INFLUENCE OF PHYSIOGRAPHY AND HUMAN ACTIVITY ON LIMNOLOGICAL CHARACTERISTICS OF LOTIC ECOSYSTEMS OF THE SOUTH COAST OF SÃO PAULO, BRAZIL.

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ABSTRACT: Influence of physiography and human activity on limnological characteristics of lotic ecosystems of the south coast of São Paulo, Brazil. In the present paper the physico-chemical characteristics of several rivers from the south coast of São Paulo, which have different colours of water (clear, black and white) and different degress of salinity, were measured. Throughout their length the rivers under study run through areas with distinct physiographical features (altitude, vegetation, geology, antropic impact, etc) and their limnological characteristics are similary distributed in well defined source-mouth gradients. The correlation obtained between two similarity matrices, one based on limnological data and the other on physiographical information, was significant ($p<0.0012$). It is concluded that physiography is the main factor determining the limnological characteristics of the individual rivers. However, in the rivers receiving sewage, pollution is the main factor influencing the limnological parameters.

Key words: limnological characteristics, lotic ecosystems, physiography, hydrographic basin, São Paulo south Coast, Brazil.

RESUMO:Influência da fisiografia e da atividade humana nas características limnológicas de sistemas lóticos do litoral sul de São Paulo, Brasil. Neste trabalho foram medidas variáveis físico-quimicas em alguns rios do litoral sul Paulista que apresentam águas de diferentes cores (claras, pretas e brancas) e diferentes graus de salinidade. Os resultados das variáveis limnológicas evidenciaram um gradiente bem definido nos rios, relacionado com o eixo nascente-foz. Os rios estudados percorrem áreas com características fisiográficas (relevo, vegetação, geologia e impactos antrópicos) distintas, que também se distribuem ao longo deste eixo. A correlação obtida entre duas matrizes de similaridade, baseadas em dados limnológicos e dados fisiográficos, foi significativa ($P<0.0012$) indicando que a fisiografia é o principal fator responsável pelas características limnológicas dos rios. Nos rios submetidos ao lançamento de esgotos orgânicos, no entanto, a poluição é o principal fator determinante das características limnológicas.

Palavras-chave: características limnologicas, lotic ecossistemas lóticos, fisiografia, bacia hidrográfica, costa sul de São Paulo, Brasil.

INTRODUCTION

Fluvial ecosystems have an enormous surface of interaction with terrestrial ecosystems (Margalef, 1983) thus the physico-chemical properties of its waters are directly related to the terrestrial areas drained by them (Payne, 1986). As an example, it was show by Gibbs (1967) that the different colors of the waters (black, white and clear) from the rivers of the Amazon basin are determined by the geological characteristics of the drained areas. The rivers with black waters run through areas where podsol soil prevails (Klinge, 1967), those with white waters originate in the Andes territory (Terciary) while rivers with clear water arise in the Pre-Cambrian range of the Guiana and Brasilian Central plateaux (Sioli, 1984). More recently, Forsberg *et al* (1988) used alkalinity of the water of Amazonian "várzea" lakes as a parameter to determine their origin. According these authors, this parameter is conservative in the region and reflected the characteristics of the river basin or the characteristics of the catchment area of the lake. Other authors (Skoulikidis, 1993; Colonnello, 1993; Sabater *et al*, 1993) have demonstrated the relationship between physiography (lithology, geomorphology, climate, petrography, pollution, human activity) with the limnological characteristics of the rivers.

In the south coast of the state of São Paulo, there are many small and medium sized hydrographic basins. The rivers of these basins drain and pass through very differents areas in terms of altitude, geology and vegetation and are also influenced to varying degrees by both the sea and man. As a result, the individual rivers exhibit special characteristics, and can be broadly classified as black, white, and clear waters rivers and tidal creeks.

There is little information in the literature about the ecology of these rivers in the south coast of São Paulo, although the region has a large diversity of lotic environments with specific physico-chemical characteristics (Por *et al.*, 1984; Por, 1986; Navarra, 1986). The present paper reports on the different physico-chemical characteristics of rivers from the south coast of São Paulo, compares the properties of their water and relates these parameters with the physiographical characteristics of the regions from which they originate.

STUDY AREA

Two areas, in the municipal district of Cananéia and Itanhaém, from the south coast of São Paulo were studied (Fig. 1). The rivers Olaria, Jacó and Perequê were studied in the first region and the rivers Itanhaém, Preto, Branco, Mambu, Aguapeú, Guaú and Campininha in the latter.

In the district of Cananéia (25° 55', 25° 10'S; 47° 50', 48° 00' W) there is a large estuarine lagoon complex where the islands of Cananéia, Comprida and Cardoso are located. The two first islands are formed by Quaternary marine deposits and are surrounded, mainly, by Holocenic sediments (clay and sand from the mangrove) (Suguio & Martin, 1978

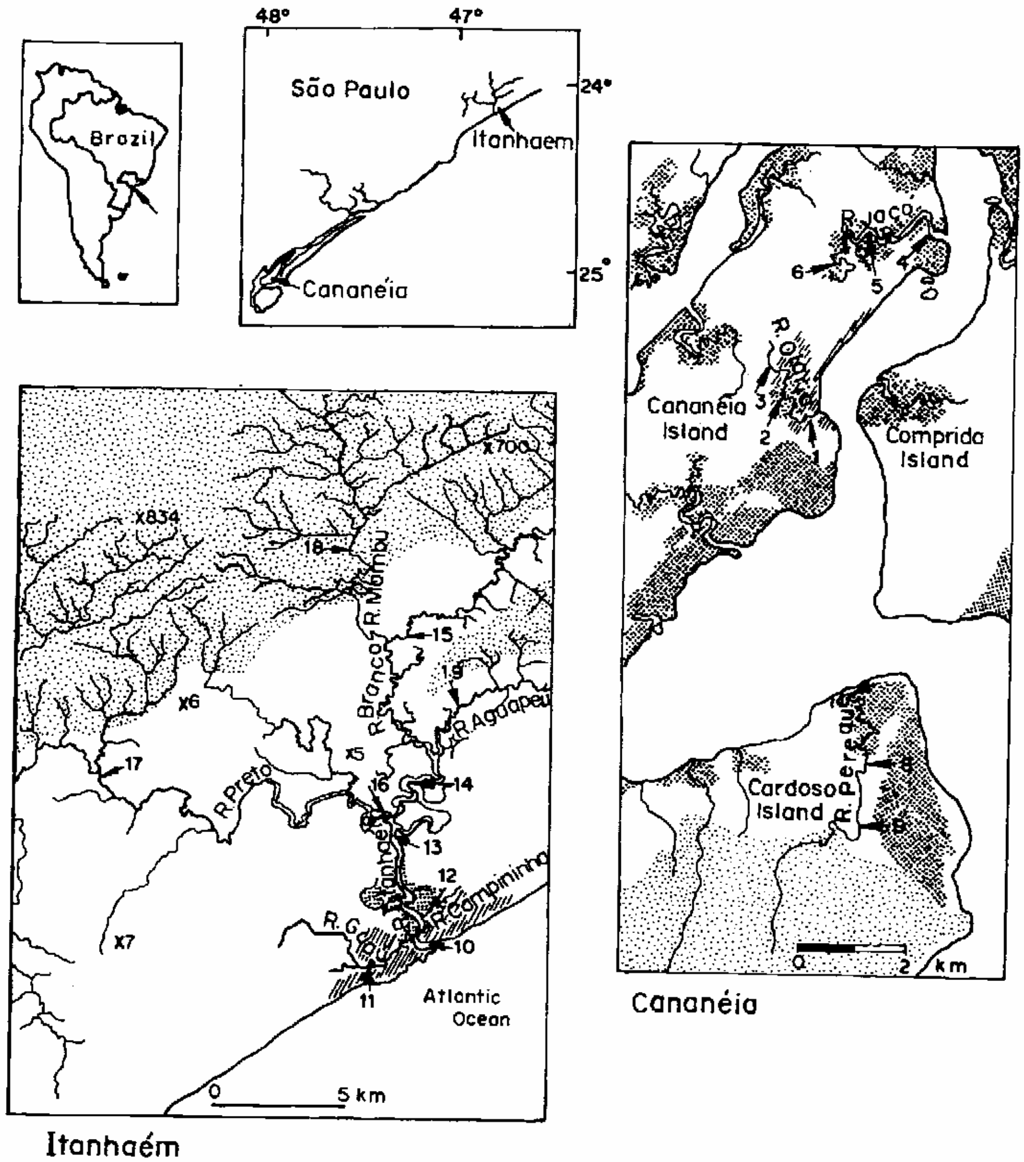

Figure 1. Location of the study area.

←n. = sampling stations,
= urban zone
= coastal plain
x n. = altitude,
= range with forest
= mangrove.

a). The Cardoso island was formed mainly by Precambrian, with some areas of Holocenic sediments in the lower regions (Suguio & Martin, 1978 a). The three rivers studied in the regions are in the islands of Cananéia (Olaria and Jacó) and Cardoso (Perequê) (Fig. 1). The river Olaria crosses the urban center and is affected by deforestation of the mangrove vegetation, urban occupation of the borders and organic drains. The Jacó river is located 4.5 km from the Olaria river, away from the urban center and the influence of man is negligible (Fig. 1). Both rivers have waters with low turbulence because of the low declivity of the region. The Perequê river is completely free of the effects of human activity being located inside the reserve area of the Parque Estadual da Ilha do Cardoso. In addition, the upper part of its bed is in a Precambrian region and only in the lower part of its course does it run through Holocenic sediments with mangrove vegetation (Fig. 1).

The basin of Itanhaém river is in the district of Itanhaém (23° 50', 24° 15'S ; 46° 35', 47° 00'W) (Fig. 1). This basin is formed by tributary rivers, that originate in the range of Serra do Mar, at 600 and 800 m and through Precambrian areas, and by rivers that begin in the coastal plain in Quaternary areas of marine origin (Suguio & Martin, 1978 b). The Serra do Mar is covered by a Tropical Rain Forest (Mata Atlântica) which is located inside the reserve area of the Parque Estadual da Serra do Mar, and is therefore almost untouched by actions of man. The coastal plain shows Coastal Plain Transitional Forest (Mata de Restinga) in which different types of human activities are observed (sand pits, banana farms and deforestation). The banks of the rivers of the lower part of the basin have mangrove vegetation because of the influence of marine waters. In this area, because of the proximity of a sizable urban center, the rivers are affected by deforestation, buildings and domestic drains.

The R. Itanhaém is formed in the coastal plain by the meeting of the Rivers Preto (black water) and Branco (white water), which have their headwaters in the Serra do Mar (Fig.1). The R. Branco has two important tributary rivers, Mambu (clear waters) and Aguapeú (black waters). The Itanhaém river has some small tributary rivers (Guaú and Campininha) in its lower part. Those rivers start in the coastal plain and run through areas with mangrove vegetation and are repository for domestic drains.

MATERIAL AND METHODS

Water surface samples were collected in nineteen sampling stations as follows: 3 from Rivers Olaria (sampling stations 1, 2, 3), Jacó (4, 5, 6), and Perequê (7, 8, 9); 2 from the rivers Itanhaém (10, 11), Preto (12, 13) and Branco (14, 15) and 1 from the rivers Mambu (16), Aguapeú (17), Campininha (18) and Guaú (19) (Fig. 1). Samples were collected at different times of the year, between February 1990 and January 1993 in a total of 9 expeditions (2/90, 7/90, 5/91, 7/91, 10/91, 3/92, 7/92, 10/92, 1/93).

The following parameters were measured for the water at the sampling stations: temperature (with a thermistor), pH, conductivity and salinity (using a pH meter and conductivimeter with glass electrode and a salt refractometer). Oxygen was determined by the Winkler method (Golterman *et al.*, 1978). The water alkalinity was obtained by titration (Mackereth *et al.*, 1978).

Samples of water were collected for the subsequent measurement of total Kjeldhal nitrogen (Mackereth *et al.*, 1978), total organic carbon (Strikland & Parsons, 1960) and total phosphorus (Golterman *et al.*, 1978). After filtration (field laboratory) of part of the samples

(Watman filter GF/C), the same methods were used to measured total dissolved nitrogen and phosphorus. Ammoniacal nitrogen and orthophosphates were determined (filtered samples) by the methods of Koroleff (1976) and Golterman *et al.* (1978), respectively. The samples were preserved by freezing and the chemical analysis were made in the laboratory of Ecologia Aquática (Depto. de Ecologia/IBRC, Unesp).

A Principal Component Analysis (PCA), based in the correlation matrix, was done with the obtained standardized data (Manly, 1986). This analysis was performed using SYSTAT package (version 5.03) (Wilkilson, 1991).

Two similarity matrices were created to verify the relationship between the water physico-chemical characteristics and the physiography. The first similarity matrix (average taxonomic distance) between the sampling stations had the limnological data as a base and the second matrix (Jaccard's coefficient) had the physiographical characteristics as a base. The original binary matrix for the physiographical characteristics was created from the analysis of the thematic maps from region under study: 1. Map of the Land Utilization from the State of São Paulo, 1:250,000, Instituto Geográfico e Cartográfico - IGC/1982, 2. Topographical Maps, 1:50,000, from the districts of Cananéia/1974 and Itanhaém/1973, Instituto Brasileiro de Geografia e Estatística, 3. Topographical Map, 1:50,000, from district of Cananéia, Diretoria de Serviço Geográfico - Ministério do Exército/1983, 4. Geological Maps from Itanhaém and Cananéia, 1:100,000 (Suguio and Martin, 1978a,b). The variables taken into account were vegetation (mangrove, restinga, forest and cultures), the lithology (continental sediments; sediments from rivers, lakes and bays; mangle and swamp sediments; and sand from the sea coast), the stratigraphy (Holocene, Quaternary from the sea and from the continent, Pre-Cambrian and Pleistocene), the relief (range and coastal plain) and the population density (low, average and high). Finally, both similarity matrix were correlated (using the Mantel test) and the significance of the matricial correlation was evaluated using 5000 permutations (Legendre & Fortin, 1989).

RESULTS AND DISCUSSION

Figures 2, 3 and 4 show the data (mean and standard deviation from the 9 collecting expeditions) obtained for each parameter measured in the 19 sampling stations.

The temperature showed annual variations of around 10°C in all the sampling stations (Table 1). Variations of temperature among sampling stations were also evident. The stations near mangrove regions, but not close to the sea (stations 2, 3, 6, and 12), showed the highest temperatures (>31°C). The sampling stations near the range region (stations 15, 17, 18 and 19) showed the lowest temperatures during the year, as for example in the Mambu river (station 18) where the maximum temperature measured was 26.6°C.

The highest O_2 saturations (> 100 %) were measured in the waters of the stations near the range (Figure 2A). These high values were determined by the characteristics of those waters of high turbulence, great transparency, low organic carbon and the presence of submerged macrophytes (*Anacharis densa*). Thomaz *et al.* (1992) and Bonetto (1986) also measured O_2 levels over the saturation points (121 % and 109 %, respectively) in the Paraná river. The O_2 levels (Figure 2A) were lower in the waters from the stations in the mangrove region (tidal creeks). The tidal creeks have high dissolved and particulate organic carbon and, as a consequence, low values of dissolved O_2 (Clough *et al.*, 1983). The O_2 levels were even lower (3.6 mg/L) in the waters from rivers that receive organic effluents and anaerobic conditions

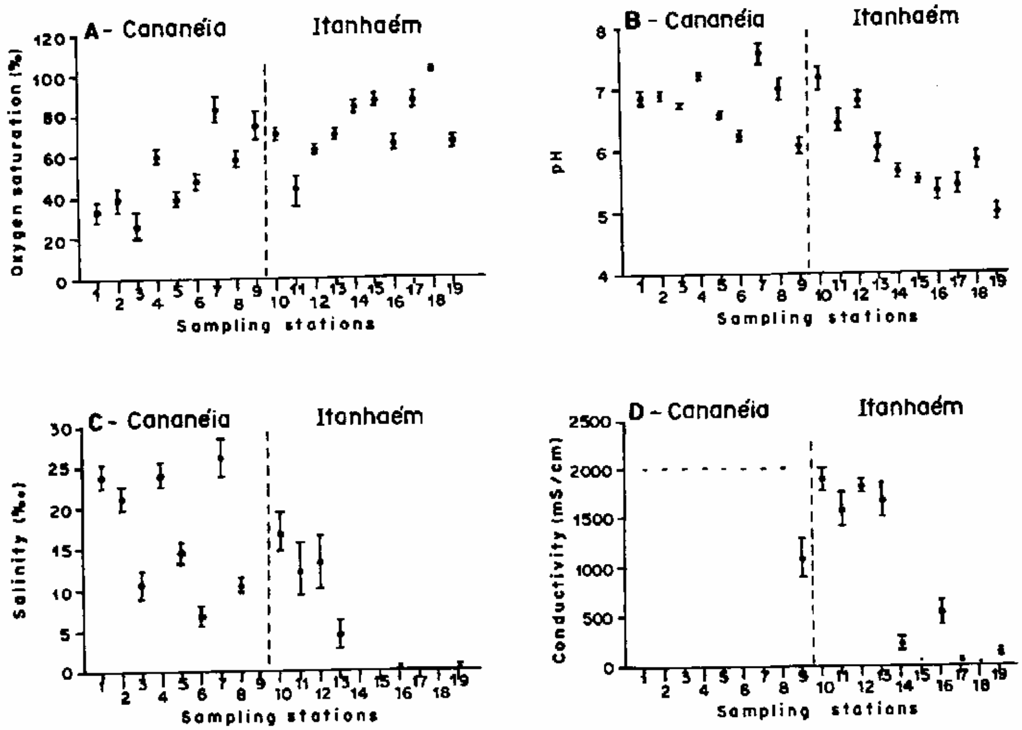

Figure. 2. Mean and standard desviation of oxygen saturation (A), pH (B), salinity (C) and conductivity (D) measured in the sampling stations.

was observed, for example, in the Guaú river. Dwivedi and Padmakumar (1983) studying a mangrove region, near Bombaim (India), which receive organic drains, measured low dissolved O_2 and anaerobic conditions during the low tide period.

The highest pHs (6.5 to 7.5) were measured in the regions close to the sea, probably due to the presence of salty water. The water from sampling stations situated farthest from the coast showed more acid and more variable pHs (Figure 2B). These stations (10, 11, 12, 13 and 16) have salty waters alternating with fresh waters during the year (Figure 2C) probably causes extensive pH variation. The lowest pH values (4.1 and 4.3) were measured in the stations 17 and 19 that corresponds to river Preto and Aguapeú. These rivers have black waters because of the presence of humic substances that confers characteristic acidity. Very acid pHs (minimum 3.7) were also found by Por (1986) in rivers with black waters from the Estação Ecológica da Juréia, in the south coast of São Paulo, between the regions of Cananéia and Itanhaém. In the Amazon region, black waters show pHs varying between 3.5 and 5.5 (Sioli, 1984). The relativity acid pH (<6.0) of the Branco river (sampling stations 14 and 15) stands out. In the Amazon region the white waters show pHs varying from neutral to slightly alkaline (Schmidt, 1973). The acid pHs measured in the Branco river could be related to the mixing of white and black waters in the basin of the Itanhaém river.

Variations in water salinity can occur relatively quickly because of tidal changes (Camargo *et al.*, 1995). Seasonal variations were noticed, mainly in the basin of Itanhaém river. The whole basin had fresh water (the conductivity was 0.26 mS/cm in station 10) in

Table I. Water temperature in the different sampling stations (minimum and maximum values).

River	sampling stations	temperature (°C) mín.	max.
Olaria	1	19.0	29.0
	2	18.9	32.0
	3	18.8	31.5
Jacó	4	19.6	30.0
	5	19.1	30.5
	6	18.8	35.0
Perequê	7	20.7	29.0
	8	21.1	27.6
	9	18.7	25.5
Itanhaém	10	19.5	29.3
Guaú	11	18.4	30.5
Campininha	12	17.2	33.0
Itanhaém	13	19.0	29.7
Branco	14	18.9	27.2
	15	16.7	30.8
Preto	16	18.5	28.0
	17	16.5	28.0
Mambú	18	15.1	26.6
Aguapeú	19	17.8	28.0

May, 1991. However, in October of 1991 salty waters were present throughout the Itanhaém river, with salinity values of 30‰ in station 10 and 5 ‰ in the station 16. This seasonal variation determines also a seasonal alteration of the biomass and of the composition of species of aquatic macrophytes in the confluence of the rivers Preto and Branco (Camargo and Florentino, in preparation). The waters from the stations close to the range are permanently fresh (Figure 2D).

Figure 3A show the results of alkalinity. The highest values were measured in the sampling stations close to the sea, due to the presence of salty water.

The values obtained for the measurement of the total organic carbon in the water were higher in areas of mangrove (stations 1 to 13) than in areas near the range (stations 14 to 19). The highest value (27.6 mg/L) was obtained in the station 4 (Jacó river) which is not polluted by drains (Figure 3B). However, this value is low when compared with the ones measured by Boto and Bunt (1981) in intact mangroves from Australia (> 40 mg/L). Higher levels of total organic carbon were not detected in the rivers that receive organic drains as Olaria (stations 1, 2, 3), Guaú (11) and Campininha (12), when compared with the rivers not polluted by drains, such as, Jacó river (stations 4, 5, 6). The majority of organic carbon present in the mangrove regions comes from the surrounding vegetation. The allochthonous material (compounds of the plant and animal origin in the particulate or partially degraded forms) is highly resistant to microbial decomposition (Wetzel, 1975). Additionally, the high rates of C/N (e.g. 60.7 in station 5) indicate low decomposition of organic matter in those

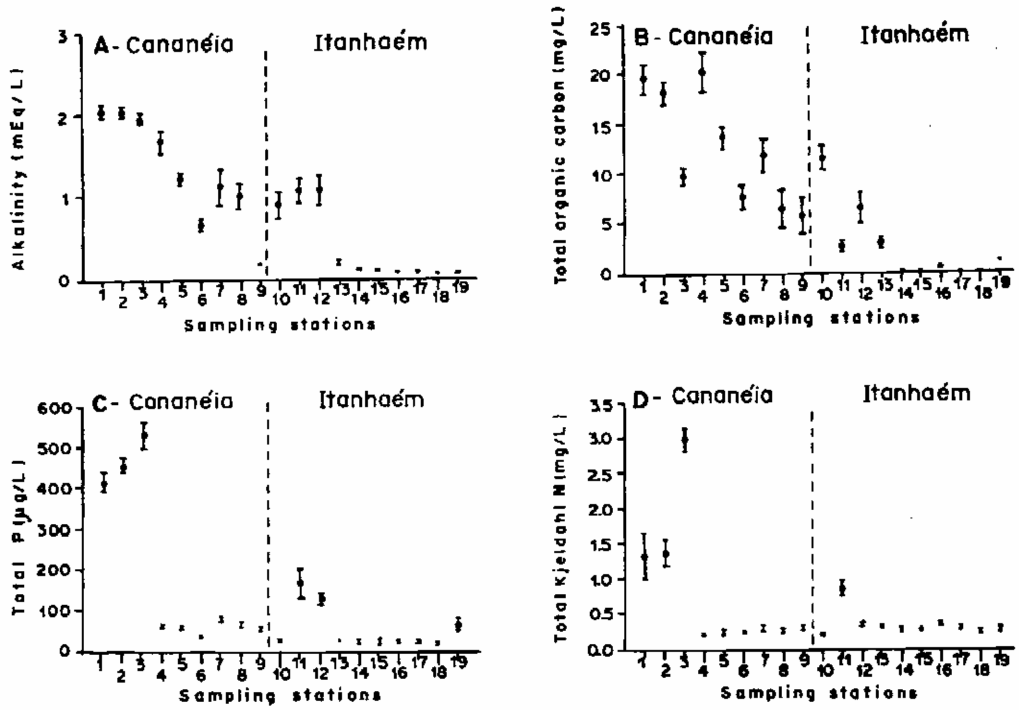

Figure. 3. Mean and standard desviation of alkalinity (A), total organic carbon (B), total P (C) and total N (D) measured in the sampling stations.

environments. The low rates C/N (e.g. 3.4 in the station 3) indicate high decomposition rates. Therefore, it is possible to say that the introduction of organic drains in the tidal creeks does not affect the organic carbon content of the waters, as the additional organic matter added is quickly eliminated by decomposition, because the organic drains consist mainly of carbohydrates, lipids proteins and nucleic acids of low molecular weight (Mason, 1981), compounds that are labile and easily degraded by microorganisms (Wetzel, 1975).

The values obtained for total phosphorus were generally lower in the waters from stations that not receive organic material from drains (mean = 24.3 µg/L) (Figure 3C). Tomaz *et al.* (1992) obtained values, varying between 6.7 and 53.6 µg/L, for the Paraná river. Total nitrogen (Figure 3D) were also low (0.06 to 0.80 mg/L) in waters without drains when compared to the values (0.14 to 3.99 mg/L) obtained from waters that receive drains. The mangrove areas are characterized by having low levels of total P and N (Hicks and Burns, 1975; Lugo *et al.*, 1976; Onuf *et al.*, 1977). However, the levels of these compounds were high (Figure 5) in rivers from mangrove areas (stations 1, 2, 3, 11 and 12) that receive organic drains. Dwivedi and Padmakumar (1983) also mentioned the enrichment of the mangrove areas into which drains introduced organic material.

The concentrations of dissolved and inorganic P and N were also lower in rivers that do not receive drains than in the ones that do (Figure 4). Although the levels of total dissolved P in the former (mean = 25.8 µg/L) were low, Henry and Gouveia (1993) obtained, in rivers from the high Paranapanema (SP-Brazil) maximum value < 20 µg/L.

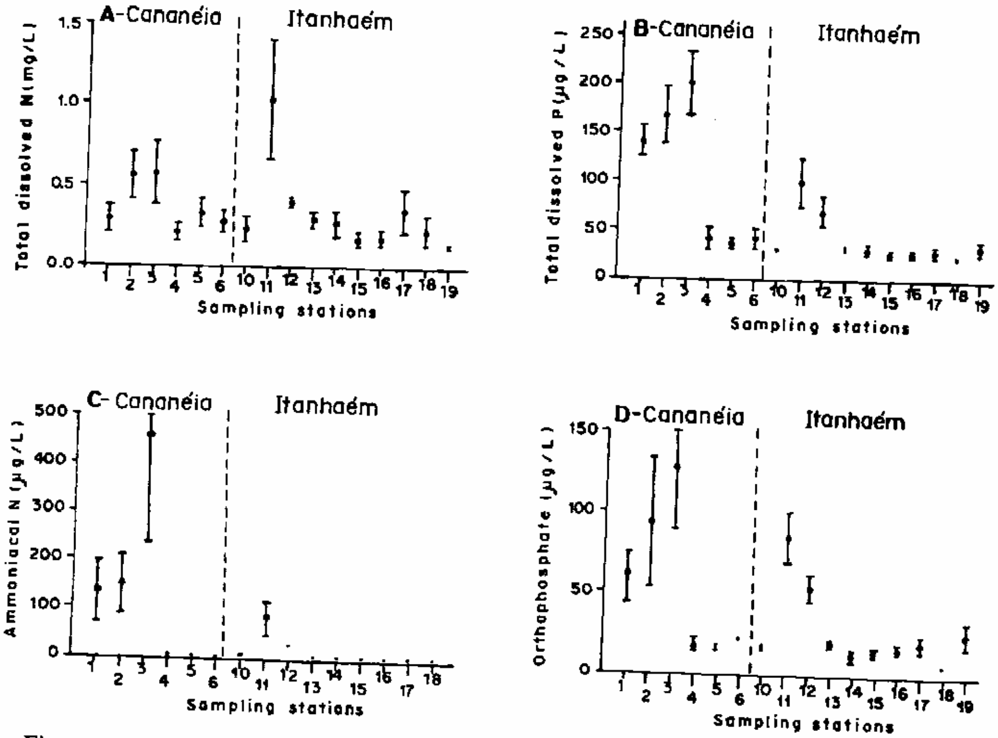

Figure. 4. Mean and standard desviation of total dissolved N (A), total dissolved P (B), ammoniacal N (C) and orthophosphates (D) measured in the sampling stations.

Although the differences between polluted and non-polluted rivers are evident, the results also show differences related to the vicinity of the sea or the range which are due to the particular physiography of each region or each river.

Table 2 shows the correlation of each parameter measured with the principal components I and II (with eigenvalues higher than 1.0), which together explain 85.5 % of the total variation. All the parameters show high correlation with component I (65.35 % of the total explained variation).

Figure 5 show the ordination of the sampling stations along the principal components I and II. A group of sampling stations could be distinguished (stations 14, 15, 16, 17, 18 and 19) and correspond to the stations situated near the range. The sequence of sampling stations that starts in the stations 9 and 13, and finishes in the station 4 corresponds to a gradient of vicinity to the coast (station that are not under the influence of organic pollution). The stations 1, 2, 3 and 11, located on the right of the Figure 1, correspond to the areas from mangrove that receive drains. Although the station 12 (Campininha river) is located near to stations that are not submitted to pollution is does receive organic effluents (Fig. 5) and it is an exception to the group mentioned previously.

This ordination pattern of the sample stations could be generally interpreted as a longitudinal gradient along the hydrographic basins resulting from the influence of physiography. The stations not distributed accordingly to this gradient are those subjected to organic effluents. Other authors (Bartarya, 1993; Skoulikidis, 1993; Colonello, 1993; Sabater *et al*, 1993), have demonstrated the relationship between the physiographical char-

Table II. Correlations of the variables with Principal Components I and II.

Variables	Principal Components I	Principal Components II
alkalinity	0.94	0.26
conductivity	0.75	0.51
total org. C	0.71	0.60
total dissolved N	0.58	-0.27
ammmoniacal N	0.80	-0.48
total N	0.80	-0.54
total dissolved P	0.94	-0.29
pH	0.70	0.60
orthophosphates	0.89	-0.39
total P	0.89	-0.32
salinity	0.72	0.62
O_2	-0.83	0.03
Eigenvalue	7.80	2.40
% variation explained	65.35	20.15

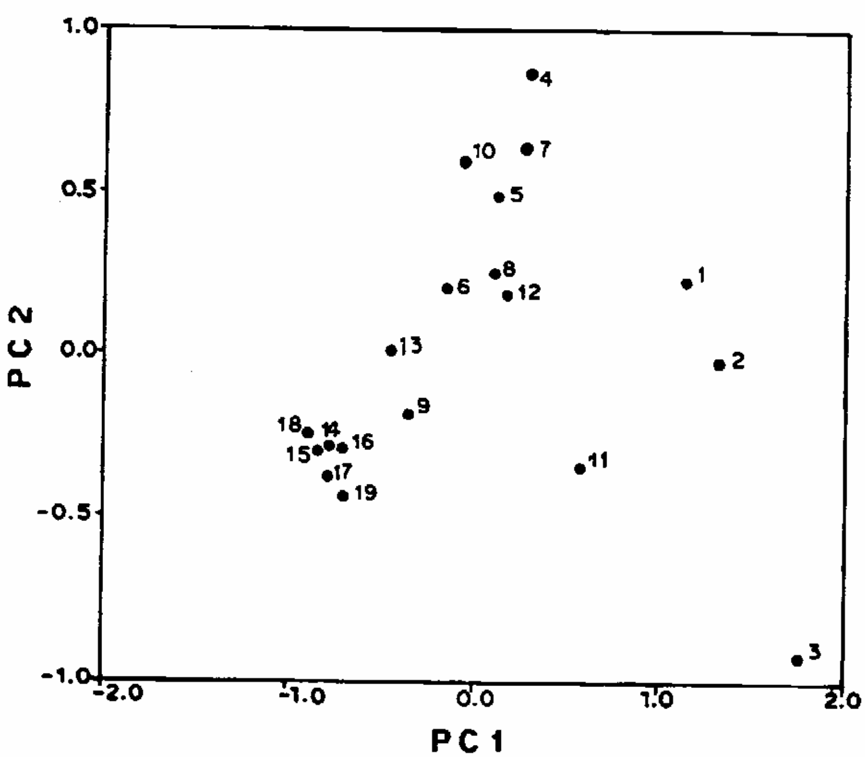

Figure. 5. Principal Component ordenation of the sampling stations.

Table III. Binary matrix of physiographic features (letters) of sampling stations.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	0	1	0	1	0	1	1	0	0	1	1	1	1	1	0	1	0
2	0	1	0	1	0	1	1	0	0	1	1	1	1	1	0	1	0
3	0	1	0	1	0	1	1	0	0	1	1	1	1	1	0	1	0
4	0	1	0	1	0	1	1	0	1	1	0	1	1	0	0	1	0
5	0	1	0	1	0	1	1	0	1	0	0	1	1	0	0	1	0
6	0	1	0	1	0	1	1	0	1	0	0	1	1	0	0	1	0
7	0	1	0	1	0	1	1	1	1	0	0	1	1	0	1	1	1
8	0	0	0	1	0	0	1	1	1	0	0	0	1	0	1	1	1
9	0	0	0	1	0	0	1	1	1	0	0	0	0	0	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	0	1	1	1	0	1	1	0	0	1	1	1	1	1	0	1	0
12	0	1	1	1	0	1	0	0	0	1	1	1	1	1	0	1	0
13	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
14	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
15	1	0	1	0	1	1	0	1	1	1	0	0	0	1	1	1	1
16	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
17	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
18	1	0	0	0	1	0	0	1	1	0	0	0	0	1	1	0	1
19	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1

1-19 sampling stations; A-continental sediments; B-mangle and swamp sediments; C-sediments from rivers, lakes and bays; D-sand from the sea and the coast;E-Quartenary; F-Holocene; G-Pleistocene; H-Pre-Cambrian; I-low population density; J-average population density;K-high population density; L- mangrove; M-restinga; N-cultures; O-forest; P-coastal plain; Q-range.

acteristics of hydrographic basins and the geochemical and limnological characteristics of the rivers. It is also relevant to mention that Skoulikidis (1993) concluded that in areas of high demographic density, pollution is the main factor determining the chemical characteristics of waters from Greek rivers. Accordingly, physiography and organic pollution also seem to be the determining factors of the limnological characteristics of the rivers from the south coast of São Paulo. To test this hypothesis, two similarity matrices were constructed, one based on the limnological characteristics of the rivers and the other on physiographic features. The original binary matrix of the physiographic characteristics is shown in Table 3. It should be emphasized that all the physiographic characteristics upstream from a determined sampling station were considered as influencing this station, having the value 1 attributed to them. The correlation obtained between the two similarity matrices (Mantel test) was 0.38 ($p<0.0012$) indicating that the limnological characteristics of the rivers of the south coast of São Paulo are influenced by the physiography and organic pollution.

It is important to emphasize that subtle differences between the stations were not demonstrated by the obtained data. It did not take into account the differences among rivers with clear, black and white waters, and also the influence of weak impacts suffered by the regions such as sand removal from Branco river or intermittent drain delivery. More studies, specially including biotic variables, is necessary to determine this differences between the rivers.

From the results obtained it can be concluded that the limnological characteristics of the rivers studied are strongly determined by physiographycal aspects (altitude, geology and vegetation). However, the rivers that receive organic effluents the pollution is the main factor determining the chemical characteristics of waters.

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