HYDROGRAPHY AND ZOOPLANKTON COMMUNITY STRUCTURE: A COMPARATIVE STUDY AMONG ESTUARIES OF THE JURÉIA-ITATINS ECOLOGICAL STATION (SOUTHEASTERN BRAZIL)

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INTRODUCTION

The Juréia-Itatins Ecological Station covers the eastern limit of the Ribeira Lowland (Fig. 1), an hydrographic basin containing the larger Ribeira do Iguape River, its tributaries and a network of coastal rivers, tidal creeks and mangrove estuaries bordering the coastline of southern São Paulo State (AbSaber, 1985; Lopes & Por, 1990). The station was established in 1979 to preserve continuous areas of the Atlantic Rainforest in southeastern Brazil (Por & Fonseca, 1984).

The river typology of the Baixada Lowland has been studied by Por (1984) and Lopes & Por (1990) who reported the occurrence of clearwater, blackwater and whitewater river types differing in their general hydrodynamic features, ionic composition, pH regime and land-water interactions. The composition of the aquatic biota also varies among river types (Por & Lopes, 1994). The hydrodynamics and plankton distribution of these rivers are greatly influenced by semidiurnal tides, which lead to strong gradients of physical, chemical and biological properties.

Previous investigations on the zooplankton distribution in the Juréia-Itatins station were carried out separately in each of the main river estuaries, usually with a 1-year interval between surveys (Lansac-Tôha & Lima, 1992; Lopes, 1994; Lopes *et al.*, 1986). Therefore, it is presently difficult to discriminate the reported spatial and

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seasonal variations in the zooplankton community structure from possible interannual variations. The objective of this paper is to analyse the zooplankton community structure of the main river estuaries of the Juréia-Itatins Station in relation to the spatial distribution of physical and chemical properties, during a restricted period of the year (wintertime).

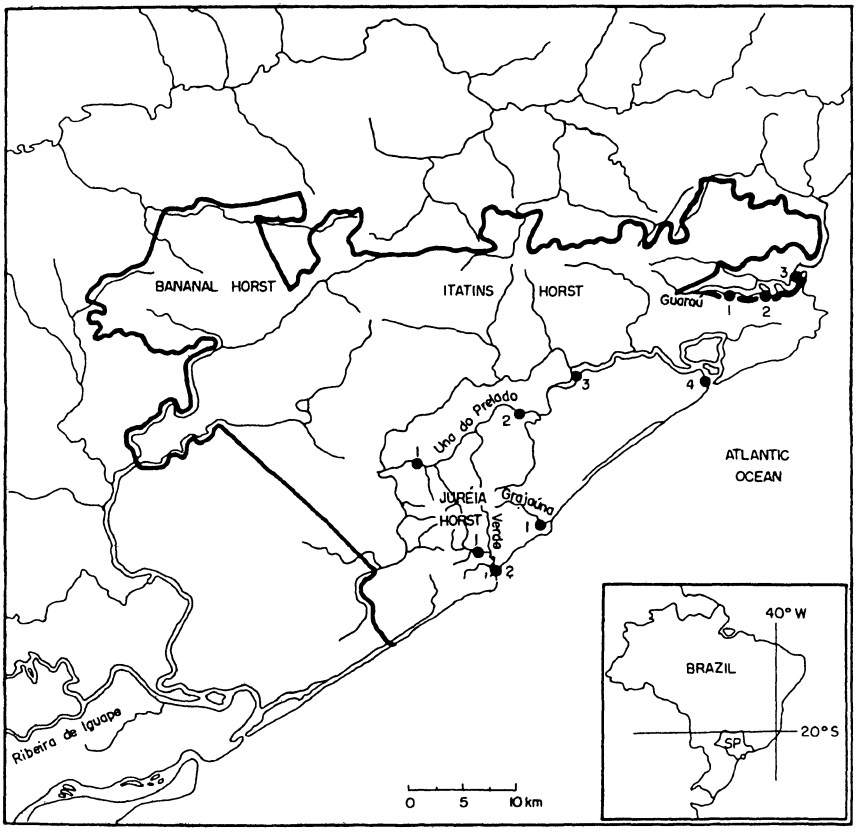

Fig. 1
Map of the study area showing the station positioning in the river estuaries and the limits of the Juréia-Itatins Ecological Station (heavy lines).

MATERIAL AND METHODS

The largest river estuaries of the nature reserve, namely Guaraú, Una do Prelado (henceforth Una), Verde and Grajaúna River estuaries were sampled from August 25 to 27, 1987 (winter period). Guaraú and Verde are clearwater rivers while Una and Grajaúna are blackwater rivers (Por, 1986). Sampling was carried out at 10 stations (Fig. 1) during both flood and ebb tides, except in Grajauna River, where only one station was sampled, during low tide.

Zooplankton samples were obtained at the surface and 0.5 m above the bottom by pouring 12 to 120 liters of water collected with a 6-liter Van Dorn bottle into a 75 µm conical net. Qualitative zooplankton samples were collected by towing a conical net similar to that described by Fraser (1966) in the surface layer and a sledge net (Dietz, Almeida Prado, 1973) in bottom waters. Both nets had a similar opening and a 75 µm mesh screen. The samples were preserved in 4% buffered formaldehyde. Both quantitative and qualitative samples were analysed without sub-sampling. The quantitative samples were counted to calculate the absolute and relative abundance of the zooplankton, the former as number of individuals per cubic meter and the latter as percentage. The relative abundance of organisms collected by net tows (qualitative samples) was also calculated. A comparison of the relative abundance between each sample pair (bottle/net tows) showed that only fish larvae were undersampled by bottle sampling. Thus, mesozooplankton collected with the Van Dorn bottle was considered representative of natural assemblages.

Water temperature and salinity were measured with a Kahlsico RS5-3 thermosalinometer and pH with a portable B-278 Micronal pHmeter. Water samples for determination of dissolved oxygen (Winklers method; Grasshoff *et al.*, 1983), chlorophyll and inorganic nutrient concentration (Strickland & Parsons, 1968) were obtained with the Van Dorn bottle at the same depths sampled for zooplankton.

A cluster analysis was performed on the correlation matrix of biotic data using the average linkage method, to characterize the zooplankton assemblages. Principal component analyses (Legendre & Legendre, 1984) were performed to identify and to explain the main trends of variability in both data sets (zooplankton abundance and environmental variables). The zooplanktonic *taxa* that occurred in less than 10% of the samples were excluded from the analysis. The biotic data was standardized and transformed ($\ln x + 1$), while raw data was used in the case of physical and chemical variables.

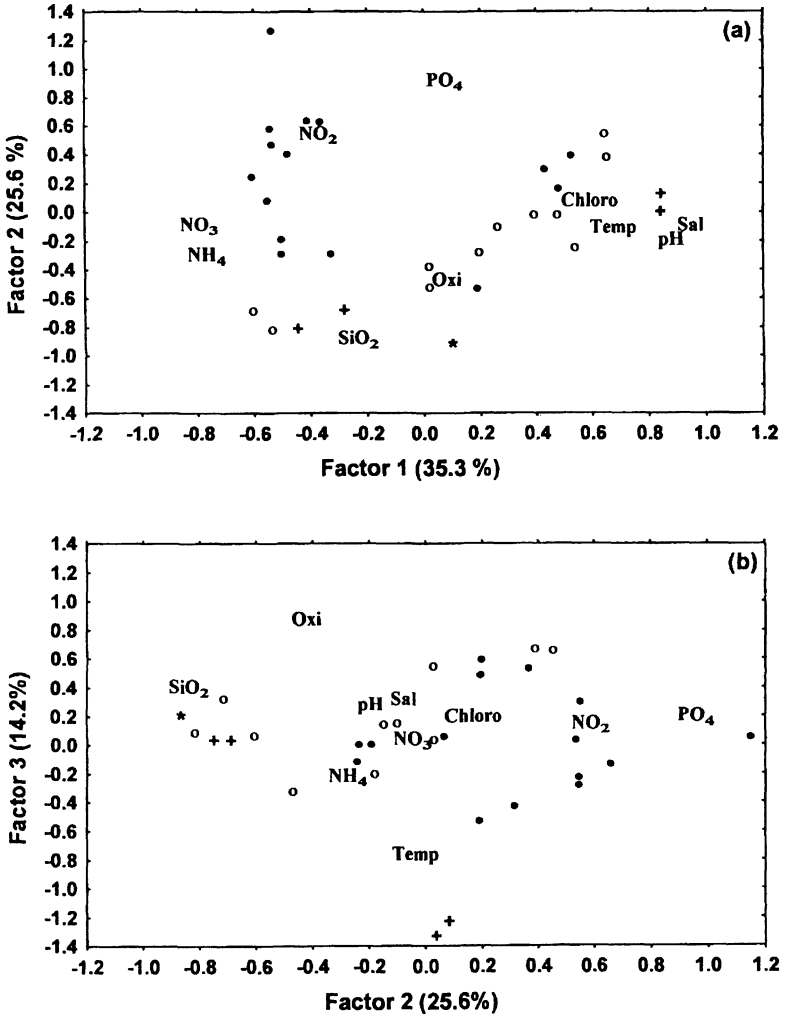

Fig. 2
Principal component analysis of hidrographical data; (a) components 1 and 2; (b) components 2 and 3. Symbols: Black dots = Una River; Open circles = Guaraú River; Crosses = Verde River; Asterisk = Grajaúna River.

RESULTS

Hydrography

Table 1 shows mean values observed for physical and chemical variables and also for total zooplankton abundance. Salinity varied from 1.5 or less (minimum of 0.01) to more than 33.5 (maximum of 35.3) in each estuary, including the short (3km) Verde River estuary. The salinity gradient had a major influence on the spatial distribution of several variables, and explained 35.3% of the total variance in Factor 1 of PCA (Fig. 2a).

Temperature, pH and chlorophyll were positively associated with salinity while nitrate and ammonia were negatively correlated with salinity (*Pearson's r = 0.05*). Total phosphate, nitrite, silicate and dissolved oxygen were uncorrelated with salinity distribution. Factor 2 (explaining 25.6% of the variance) separated the low-salinity stretches of Una River, with high phosphate, nitrite, nitrate and ammonia concentration, from the low-salinity stretches of Guaraú and Verde rivers, containing higher silicate and dissolved oxygen concentration than in Una River. Therefore, this axis represents the differences in the chemical composition of blackwater and clearwater rivers. Vertical stratification of most variables was pronounced in the Verde River estuary but not in Guaraú and Una rivers. Indeed, Factor 3 (14.2% of the total variance) was a component of vertical stratification, indicating that the vertical salinity gradient observed in the Verde River estuary was accompanied by a strong thermal and oxygen stratification (Fig. 2b). For example, at station 1 in Verde River, surface temperature was 6.3°C colder than at the bottom, which in turn had oxygen concentrations as low as 1.50 ml/l. This strong vertical variability is also pointed out by the high standard deviations recorded for several environmental variables in Verde River, especially at station 1 (Table 1).

Zooplankton composition and distribution

The copepods had the highest species richness among the holoplankton (Table 2). Local species are common in Brazilian tropical and subtropical estuaries (Almeida Prado-Por & Lansac-Tôha, 1984; Björnberg, 1981; Lopes, 1994) and ranged from true estuarine (e.g., *Pseudodiaptomus richardi*) to stenohaline marine species (e.g., *Eucalanus pileatus*, *Corycaeus giesbrechti*). Freshwater copepods were mostly tychoplanktonic forms, such as the cyclopoids *Halicyclops* spp. and harpacticoids like *Metis* and *Darcythompsonia*. Other holoplanktonic groups were composed mainly by euryhaline marine species such as the cladoceran *Penilia avirostris*, the appendicularian *Oikopleura dioica* and the arrow worms *Sagitta friderici* and *S. enflata*. However, these groups were not as diverse and abundant as the copepods. The dominant meroplanktonic organisms were polychaete larvae and barnacle nauplii which occurred in all stations subjected to seawater intrusion.

Table 1 - Environmental data and total zooplankton abundance (averages, with standard deviatinons in parenthesis) recorded at the 10 stations of the river estuaries in the Juréia-Itatins area (37 observations from surface and bottom samples, obtained during high tide and low tide). Data form Grajaúna River represent single observations; n.d. = no data. Salinity values are expressed according to the Practical Salinity Scale (UNESCO, 1984).

River/ station	Temperature (°C)	salinity	pH	Dissolved oxygen (ml/l)	Chlorophyll (mg/l)	PO_4 (μM)	NO_2 (μM)	NO_3 (μM)	NH_4 (μM)	SiO_2 (μM)	Total zooplankton ($ind.m^{-3}$)
Verde 1	21.67	17.12	7.25	3.78	1.69	0.26	0.06	1.06	0.13	38.87	45,516
	(3.14)	(18.23)	(0.95)	(2.59)	(1.88)	(0.10)	(0<01)	(1.24)	(0.07)	(4.82)	(50,682)
Verde 2	21.40	17.47	7.52	5.10	1.87	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	(2.17)	(17.30)	(1.25)	(0.83)	(1.98)						(61,392)
Guaraú	(18.82)	2.75	6.60	4.94	3.85	0.23	0.09	2.02	0.15	47.51	10,241
	(0.66)	(2.60)	(0.28)	(0.89)	(0.45)	(0.04)	(0.01)	(0.46)	(0.04)	(17.44)	(8,270)
Guaraú 2	19.80	17.12	7.85	4.35	7.77	0.30	0.11	1.91	0.12	21,43	18,645
	(0.42)	(7.64)	(0.47)	(0.45)	(2.42)	(0.09)	(0.02)	(0.48)	(0.08)	(8.97)	(18,671)
Guaraú 3	19.60	30.25	8.62	5.33	6.89	0.57	0.08	0.47	0.04	24.92	42,454
	(0.94)	(6.23)	(0.09)	(0.13)	(1.17)	(0.20)	(0.02)	(0.46)	(<0.01)	(6.31)	(37,260)
Una 1	18.65	0.05	5.42	2.92	2.20	0.67	0.11	3.88	0.40	18.60	3,902
	(0.41)	(0.10)	(0.10)	(0.27)	(1.08)	(0.03)	(0.01)	(1.82)	(0.28)	(2.16)	(1,216)
Una 2	18.72	0.22	5.50	3.17	1.65	0.56	0.32	8.63	0.61	19.93	12,873
	(0.05)	(0.05)	(0.08)	(1.24)	(0.81)	(0.18)	(0.42)	(9.82)	(0.46)	(6.98)	(14,314)
Una 3	18.60	2.70	5.95	4.39	1.59	0.48	0.07	2.79	0.52	27.07	12,383
	(0.35)	(2.66)	(0.06)	(0.07)	(0.21)	(0.25)	(0.01)	(1.53)	(0.44)	(5.65)	(9,284)
Una 4	19.40	33.80	8.80	5.26	1.92	0.60	0.06	0.90	0.13	25.08	58.879
	(0.69)	(0.00)	(0.11)	(0.17)	(0.58)	(0.21)	(0.01)	(1.28)	(0.10)	(7.47)	(3.699)
Grajaúna 1	19.50	26.1	7.20	5.01	2.40	0.18	0.07	1.29	0.20	78.90	18,667

Table 2 - List of zooplankton *taxa* recorded in the river estuaries of the Juréia – Itatins area during the studied period. Symbols used in the PCA are shown in parenthesis.

Holoplankton

Copepoda
- *Eucalanus pileatus* (Ep)
- *Paracalanus quasimodo* (Pq)
- *P. crassirostris* (Pc)
- *Temora stylifera*
- *Centropages velificatus*
- *Pseudodiaptomus acutus* (Pa)
- *P. richardi* (Pr)
- *Acartia lilljeborgi* (Al)
- Oithoma hebes (Oh)
- *O oswaldocruzzi* (Ow)
- *O. plumifera*
- *Tropocyclops prasinus* (Tp)
- *Microcyclops anceps*
- *Halicyclops bjornbergae* (Hb)
- *Halicyclops* sp 1
- *Saphirella* sp.
- *Ergasilidae* sp 1-3
- *Oncaea curta*
- *O. media* (Om)
- *O. subtilis*
- *Corycaeus giesbrechti*
- *Euterpina acutiofrons* (Ea)
- *Tisbella* sp (Tb)
- *Metis* sp.
- *Darcythompsonia* sp. (Da)

Harpacticoida sp 1-3

Foraminifera

Acantharia

Tintininnina
- *Eutintinnus lusus-undae*
- *Favella ehrenbergi* (Fe)
- *Leprotintinnus nordqvisti*
- *Tintinnopsis* spp. (Ti)

Hydromedusae

Siphonophora

Turbellaria – Acoela (Ac)

Rotifera
- *Brachionus falcatus*
- *Lepadella patela*
- *Synchaeta bicornis* (Sb)
- *Synchaeta* sp 1 (Ss)

Nematoda

Halacaridae

Cladocera
- *Penilia avirostris*
- *Bosminopsis deitersi* (Bd)

Chydoridae (Ch)

Decapoda
- *Lucifer faxoni*

Ostracoda

Tanaidacea
- *Kalliapseudes schubarti*

Amphipoda

Epicaridae sp 1-2

Appendicularia
- *Oikopleura dioica* (Oi)

Chaetognatha
- *Sagitta friderici* (Sf)
- *S. enflata.*

Meroplankton

Gastropoda (Ga)

Bivalvia (Bi)

Polychaeta (Po)

Cirripedia (Ci)

Brachyura (Br)

Insecta

Chironomidae (Ch)

Culicidae

Ephemeroptera (Eh)

Trichoptera

Echinodermata (Ed)

Piscis – eggs and larvae

The numerical abundance of total zooplankton varied from 567 to 124,533 organisms m^{-3}. Higher concentrations were associated with higher salinities, i.e., the abundance of organisms increased seawards in Guaraú River and Una River and was higher in the bottom waters of Verde River.

Distinct zooplanktonic associations were observed in each of the river estuaries, as shown by cluster analysis (Fig. 3). The calanoid copepod *P. richardi* dominated at the low-salinity areas of both Guaraú River and Una River, attaining higher abundance in the latter. Therefore, *P. richardi* appears in group A of the cluster analysis together with other representative *taxa* of the inner stations of Una River (st. 1-3), namely the copepods *Tropocyclops prasinus* and *Darcythompsonia* sp., cladocerans including *Bosminopsis deitersi* and chydorids, and insect larvae of ephemeropterans and chironomids. In the Guaraú River (st. 1), *Pseudodiaptomus richardi* was associated with the copepods *Oithona oswaldocruzi* and *Halicyclops bjornbergae* and with the rotifer *Synchaeta bicornis*, which formed the group B in cluster analysis. There were no freshwater or typical estuarine plankton (*sensu* Jeffries, 1967) associated with the thin (< 0.5 m) surface water layer of near-zero salinity observed in the Verde River estuary. Estuarine-marine and marine-euryhaline species, such as the tintinnids *Favella ehrenbergi* and *Tintinnopsis* spp., the copepods *Oithona hebes*, *Acartia lilljeborgi* and *Tisbella* sp., the appendicularian *Oikopleura dioica*, the rotifer *Synchaeta* sp. and acoel turbellarians represented the zooplanktonic association of this river estuary (group C1 of cluster analysis), occurring only in the high-salinity bottom waters. The copepods *Acartia lilljeborgi* and *Oithona hebes* were also observed in the other estuaries, but at much lower abundances as compared to Verde River. The *taxa* associated with the outer stations of Guaraú (st. 2 and 3) and Una (st. 4) estuaries were basically the same, corresponding to group C2 of the cluster analysis (Fig. 3). However, the two sub-groups formed by *Sagitta friderici* and *Paracalanus quasimodo*, and by brachyuran zoeae, cirripede nauplii and polychaete larvae, were more strongly associated with the outer stations of Una and Guaraú rivers, respectively. The remaining species had similar abundances in both estuaries.

The PCA computed for the biological data shows the positioning of the above-mentioned associations in relation to the points-objects corresponding to the zooplankton samples (Fig. 4). Each component of this analysis matches the previous interpretation suggested for the environmental variables. Factor 1 (31.2% of variance explanation) represents the salinity gradient affecting the zooplankton distribution. Factor 2 (14.1%) is related to the distinct associations found at low-salinity areas of blackwater and clearwater estuaries. Factor 3 (12.0%) indicates the influence of vertical stratification on the zooplankton composition of the Verde River estuary.

DISCUSSION

Hydrography

Since the river estuaries of the Juréia-Itatins area are short and empty directly into the sea, their whole extension is under the combined influence of semi-diurnal tides and freshwater discharge (Lopes & Por, 1990; Por et al., 1984), which ultimately determine the observed high salinity variations. The salinity gradient was predominantly vertical in the Verde River, in opposition to the horizontal pattern verified in Guaraú and Una River estuaries. This was probably due to the occurrence of a sandy bar in its mouth, limiting tidal movement and water exchange between the river and the adjacent sea. Indeed, during the present survey the mouth of Verde River was about 1.5 m wide and 0.5 m deep, and only a thin layer of cold (~18.5 °C) freshwater originated in the upper stretch was flowing out to the sea. Therefore, in this case water column stability may have contributed to the development of the salinity vertical stratification and the associated low-oxygen concentrations close to the bottom. This seems to be a recurrent situation in the Verde River estuary during the dry winter period (Lopes *et al.*, 1986).

Differences in the chemical properties at the low-salinity sections of the estuaries agree with previously reported characteristics of blackwater and clearwater stream. Both river types are chloride-dominated and poor in ionic content as compared to the well-buffered whitewater rivers, such as the Ribeira do Iguape River (Lopes & Por, 1990; Por, 1986). However, blackwater streams are strongly influenced by the podzolic soils of the post-Pliocenic alluvial plain, which contribute with high amounts of humic and fulvic substances. Thus, it is likely that the high concentrations of phosphorus and nitrogen (in the form of NO^{-}_2, NO^{-}_3 and NH^{+}_4) found at the inner stations of Una River are connected to decomposition processes of organic matter. In contrast, clearwater streams are originated on Pre-Cambrian horsts, whose soil is extremely lixiviated but rich in minerals composed by a high proportion of silica in a relatively soluble form (e.g., feldspars; Bigarella, 1978). This might explain the higher concentrations of silicate found in the well-oxygenated waters of Guaraú River (st. 1) and Verde River (surface water of both stations) together with the observed low phosphorus and nitrogen content, as shown by the PCA.

Zooplankton community

Distinct zooplanktonic associations were recorded at the low-salinity areas of the Una and Guaraú river estuaries while near-zero zooplankton densities were observed at the thin freshwater layer occurring in the Verde River estuary. Although the spatial distribution of zooplankton showed a close relationship with most physical and chemical properties, as demonstrated by the PCA, the analyzed abiotic factors might not explain alone the occurrence of different populations in these closely situated river

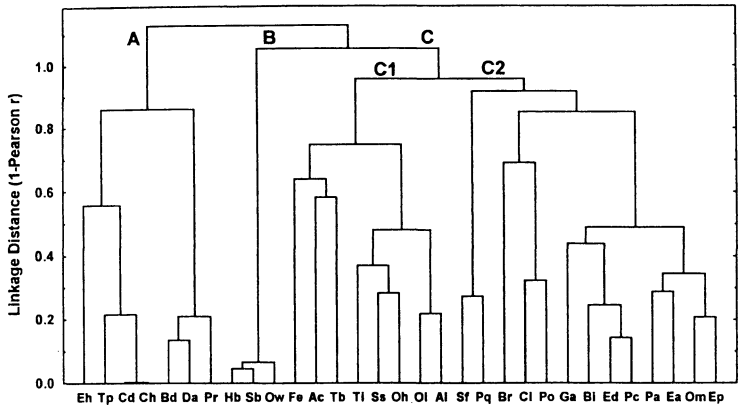

Fig. 3

Cluster analysis of the dominant zooplankton *taxa*. Letters A-C refer to the main zooplanktonic associations recorded in the 4 river estuaries during the studied period. Species symbols are explained in Table 2.

estuaries. The effect of river size on the structuring of zooplankton communities in the Atlantic lowland may be as important as the influence of other abiotic factors (Brönmark *et al.*, 1984). It is to be expected since river size influences estuarine hydrodynamics, which in turn affects the transport of planktonic populations together with physical and chemical properties. This is exemplified by comparing the studied river estuaries.

The short (~3 km) Verde River estuary is strongly influenced by the sea and most of its water column is dominated by high (30) salinity water (Lopes *et al.*, 1986). Short river estuaries emptying directly into the sea, like Verde River, do not support permanent populations of freshwater or typical estuarine zooplankton, including here the copepod *Pseudodiaptomus richardi*. Guaraú River estuary (~15km long) has a near-permanent oligohaline stretch (Lopes, 1994; present study) which provides a habitat for estuarine species such as *P. richardi* (the dominant one), *Synchaeta bicornis*, *Oithona oswaldocruzi* and *Halicyclops* spp. Una River estuary (~80 km long) is apparently large enough to stand for permanent freshwater populations.

However, most taxa recorded at the inner stations of Una River corresponded to a typical drifting community (the kinon community of Fittkau, 1977). This gives further support to the idea that the low pH and high humic acid content of blackwater rivers such as Una River affects negatively the development of planktonic populations (Lopes & Por, 1990; Por, 1986; Por *et al.*, 1984). In this case, most of the aquatic fauna seems to be confined to the well-buffered micro-habitat provided by macrophyte roots (Lopes & Por, 1990). The low diversity and abundance of the planktonic biota in blackwaters are well documented in the Amazonian rivers (Sioli, 1984), but the ultimate causes for

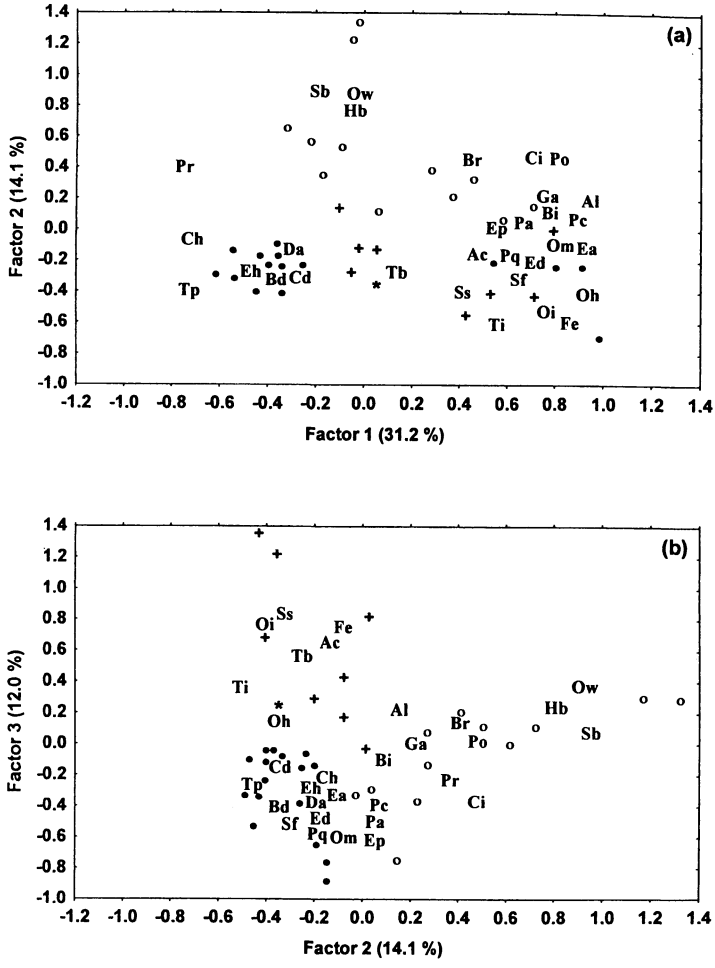

Fig. 4
Principal component analysis of zooplankton abundance data; (a) components 1 and 2; (b) components 2 and 3. Symbols of point-objects as in Figure 2. Abbreviations used for the variables are explained in Table 2.

this phenomenon are still under debate (see Walker, 1987). This points out the need for detailed experimental work on the physiological responses of zooplanktonic organisms to high humic acid concentrations.

Lopes & Por (1990) mentioned that the zooplankton composition is relatively similar in the high-salinity sections of the river estuaries of the Juréia-Itatins area. Accordingly, most estuarine-marine and marine-euryhaline species grouped together in the cluster analysis (Fig. 3), but the results also suggested that significant differences may occur in certain periods of the year. This was the case for species forming group C1 of the cluster analysis, including tintinnid ciliates, appendicularians, acoel turbellarians and three species of copepods. These species were closely associated with the low-oxygen bottom layers of the Verde River, occurring at low densities in the other estuaries. The high abundance of these zooplankters was possibly related to high numbers of pico- and nanoplanktonic organisms that comprise their direct or indirect food source (see Lopes, 1994). Thus, the observed low oxygen concentrations, associated with limited water circulation and strong thermohaline stratification, might have favored the development of a microbial-based food web in the Verde River estuary during the studied period. Seasonal differences in the zooplankton community structure among river estuaries of the Atlantic lowland are therefore to be expected, especially in the areas more strongly influenced by the sea.

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ABSTRACT

The spatial distribution of zooplankton and hydrographical variables was investigated in the larger river estuaries of the Juréia-Itatins Ecological Station and compared through multivariate analysis. The distribution of most abiotic and biotic descriptors paralleled the salinity gradient, which explained a high percentage of the observed variance. The low-salinity stretches of clearwater rivers presented low phosphorus and nitrogen but comparatively high silicate concentrations, the opposite occurring in equivalent areas of blackwater rivers. Distinct zooplanktonic associations occurred in each river estuary. The copepod *Pseudodiaptomus richardi* dominated in the inner reaches of Guaraú and Una rivers, but this species was accompanied by different associations in each of these systems. No freshwater or typical estuarine species occurred in Verde River estuary. Only slight differences were observed between Guaraú and Una River estuaries regarding the estuarine-marine and marine-euryhaline biota. On the other hand, the dominant

estuarine-marine species that occurred in Verde River estuary were not abundant in the other estuaries. The present results suggest a major influence of chemical properties and river size on the distribution of estuarine zooplankton communities along the Brazilian coast.

Key words: Zooplankton, estuaries, distribution, hydrography, Brazil.

RESUMO

Hidrografia e estrutura da comunidade zooplanctônica: um estudo comparativo de estuários da Estação Ecológica de Juréia-Itatins (Brasil). A distribuição espacial do zooplâncton e de variáveis hidrográficas foi investigada nos principais estuários da Estação Ecológica de Juréia-Itatins e comparada através de técnicas multivariadas. A distribuição da maioria dos descritores bióticos e abióticos acompanhou o gradiente de salinidade, que explicou uma alta porcentagem da variância. Nos trechos de baixa salinidade dos rios de águas claras ocorreram concentrações baixas de fosfato e nitrogênio, associadas com concentrações comparativamente altas de silicato. O oposto foi observado em áreas equivalentes dos rios de águas pretas. Diferentes associações zooplanctônicas ocorreram em cada rio. O copépode *Pseudodiaptomus richardi* dominou nos setores mais internos dos rios Guaraú e Una, mas foi acompanhado por associações distintas em cada um dos sistemas. Não ocorreram espécies tipicamente estuarinas ou de água doce no estuário do rio Verde. Foram notadas somente pequenas diferenças entre os estuários dos rios Guaraú e Una, com relação à biota estuarino-marinha e marinho-eurihalina. Por outro lado, as espécies estuarino-marinhas dominantes no estuário do rio Verde não foram abundantes nos demais estuários. Estes resultados sugerem que as propriedades hidroquímicas e o tamanho do rio exercem uma influência importante sobre a distribuição das comunidades zooplanctônicas nos ambientes estuarinos da costa do Brasil.

Palavras-chave: zooplâncton, estuários, distribuição, hidrografia, Brasil

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