10 (0,1)**	0,05 (0,0)	**0,07 (0,1)**	0,01 (0,0)	0,02 (0,0)	0,02 (0,0)	0,03 (0,0)
Na^{+}	0,10 (0,1)	**0,27 (0,2)**	**0,20 (0,2)**	0,12 (0,2)	0,08 (0,1)	0,03 (0,0)	0,12 (0,2)	0,08 (0,1)
Value S (sum of basis)	0,71 (0,3)	**3,91 (2,5)**	1,96 (1,8)	**2,59 (2,8)**	1,41 (3,5)	1,18 (1,5)	0,61 (0,3)	0,83 (0,4)
Al^{+++}	0,01 (0,0)	**0,13 (0,1)**	0,03 (0,1)	**0,12 (0,1)**	0,03 (0,1)	0,06 (0,1)	0,01 (0,0)	0,02 (0,0)
H^{+}	0,09 (0,1)	**3,29 (2,4)**	0,27 (0,6)	**2,34 (2,0)**	0,10 (0,1)	0,96 (1,0)	0,05 (0,1)	0,96 (0,6)
Value T (Cátion Exchange capacity)	0,83 (0,3)	**7,33 (3,8)**	2,29 (2,0)	**5,06 (4,6)**	1,54 (3,5)	**2,20 (2,5)**	0,68 (0,4)	**1,80 (0,7)**
Value V (basis saturation)	**88,06 (14,6)**	54,94 (21,2)	**87,63 (17,2)**	50,25 (16,6)	**85,56 (15,1)**	50,94 (12,1)	**93,06 (11,0)**	48,13 (15,0)
110Al/S + Al^{+++} (aluminum saturation)	0,75 (3,0)	**5,06 (6,7)**	0,88 (0,8)	**5,63 (1,9)**	0,19 (7,0)	**5,63 (7,8)**	1,44 (4,0)	**1,81 (3,9)**
Avaiable P mg/kg	**24,69 (38,9)**	**14,38 (15,9)**	**19,50 (2,8)**	**14,19 (19,8)**	4,69 (27,6)	3,13 (3,2)	3,13 (1,0)	3,38 (2,8)
pH Water	6,97 (0,5)	**5,49 (0,5)**	7,16 (0,9)	**5,37 (0,5)**	6,94 (0,6)	**5,38 (0,3)**	6,85 (0,5)	**5,56 (0,3)**
pH KCl	6,51 (0,6)	**4,63 (0,6)**	6,71 (1,0)	**4,60 (0,7)**	6,40 (0,7)	**4,46 (0,4)**	6,35 (0,6)	**4,68 (0,4)**
C (g/kg)	0,96 (0,5)	**17,13 (12,4)**	2,84 (4,2)	**11,41 (10,7)**	0,86 (0,4)	**3,94 (4,4)**	0,63 (0,3)	**4,89 (2,9)**
N (g/kg)	0,13 (0,1)	**1,27 (0,9)**	0,31 (0,3)	**0,86 (0,7)**	0,11 (0,0)	**0,38 (0,5)**	0,11 (0,0)	**0,31 (0,1)**
Organic Matter(g/kg)	1,66 (0,8)	**29,54 (21,4)**	4,89 (0,8)	**19,68 (7,3)**	1,49 (18,5)	**6,80 (7,6)**	1,07 (0,6)	**8,43 (4,9)**
Soil humidity	2% (0,0)	**11% (0,1)**	5% (0,0)	4% (0,1)	2% (0,0)	3% (0,0)	2% (0,0)	3% (0,0)
Soil temperature	25,25 (3,3)	25,63 (1,7)	26,81 (3,5)	26,63 (3,8)	26,72 (2,6)	25,31 (2,2)	**28,56 (3,7)**	26,56 (2,2)

Obs.: (HP) halophyte-psammophyte vegetation, (FD) foredune zone. Significant values in bold.

and richness values of collembolan populations are strictly related to vegetation cover of the biotopes where they live (Arbea & Blasco-Zumeta, 2001), we can infer that this environment is more stable and, therefore, favorable to the development of fauna.

The smallest diversity and richness values in some areas can be related to the high abundance in some species, such as *Autrogastrura travassosi* and *Xenylla maritima*, which have the property of aggregating; consequently, it causes reduction in the equitability index of the area. Some authors, such as Pozo *et al.* (1986) and Gama *et al.* (1995), had already observed this event when they studied collembolan populations in several plant communities in Europe.

TABLE 3. Values of "p" obtained for the Tukey Test applied to verify the relationship between the soil parameters and impacted and preserved areas and the halophyte-psammophyte vegetation and foredune zone biotopes.

Obs.: Significant values of $p<0.05$ in bold.

SOIL PARAMETERS	IMPACTED *X* PRESERVED AREAS	HP X FD BIOTOPES
Ca	**0,0007845**	**0,004297**
Mg	**0,0081553**	0,071178
K	**0,0000009**	**0,001094**
Na	**0,0007320**	0,973769
Al	**0,0094359**	**0,000041**
H	**0,0003166**	**0,000009**
Available P	**0,0000220**	0,236870
pH water	0,6868289	**0,000009**
Organic Matter	**0,0000730**	**0,000009**
Soil Humidity	**0,0004103**	**0,005394**
Soil Temperature	0,1867307	0,134310

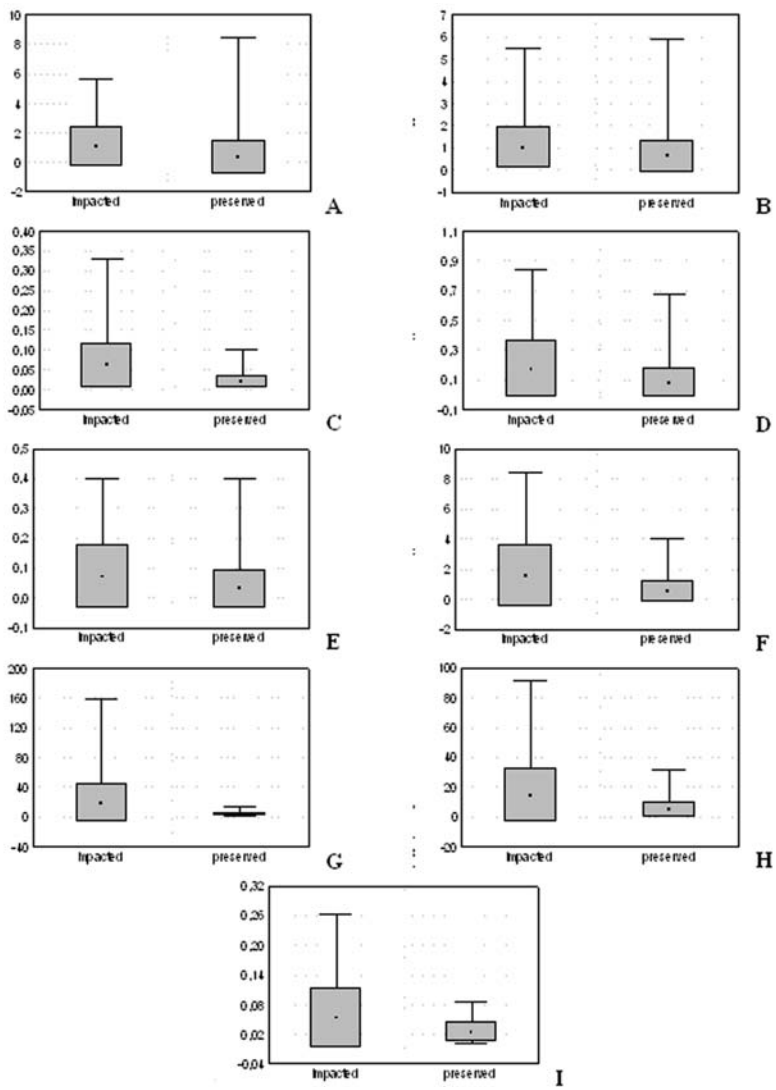

Fig.2 (A-I)- The maximum, minimum, mean and standard deviation of the soil parameters: Ca, Mg, K, Na, Al, H, available P, organic matter and soil humidity, respectively A to I, in preserved and impacted areas, p* significant. (I) Max. and Min., (□) mean+SD and mean-SD, (■) mean.

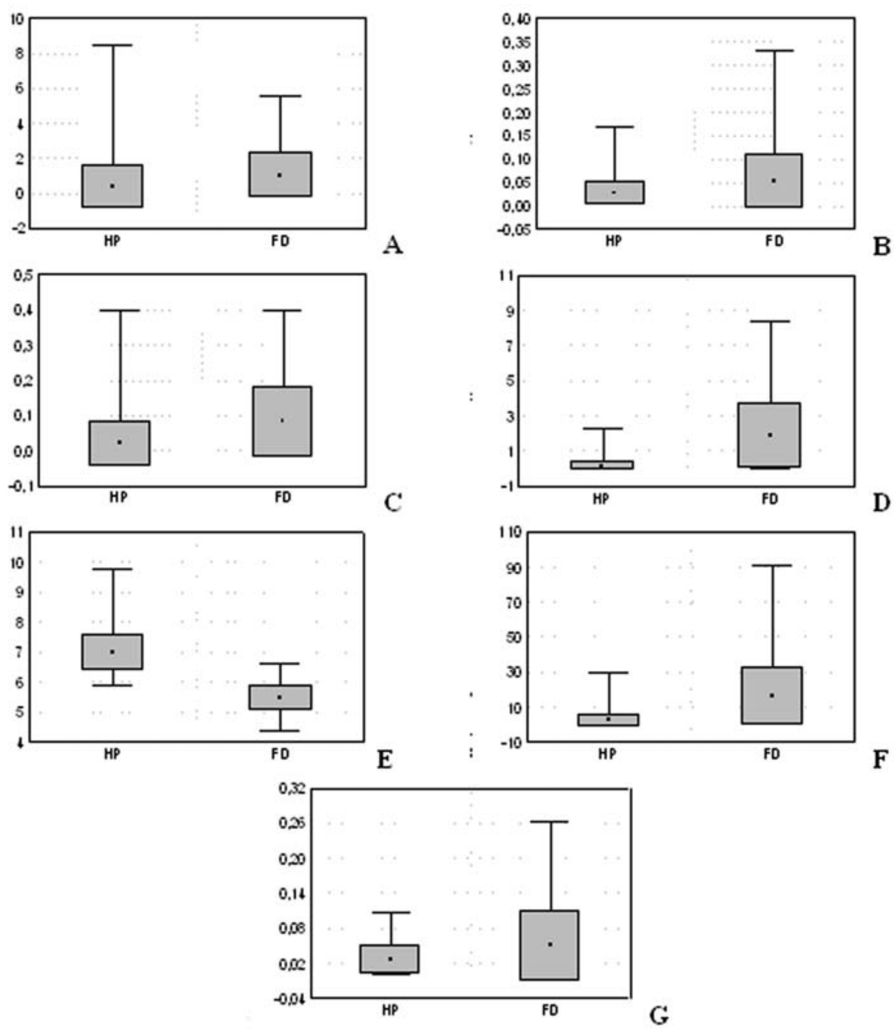

Fig.3 (A-G)- The maximum, minimum, mean and standard deviation of the soil parameters: Ca, K, Al, H, pH, organic matter and soil humidity, respectively A to G, in the halophyte-psammophyte vegetation and foredune zone environments, p* significant. (I) Max. and Min., (□) mean+SD and mean-SD, (■) mean.

However, the Student's *t* test didn't show significant differences in values of diversity and richness in the sampled areas, neither on sampled environments for $p<0.05$.

Percentage of species contribution

In the preserved areas, *Paraxenylla piloua* was more abundant in halophyte-psammophyte vegetation environment (Itaipuaçu- 76% and Maricá-72%),while in foredune zone the most representative species were *Xenylla welchi*, *X. maritima* and *Friesea reducta* (Itaipuaçu-71%, 19% and 6%; Maricá-62%, 23% and 10%) (Fig.4).

In the impacted areas, in each locality and sampled environment, one or two species predominated. In the halophyte-psammophyte vegetation environment of Itaipuaçu, the most abundant species were *Brachystomella contorta* (71%) and *Fissuraphorura cubanica* (17%), while in Maricá, *Austrogastrura travassosi* predominated with 86%. In the foredune zone of Itaipuaçu, we observed higher abundance of *Friesea reducta* (36%) and *Brachystomella agrosa* (31%), while in Maricá, *Xenylla maritima* (83%) contributed most.

From these results we can affirm that there is a distribution pattern with predominance of some species in preserved areas. However, in impacted areas this pattern does not occur and there is predominance of one or two species in each environment of each sampled locality. This predominance occurs due to the property of some species of forming aggregates, as *Austrogastrura travassosi* and *Xenylla maritima*, or due to the high ecological valence shown by others, as *Brachystomella contorta* and *B. agrosa*. Similar data were verified by Fountain & Hopkin (2004); they showed that the abundance of individuals of few dominant species increases, while the sensitive ones have reduced abundance in communities under stress.

TABLE 4. Total abundance of the Poduromorpha species, Diversity, Richness and Evenness in the sampled areas.

	Impacted				Preserved			
	Itaipuaçu		Maricá		Itaipuaçu		Maricá	
	HP	FD	HP	FD	HP	FD	HP	FD
Friesea claviseta							1	
Friesea magnicornis	1							
Friesea mirabilis	1		26				1	
Friesea reducta		75		29		39		52
Pseudachorutes difficilis		16		9		3		8
Aethiopella littoralis				5				
Neotropiella sp.		1						
Arlesia sp.				1				
Hylaeanura infima								1
Brachystomella agrosa	1	66	1	35		8		
Brachystomella ceciliae		1	12	4		12	2	9
Brachystomella contorta	13	14						
Maricaella duna		8				2		
Rapoportella pitomboi			2		1	1		
Austrogastrura travassosi			1841				1	
Xenylla maritima		1		410	5	108		114
Xenylla welchi			22		24	427	4	311
Paraxenylla piloua			213		106		99	
Acherontiella globulata			3					
Thalassaphorura sp.				1				
Fissuraphorura cubanica	3		30					
Mesaphorura amazonica		1				3	30	1
Mesaphorura yosii		29	3	2	1	5		5
TOTAL	19	212	2153	496	137	608	138	501
Number of taxa	5	10	10	9	5	10	7	8
Diversity (Shannon-Weaver)	0,44	0,69	0,25	0,31	0,30	0,43	0,36	0,47
Richness (Margalef)	3,13	3,87	2,70	2,97	1,87	3,23	2,80	2,59
Evenness (Hill)	2,00	3,00	1,22	1,22	1,68	1,66	1,78	2,07

Obs.: (HP) halophyte-psammophyte vegetation, (FD) foredune zone.

Indicator species

Impacted and preserved areas

According to the Indicator species test for impacted and preserved areas, *Austrogastrura travassosi* and *Brachystomella agrosa* acted as indicators of impacted areas, while *Xenylla welchi* acted as indicator of preserved areas (Tab.5).

Halophyte-psammophyte vegetation and foredune zone environments

In relation to the environmental type, the indicator species of halophyte-psammophyte vegetation were represented by *Paraxenylla piloua, Austrogastrura travassosi and Friesea mirabilis.* On the other hand, *Xenylla maritima, Mesaphorura yosii, Friesea reducta* and *Pseudachorutes difficilis* were indicators of foredune zone (Tab.6).

Austrogastrura travassosi was the only species that acted as indicator of both halophyte-psammophyte vegetation and impacted areas (see Tabs.5-6).

Relationship between species and environmental parameters

It was not verified significant seasonal pattern for the species studied here, as observed by Pozo (1986), Oliveira & Deharveng (1992) and Fernandes (2001) for the collembolan populations in Spain as well as in Central Amazonian disturbed forests and "Restinga de Itaipuaçu", respectively. A higher abundance of the species *Brachystomella agrosa*, *B. contorta*, *Fissuraphorura cubanica* and *Mesaphorura amazonica* was just verified during the summer months.

The species *Rapoportella pitomboi*, *Maricaella duna* and *Hylaeanura infima*, previously recorded from innerdune zones and flooded areas by Fernandes & Mendonça (2004), had their occurrence extended to the halophyte-psammophyte vegetation and foredune zone environments in the present study. Other species such as *Mesaphorura maricaensis*, *Onychiurus* cf. *mariapetrae*, *Micranurida fluminensis* and *Arlesia intermedia*, which also occupied innerdune zones and flooded areas, were not found in the environments

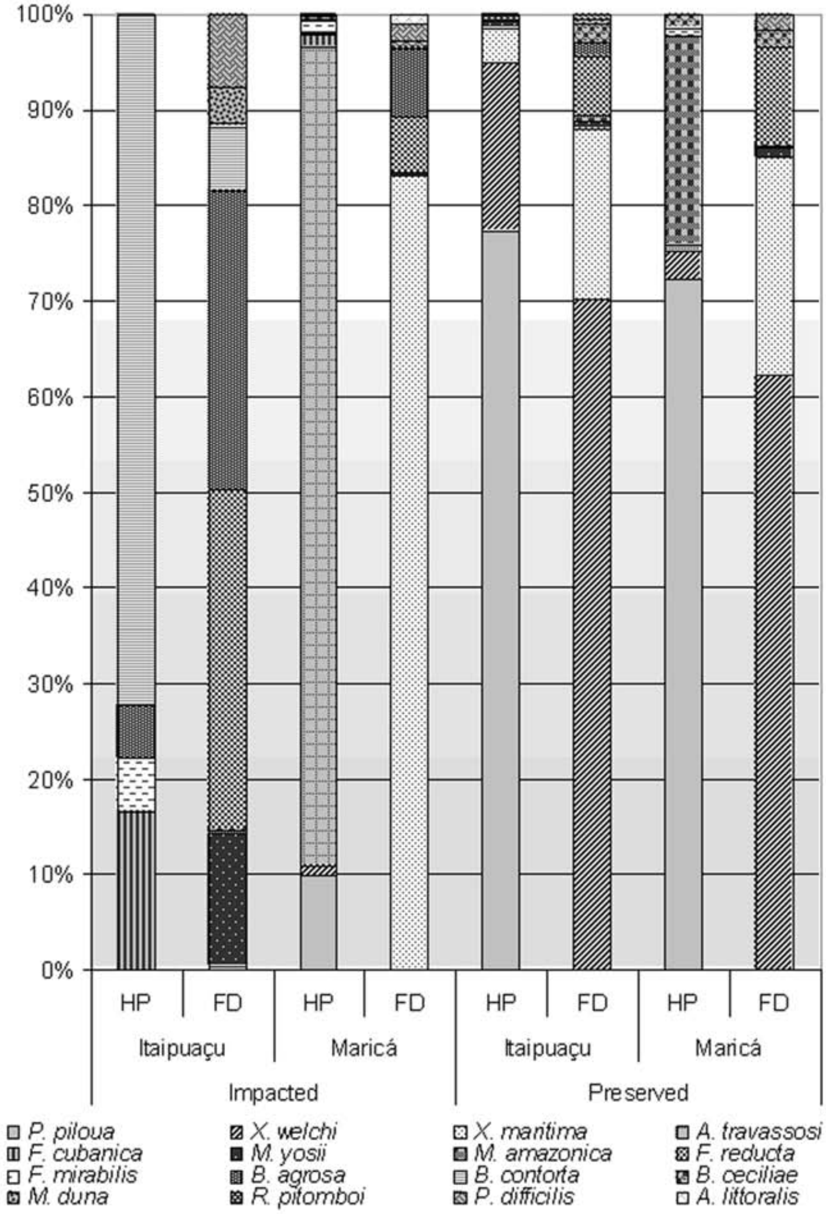

Fig.4- Percentage of Poduromorpha species contribution in sampled areas (Species with ≤ 1% of abundance were excluded).

sampled here; it confirms their preference for the areas they had been found before.

Friesea mirabilis, considered to be ecologically generalist (Hagvar, 1982), was only found in halophyte-psammophyte vegetation where it was named as its own indicator (p=0.0050). Despite its acidophily, predicted by Ácon (1974) and Ponge & Prat (1982), its presence with pH around 7 in halophyte-psammophyte vegetation also indicated a calcium affinity, which was already observed by Hagvar & Abrahamsen (1980). Its occurrence in modified habitats (Greenslade & Deharveng, 1997) was confirmed, in the present study, by the highest abundance in impacted areas. Its presence in beach sand was also signaled in Malta by Thibaud & Christian (1989) and in Lesser Antilles by Thibaud (1993), confirming its preference for sandy environments.

Friesea reducta, already recorded from sand dune substrates in "Restinga de Itaipuaçu" by Fernandes & Mendonça (2004), was found again in the present study, only in the foredune zone out of the four sampled sites where it was named as indicator (p=0,0001).

TABLE 5. Results obtained from the indicator species test of impacted and preserved areas in "Restinga de Maricá".

	IMPACTED	PRESERVED	p *
Friesea claviseta	0	3	0,4870
Friesea magnicornis	3	0	1,0000
Friesea mirabilis	13	0	0,0890
Friesea reducta	20	19	0,9280
Pseudachorutes difficilis	16	8	0,5520
Aethiopella littoralis	11	0	0,1270
Neotropiella sp.	3	0	1,0000
Arlesia sp.	3	0	1,0000
Hylaeanura infima	0	3	0,4630
Brachystomella agrosa	**29**	**0**	**0,0110**
Brachystomella ceciliae	6	19	0,2730
Brachystomella contorta	5	0	0,4790
Maricaella duna	6	1	0,6780
Rapoportella pitomboi	2	3	1,0000
Austrogastrura travassosi	**21**	**0**	**0,0060**
Xenylla maritima	15	15	0,9910
Xenylla welchi	**0**	**49**	**0,0010**
Paraxenylla piloua	9	14	0,6660
Acherontiella globulata	5	0	0,4820
Thalasaphorura sp.	3	0	1,0000
Fissuraphorura cubanica	8	0	0,2340
Mesaphorura amazonica	0	11	0,1290
Mesaphorura yosii	25	6	0,1100
Average	9	7	

Obs.: Significant values of p<0.05 in bold.

TABLE 6. Results obtained from the indicator species test of halophyte-psamophyte vegetation (HP) and foredune zone (FD) in "Restinga de Maricá".

	HP	FD	p *
Friesea claviseta	4	0	0,3600
Friesea magnicornis	4	0	0,3390
Friesea mirabilis	**23**	**0**	**0,0050**
Friesea reducta	**0**	**61**	**0,0010**
Pseudachorutes difficilis	**0**	**37**	**0,0030**
Aethiopella littoralis	0	9	0,2870
Neotropiella sp.	0	2	1,0000
Arlesia sp.	0	2	1,0000
Hylaeanura infima	0	2	1,0000
Brachystomella agrosa	0	25	0,0520
Brachystomella ceciliae	8	14	0,6890
Brachystomella contorta	2	1	1,0000
Maricaella duna	0	11	0,1500
Rapoportella pitomboi	10	0	0,1280
Austrogastrura travassosi	**35**	**0**	**0,0010**
Xenylla maritima	**0**	**45**	**0,0030**
Xenylla welchi	2	25	0,2060
Paraxenylla piloua	**62**	**0**	**0,0010**
Acherontiella globulata	8	0	0,1150
Thalasaphorura sp.	0	2	1,0000
Fissuraphorura cubanica	12	0	0,0550
Mesaphorura amazonica	4	1	0,9880
Mesaphorura yosii	**1**	**35**	**0,0100**
Average	8	12	

Obs.: (HP) halophyte-psammophyte vegetation; (FD) foredune zone. Significant values of p<0.05 in bold.

Its restrict location to the foredune zone of "Restinga de Maricá" diverges from the generalist condition predicted in literature (Massoud & Thibaud, 1980; Thibaud & Massoud, 1983).

Pseudachorutes difficilis, already recorded from sand dune substrate and flood areas of "Restinga de Itaipuaçu" by Fernandes & Mendonça (2004), was only found in the foredune zone out of the four sampled sites where it was named as indicator (p=0.003).

Aethiopella littoralis occurred in the foredune zone of Maricá impacted area, which confirms the previous studies in the region (Fernandes & Mendonça, 2004). These data corroborate its preference for an impacted and sandy environment.

Hylaeanura infima, recorded from innerdune zones and flooded areas of "Restinga de Itaipuaçu" by Fernandes & Mendonça (2004), had its occurrence extended to the foredune zone environment and to the district of Maricá in the present study. Its presence in "restinga" and higrophilus environments such as very humid forest litter and humus in Alto Xingu, Manaus, Belém and Amazonian Peru (Arlé, 1966), in bushy forest litter, cut-down-tree branches, primary and secondary forests, mossy rotten stems in French Guiana (Najt *et al.*, 1990), as well as in degraded forests in Lesser Antilles (Thibaud & Massoud, 1983) emphasizes its wide ecological valence.

Brachystomella agrosa, common in all Neotropical Region and abundant in Brazil, had already been recorded from sand dune sustrates and flooded areas in "Restinga de Maricá" by Fernandes & Mendonça (2004). In the present study, this species was more abundant in the foredune zone of impacted areas; so, it was named as indicator of impacted environment (p=0.011).

Brachystomella ceciliae was found by Fernandes & Mendonça (2004) in sand dune substrates and flood areas of "Restinga de Itaipuaçu", being frequent during the year. In the present study, it presented good distribution in both sampled environments as well as in all the areas, which confirms its stability in the sampled ecosystem.

Brachystomella contorta occurred, in the present study, in impacted areas of "Restinga de Itaipuaçu", both in halophyte-psammophyte vegetation and foredune zone, from which its presence had already been recorded (Fernandes & Mendonça, 2004). This wide geographical distribution and wide ecological valence species (Najt & Palacios-Vargas, 1986) had already been recorded from degraded acacia forest in Jamaica by Massoud & Bellinger (1963), from disturbed areas in Hawaii by Christiansen & Bellinger (1992) and from littoral edaphic successions in Lesser Antilles by Massoud & Thibaud (1980), which suggests that sandy and impacted environments favor colonization by *B. contorta*.

Maricaella duna, previously found in litter and in sand dune soil of "Restinga de Itaipuaçu" (Mendonça & Fernandes, 1997; Fernandes & Mendonça, 2004), acted as characteristic of the environment and the sampled locality again in the present study.

Rapoportella pitomboi, previously recorded from sand dune and flood area substrates of "Restinga de Itaipuaçu" by Fernandes & Mendonça (2004), was found here both in halophyte-psammophyte vegetation and foredune zone environments of preserved and impacted areas. Thus, we dealt with a widely distributed species in "Restinga de Maricá". Curiously, this species was described by Mendonça & Fernandes (1995) who based it on samples collected at high altitudes in "Serra de Itatiaia": they were pink samples, different from the bluish ones of the Restinga.

Austrogastrura travassosi was recorded and re-described by Thibaud & Palacios-Vargas (1999), based on the material collected from the beach sand in Rio de Janeiro (Prainha and Marambaia). In "Restinga de Maricá", it was the most abundant and sometimes it showed formation of aggregates. Besides that, it acted as indicator of both halophyte-psammophyte vegetation (p=0.001) and impacted area (p= 0.006).

Xenylla maritima showed high abundance in "Restinga de Maricá", mainly occurring in foredune zone environments where it was named as indicator (p=0.003). This species had already been recorded by Fernandes & Mendonça (2004) from sand dune and flood areas in "Restinga de Itaipuaçu" where it was the most abundant and frequent of all the Poduromorpha species. The indications here attributed to this species are corroborated by Arbea & Jordana (1991) who highlighted its xerophile condition, abundant presence and small ecological requirement.

Xenylla welchi is generally found in a large number of individuals and forms aggregates (Bandyopadhyaja & Choudhuri, 2002; Thibaud *et al.*, 2004). It occurred in almost all the sampling sites of "Restinga de Maricá" and it was more abundant in preserved areas where it acted as indicator (p=0.001). This indication diverges from the previous records in which its presence was signaled in litter of disturbed areas in Hawaii (Christiansen & Bellinger, 1992) and in cultivated agricultural soils in the State of Espírito Santo (Culik *et al.*, 2002).

Paraxenylla piloua was described by Thibaud & Weiner (1997), based on samples collected from beach sand of New Caledonia. This species was only found in halophyte-psammophyte vegetation in "Restinga de Maricá" where it was named as indicator (with p=0.001). Its high abundance in this environment was verified in both impacted and preserved areas.

Acherontiella globulata, for the first time recorded from sand dune substrate in the region by Fernandes & Mendonça (2004), showed a restrict distribution to halophyte-psammophyte vegetation area in the present study.

Fissuraphorura cubanica, hemiedaphic-psammophyte species, already recorded in Brazil from beach sand of the State of Espírito Santo (Thibaud & Palacios-Vargas, 1999), was verified in halophyte-psammophyte vegetation of impacted areas in the present study. Its occurrence in beach sand recorded in Vietnam (Thibaud, 2002) and French Guiana (Thibaud, 2004), as well as its occurrence in environments modified by human action observed by Rusek (1991) and Mendonça (pers. comm.) in soil and litter of gardens in Cuba and Brazil, respectively, corroborate its presence in environments that are predominantly sandy and impacted.

Mesaphorura amazonica only occurred in the summer months and showed a higher abundance in preserved areas. This occurrence restrict to the summer had already been observed by Fernandes & Mendonça (2004) in sand dune substrate in "Restinga de Itaipuaçu". This species was described by Oliveira & Thibaud (1992) based on samples collected from primary and secondary forest litter in the State of Amazonas; it seems to present an ecological ambivalence for being present in such distinct environments.

Mesaphorura yosii was firstly recorded from beach sand in "Restinga de Maricá" by Thibaud & Palácios-Vargas (1999), and later on by Fernandes & Mendonça (2004) from sand dune substrates and flooded areas in "Restinga de Itaipuaçu". In the present study, this species was well distributed throughout all collected areas, and it was more abundant in the foredune zone environments where it acted as indicator (with p=0.01). This preference for environments with acid pH is corroborated by Hagvar (1990) and Ponge (2000), who characterize it as acidophilic in their studies. Its abundant presence in disturbed environment had already been observed by Oliveira & Deharveng (1995) in Central Amazonia, by Christiansen & Bellinger (1992) in Hawaii as well as in beach sand of New Caledonia (Thibaud & Weiner, 1997), which indicated its preference for sandy and impacted environment.

As it was found only one sample of *Friesea claviseta*, *F. magnicornis*, *Neotropiella* sp., *Arlesia* sp. and *Thalassaphorura* sp., it was not possible to consider their relationships with environmental parameters, but only to record their occurrence in "Restinga de Maricá". Among these, *F. claviseta* had already been recorded from garden soils in Australia (Greenslade & Deharveng, 1997) and from littoral areas of Ireland (Bolger, 1986). The species *F. magnicornis* had also been recorded from gardens in Lesser Antilles (Massoud & Thibaud, 1980) and from the littoral of the Galápagos Islands (Najt *et al.*, 1991).

Canonical Correspondence Analysis

The relationship between the species and the environmental parameters which evidence the differences in community structure of the studied areas was obtained through the Canonical Correspondence Analysis, which was highly significant.

On axis 1, representing 13.6% of the total variation, the element that most influenced species distribution was soil pH which originated the separation of species into two groups (Fig.5).

Friesea mirabilis, Paraxenylla piloua, Acherontiella globulata, Austrograstrura travassosi, Fissuraphorura cubanica, Rapoportella pitomboi and Brachystomella contorta gathered on the left side of the graph; they occurred in halophyte-psammophyte vegetation environment where soil pH was less acid. Among these, *P. piloua*, *A. travassosi* and *F. mirabilis* were considered to be indicators of this environment and *F. mirabilis* was pointed out as calciophilic by Hagvar & Abrahamsen (1980).

Mesaphorura amazonica, M. yosii, Xenylla welchi, X. maritima, Brachystomella ceciliae, B. agrosa, Maricaella duna, Friesea reducta, Pseudachorutes difficilis and *Aethiopella littoralis* gathered opposite the graph. Their distribution through the foredune zone is conditioned by soil lower acidic pH. Among the species mentioned above, *F. reducta*, *P. difficilis*, *X. maritima* and *M. yosii* were still named as indicators of this environment; *M. yosii* has already been pointed out as acidophilic by Hagvar (1990), Ponge (2000) and Kuperman *et al.* (2002).

On axis 2, which represented 6% of the total variation, the elements that mostly influenced the species distribution were soil humidity (SH), Calcium (Ca), Magnesium (Mg) and Potassium (K). The foredune zone environment of Itaipuaçu (IPB) impacted area showed to be strongly related to these elements. This axis even separated the upper parts of preserved areas (Fig.5).

The data related to soil pH, observed here, are in agreement with Thibaud & Christian (1989) who showed the relationship of this element with the collembolan distribution and composition found in the Mediterranean coastal sands. Other authors, such as Pozo (1986), Castaño-Meneses *et al.* (2001) and Cutz-Pool *et al.* (2003) also identified pH as one of the most important elements of soil, able to modify the distribution of organisms and to affect edaphic populations in a heterogeneous way, benefiting some groups and making the most sensitive ones disappear. Species distribution or groups of Collembola species distribution in acid, neutral or alkaline soils may be affected by environmental changes caused by human action, which results in their ecological requirement change (Salmon *et al.*, 2002).

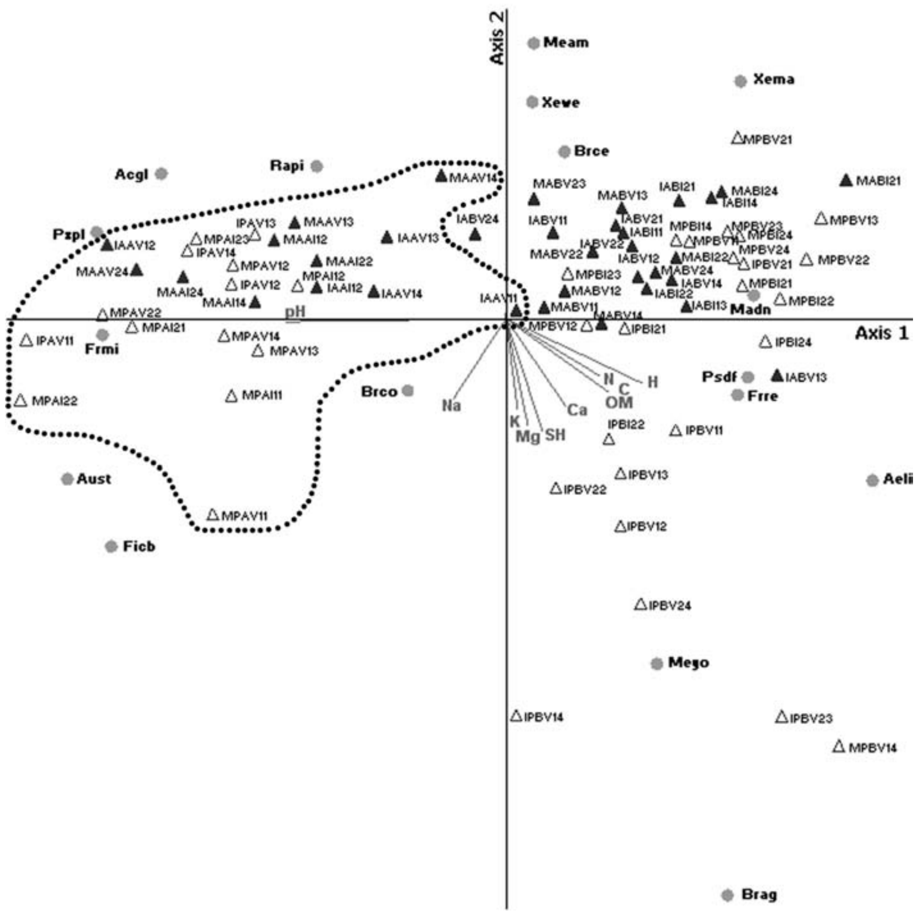

Fig.5- Canonical Correspondence Analysis based on “species versus samples versus abiotic parameters”. Full triangles represent preserved areas; empty triangles represent impacted areas; the triangles inside the dotted area represent halophyte-psammophyte vegetation; circles represent species. (Species: Acgl- *Acherontiella globulata* Thibaud and Massoud, 1980; Aeli- *Aethiopella littoralis* Mendonça and Fernandes, 2002; Aust- *Austrogastrura travassosi* (Arlé, 1939); Brag- *Brachystomella agrosa* Wray, 1953; Brce- *Brachystomella ceciliae* Fernandes and Mendonça, 2004; Brco- *Brachystomella contorta* Denis, 1931; Ficb- *Fissuraphorura cubanica* Rusek, 1991; Frmi- *Friesea mirabilis* (Tullberg, 1871); Frre- *Friesea reducta* Denis 1931; Madn- *Maricaella duna* Mendonça and Fernandes, 1997; Meam- *Mesaphorura amazonica* Oliveira and Thibaud, 1992; Meyo- *Mesaphorura yosii* (Rusek, 1967); Psdf- *Pseudachorutes difficilis* Denis, 1931; Pxsp- *Paraxenylla piloua* Thibaud and Weiner, 1997; Rapi- *Rapoportella pitomboi* Mendonça and Fernandes, 1995; Xema- *Xenylla maritima* Tullberg, 1869; Xewe- *Xenylla welchi* Folsom, 1916. Sampling points: IPA- Itaipuaçu (impacted area), halophyte-psammophyte vegetation; IPB- Itaipuaçu (impacted area), foredune zone; IAA- Itaipuaçu- APA (preserved area), halophyte-psammophyte vegetation; IAB- Itaipuaçu- APA (preserved area), foredune zone; MAA- Maricá- APA (preserved area), halophyte-psammophyte vegetation; MAB- Maricá- APA (preserved area), foredune zone; MPA- Maricá (impacted area), halophyte-psammophyte vegetation; MPB- Maricá (impacted area), foredune zone;V1- rain season 1 (January); V2- rain season 2 (December); I1- dry season 1 (June); I2- dry season 2 (July).

Soil humidity, here evidenced as a determinant element on the composition and structure of the analyzed communities, was in agreement with the observations made by Fjellberg (1985), Pozo (1986), Vegter *et al.* (1988) and Miranda-Rangel & Palacios-Vargas (1992). They evidenced, in their studies, that springtails are very sensitive to humidity variation which strongly affects them.

Since the distinction between halophyte-psammophyte vegetation and foredune zone environments was evidenced, a new Canonical Correspondence Analysis was performed in order to try to establish a closer relationship of species with abiotic parameters within each environment.

In relation to the halophyte-psammophyte vegetation environment, axis 1 (representing 11.3% of variation) partially separated the preserved areas on its left side, except for one of them in Maricá (MAAI12) (Fig.6). On this axis, the most important elements were Magnesium (Mg), Calcium (Ca) and Hydrogen (H).

On axis 2 (representing 7.4% of variation), the elements that most influenced the species distribution were pH and Hydrogen (H).

In relation to the foredune zone, axis 1 (representing 12.8% of variation) separated the preserved areas on its right side, except for one sample in Itaipuaçu (IABV13) (Fig.7). Among the impacted areas, the samples of Itaipuaçu (IPB) split from the others. On this axis, the elements that most influenced species distribution were soil humidity (SH), Magnesium (Mg), Sodium (Na) and Potassium (K).

On axis 2 (representing 7.9%of variation), again the elements that mostly influenced species distribution were pH and soil humidity (SH).

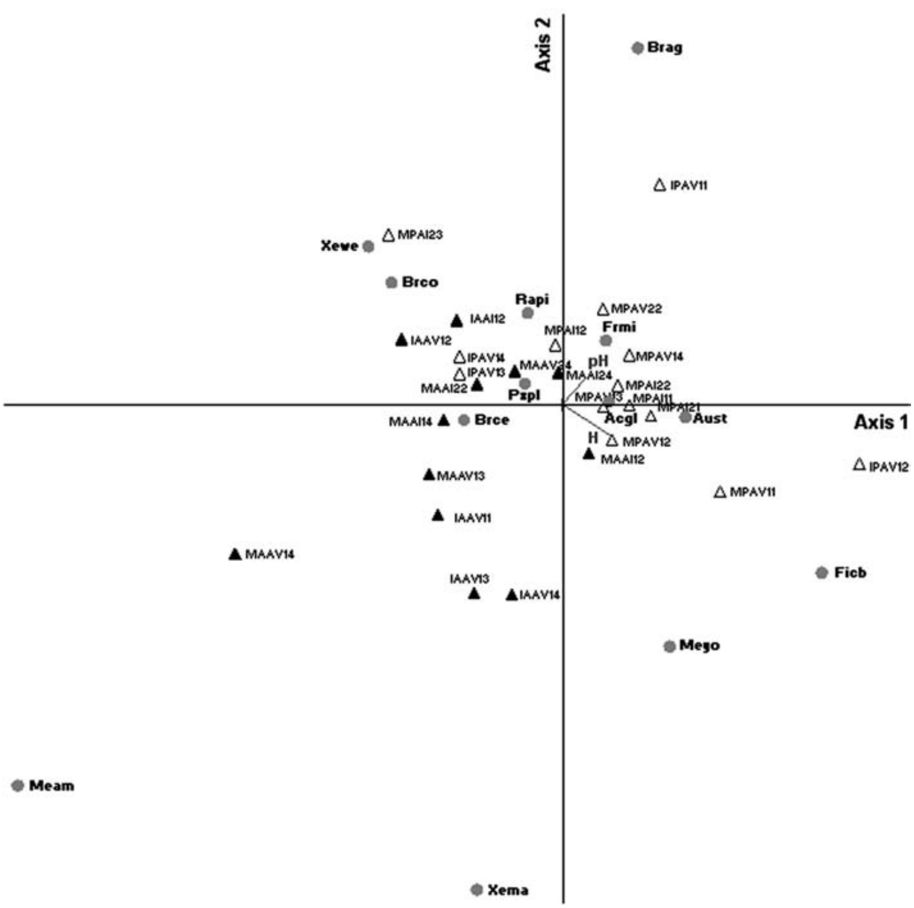

Fig.6- Canonical Correspondence Analysis based on “species versus samples of the halophyte-psammophyte vegetation versus abiotic parameters”. Full triangles represent preserved areas; empty triangles represent impacted areas; circles represent species.

Fig.7- Canonical Correspondence Analysis based on "species versus samples of the foredune zone versus abiotic parameters". Full triangles represent preserved areas; empty triangles represent impacted areas; circles represent species.

From the results obtained through Canonical Analyses, we can affirm that the faunal variability was kept in preserved areas in each environment (halophyte-psammophyte vegetation and foredune zone), and the determinant elements on species distribution were represented by soil humidity, pH and base content.

Representing the first essay on the use of Order Poduromorpha species and on the management of preserved and impacted "restingas" ecosystems; this article improved the knowledge of this Order and enlarged the number of species recorded from Brazil. Future studies aiming a survey of Poduromorpha in other "restingas" will be of great importance to the studies of systematic, structure comparison and composition, as well as the use of indicator species on recovery of impacted areas.

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