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LITTORAL ZONE OF SOUTH-BRAZILIAN COASTAL LAKES: ELEMENTAL COMPOSITION OF THE SEDIMENTS

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Resumo:

"Zona litoral de lagos costeiros sul-brasileiros: componentes dos sedimentos"

A interrelação dos nutrientes fósforo, nitrogênio, cálcio, magnésio e potássio, ao longo de um gradiente sedimentológico e na camada superficial do sedimento, diferenciou as zonas litoral de nove lagoas costeiras no Rio Grande do Sul. Os nutrientes na camada superficial encontram-se relacionados aos processos dinâmicos que ocorrem na coluna d'água e à decomposição de detritos acumulados nessas áreas. Na superfície do sedimento, o fósforo, o nitrogênio e o cálcio apresentam relações químicas similares.

A correlação entre nutrientes e metais pesados sugere uma tendência comum de aumento e decréscimo ao longo do gradiente. Apenas 29,6% da variação observada é explicada por outros mecanismos que encontram-se relacionados à anomalia das camadas no perfil. Os metais pesados apresentam grande diferenças nos padrões de acumulação na zona litoral. A distribuição dos metais pesados nos perfis sedimentológicos reflete processos naturais e, em alguns casos, fracos inputs atmosféricos. Os resultados obtidos para metais pesados na zona litoral das lagoas estudadas encontram-se abaixo dos valores citados para sedimentos lacustres de outros sistemas brasileiros.

Abstract:

The interrelationships of the nutrient elements phosphorus, nitrogen, calcium, magnesium, sodium and potassium along the sediment cores and in the uppermost strata differentiated the littoral zones of nine coastal lakes in Rio Grande do Sul. Nutrients in the superficial layer are likely to be related to the dynamics of the processes occurring in the water column, and to the detrital decomposition. Phosphorus, nitrogen, and calcium showed similar chemical relationships in the uppermost strata. The correlation among the nutrient elements and the heavy metals lead, cadmium, cooper and zinc suggested a common trend of increasing and decreasing along the sediment gradient. Only 29.6% of the observed variance is explained by other mechanisms related to anomalous strata in the sediment cores. The pattern of heavy metal accumulation differed greatly among the littoral zones. Its distribution along the sediment profiles reflects naturally occurring processes and, in some cases, weak atmospheric inputs. The levels of heavy metals commonly observed in lacustrine sediments in other brazilian aquatic systems are by far higher than the values found in the presente study.

Introduction

Mineral element concentrations in superficial sediments are likely to be related to several factors that reflect the dynamics of the processes occurring in the water column. In the littoral zone sediment nutrient are representative of such dynamics and are likely to determine the growth and biomass distribution of submerged and emergent macrophytes (MISRA, 1938; BARKO & SMART, 1978, 1980, 1981, 1983, 1986; CARIGNAN & KALFF, 1979; DeLAUNE *et al.*, 1979; BARKO, 1982, 1983; SPENCE, 1982; HUEBERT & GORHAM, 1983; SMART & BARKO, 1985).

Metals are present in sediments in many chemical forms that differ greatly in their bioavailability. In areas of accumulation of fine materials (HÅKANSON, 1988) or sedimentation of particulate matter (HART, 1982) heavy metals in superficial sediments are generally higher.

The purpose of the present study was (1) to evaluate nutrients and heavy metal contents and distribution in sediments from areas dominated by the bulrush *Scirpus californicus* (C. A. Mey) Steud., and (2) to compare the littoral zone of subtropical coastal lakes of southern Brazil regarding elemental distribution in sediment cores.

Material and Methods

Field investigations were carried out during summer (from December 1985 to mid March 1986) in nine selected lakes of the Coastal Plain of Rio Grande do Sul (Table 1, Fig. 1). Except for Barros Lake, whose formation is related to Pleistocene events, all other lakes are situated on the Holocene terrace (SCHWARZBOLD & SCHÄFER, 1984; VILLWOCK, 1984).

Table 1: Location and morphometric parameters of the nine studies coastal lakes.

Lake	latitude S	longitude W	surface area (km^2)	maximums depth (m)*
1. Palmital	29°49'	50°09'	11.7	3.0
2. Caieira	29°51'	50°08'	2.5	2.0
3. Peixoto	29°52'	50°14'	3.3	2.5
4. Barros	29°55'	50°23'	89.8	4.3
5. Emboaba	29°58'	50°13'	1.3	1.7
6. Rincão das Éguas	30°18'	50°18'	5.5	3.5
7. Porteira	30°22'	50°20'	18.7	4.2
8. Barros-Solidão	30°31'	50°24	7.6	7.5
9. Tarumã	30°45'	50°34'	4.2	6.0

*- From SCHWARZBOLD & SCHÄFER (1984), except for Barros lake.

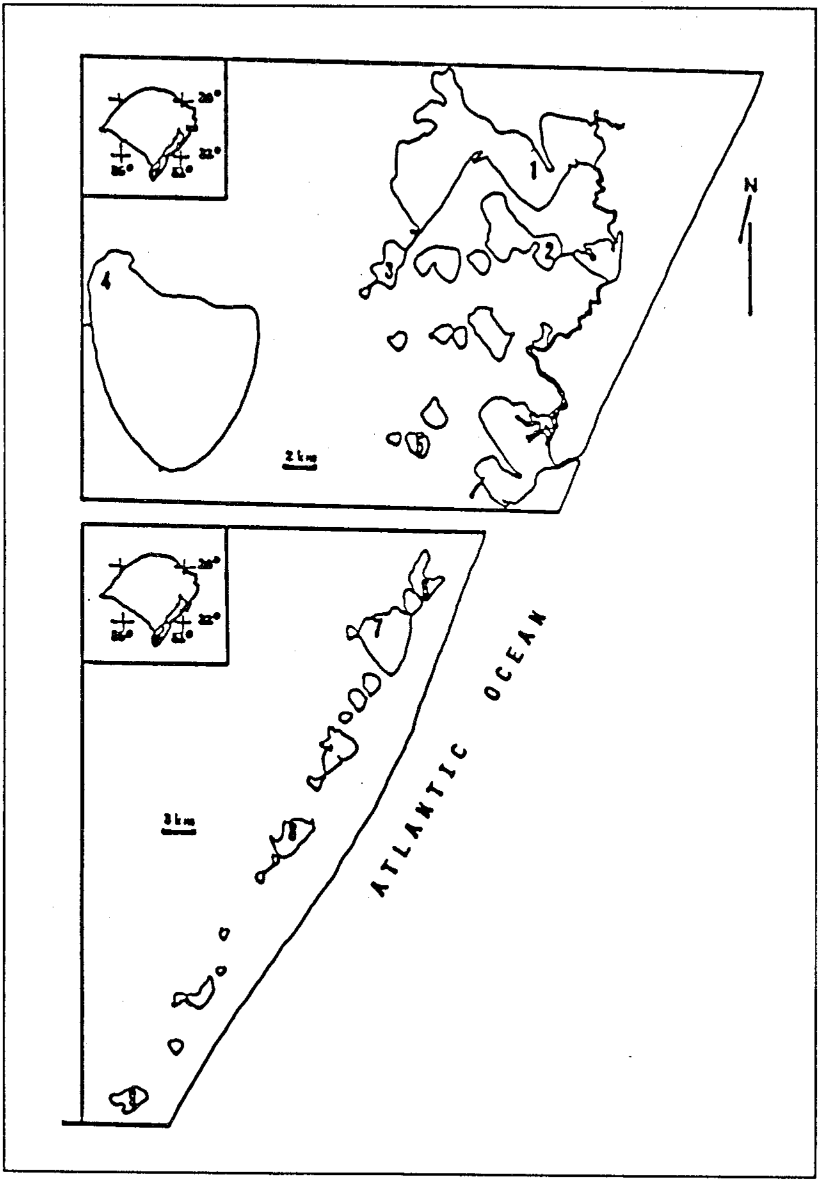

Figure 1: Location map of the lakes studied. Numbers refer to lakes mentioned in Table 1.

Sediment samples were taken with a 60 cm core and transported to the laboratory under deep freeze conditions. As underground parts of the emergent macrophytes (rhizomes and roots) were located in the upper 16 to 12 cm only the top 20 cm sediments were analyzed.

Sediment data were summarized by averaging triplicate samples every 2 cm, for each parameter. Chemical parameters of the sediments were analyzed according to STRICKLAND & PARSONS (1968), ZAHRADNIK (1981), AMERICAN PUBLIC HEALTH ASSOCIATION (1985) and ALLEN *et al.* (1986).

For analytical purposes sediments were dried at 60°C to a constant weight and ground with a mill. Phosphorus was determined via the ascorbic acid method after persulfate digestion. Nitrogen was determined by the Kjeldahl digestion method using a multiple digestion unit (FAITHFULL, 1969, 1971). Samples for calcium, potassium and sodium were analyzed with an Eppendorf flame photometer. Magnesium concentrations and heavy metals were estimated with a Perkin-Elmer 5000 atomic absorption spectrophotometer. Available metals were obtained by extraction of the sediments for 2 hours with 0.5M HCl (AGEMIAN & CHAU, 1976).

Results and Discussion

Changes in the vertical profile of mineral elements were examined in sediment cores of the littoral zone dominated by the bulrush *Scirpus californicus*. Due to naturally occurring processes, and to the fact that each lake acts, to some extent, as an island for each a macrophyte community (according to the lakes peculiarities), the nutrient distribution along the sediment profile differed between them. The occurrence of sheltered margins also influences the nutrient gradients since wind action promotes erosion or mixing of superficial sediments. Moreover, it is generally known that a certain type of mixing promoted by active sediment burrowers as oligochaetes, chironomids, ostracods and amphipods might also influence nutrient profiles (VINER, 1977; GRANÉLI, 1979; KAMP-NIELSEN *et al.*, 1982; RIPPEY & JEWSON, 1982; ROBBINS, 1982; SMAYDA, 1990). For these reasons, nutrient accumulations in superficial sediment layers are probably related to factors that do not reflect directly the trophic state of the lakes.

In the coastal lakes of Rio Grande do Sul, relatively high concentrations of phosphorus were observed in Caieira (mean of 46.65 ppm) and Peixoto (mean of 42.99 ppm) lakes (Tab. 2.). Porteira Lake with a mean of 24.89 ppm P g d.w. in the sediment cores also showed the more richly organic layers. It is very likely that phosphorus levels are associated with organic matter content in sediments. Independent of metabolic uptake, a high phosphate adsorbing capability is shown by organic material in the sediments of tropical lakes and reservoirs (VINER, 1977; ESTEVES, 1983). Nitrogen was extremely high in the uppermost sediment of Caieira Lake (mean of 950.05 ppm). As mentioned elsewhere (FISH & ANDREW, 1980), in undisturbed sediments phosphorus and nitrogen enhancement in superficial layers can merely result from detrital decomposition. In Porteira Lake, nitrogen presented the highest levels in the rhizome layer, where also sodium increased markedly. Calcium and magnesium showed the same tendency.

Turbulence effects in the uppermost sediments can imply that such layers are taking part in nutrient recycling to the lake water (GANF, 1974; VINER, 1977). The highest calcium concentrations were found in the uppermost sediment of Caieira (mean of 1731.91 ppm) and Emboaba (mean of 801.43 ppm) lakes, and in the sediment cores of Porteira Lake (mean of 2822.62 ppm). Mean nutrient concentrations in the littoral zone of these lakes are extremely low if compared to values obtained by ESTEVES (1983) in sediments from some tropical reservoirs in southeastern Brazil. Estimations of potassium in the sediment core were low and not usually detectable, except for Emboaba Lake (in the uppermost 2 cm of sediment).

Table 2: Sediment nutrients (ppm) in the littoral zone. Means and standard deviations are based on triplicate determinations, including surface (0 to 1 cm depth) and each 2 cm interval up to 20 cm depth (n= 33).

Lake	P	N	Ca	Mg	Na	K
Palmital	13.39	51.00	77.51	24.04	9.12	0
	(8.67)	(19.11)	(18.62)	(10.30)	(6.05)	
Caieira	46.65	264.99	575.17	22.03	13.56	0
	(42.74)	(340.19)	(746.58)	(17.82)	(11.48)	
Peixoto	42.99	128.53	72.72	19.86	18.11	0
	(19.68)	(49.23)	(36.01)	(21.45)	(7.84)	
Barros	12.87	40.44	116.90	31.38	7.37	2.28
	(7.46)	(38.95)	(124.43)	(29.05)	(7.21)	(7.56)
Emboaba	19.96	117.88	213.09	15.50	17.50	7.47
	(4.66)	(25.76)	(294.07)	(32.01)	(13.56)	(16.65)
R. Éguas	20.72	28.26	32.30	10.35	10.75	0
	(5.36)	(16.43)	(10.67)	(5.33)	(5.13)	
Porteira	24.89	1113.10	2822.62	1000.01	306.86	0
	(16.16)	(1041.76)	(1686.50)	(478.31)	(168.25)	
B. Solidão	11.11	33.93	38.92	4.19	5.41	0
	(4.74)	(33.04)	(9.46)	(3.52)	(3.40)	
Tarumã	11.98	47.46	40.40	21.99	12.60	0
	(4.92)	(52.97)	(17.41)	(6.23)	(5.67)	

Co-precipitation of phosphate and calcium could be an explanation for the relationship found in the sediment gradients in Caieira (r^2=.947; $p<0.001$), Barros (r^2=.828; $p<0.001$) and Porteira (r^2=.503; $p<0.05$) lakes . It may be pointed out that such relations are more likely due to the nearness of the shore, and the amount of organic matter, than to co-precipitation itself.

Furthermore, it appears that for the present chemical conditions in the lakes, phosphorus is more probably associated with iron.

Mineral element concentrations in superficial sediment layers are likely to be related to several factors that, to some extent, reflect the dynamics of the processes occurring in the water column, rather than the trophic status of the lakes. Sediment cores collected in the littoral zone are representative samples of such dynamics. In order to examine superficial sediment alterations among different lakes the relative mean deviation of each element was computed and compared between the sediment cores and the uppermost 2 cm (Fig. 2).

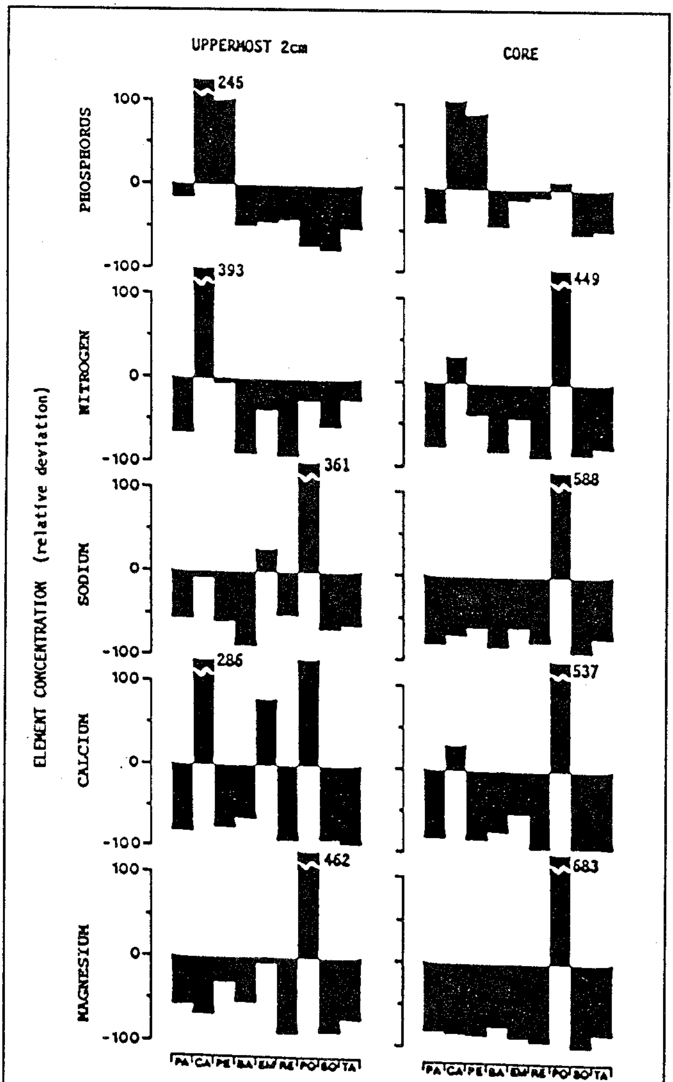

Figure 2: Mean nutrient concentrations in the sediments expressed as percent deviation from the littoral zone mean concentration. Columns show the superficial sediments (left) and the sediment cores (right) for each lake.
PA= Palmital;
CA= Caieira;
PE= Peixoto; BA= Barros;
EM=Emboaba;
RE= Rincão das Éguas;
PO= Porteira;
SO= Barros-Solidão e
TA= Tarumã.

In a general pattern, the littoral zone of Porteira Lake appears to be composed of the more nutrient rich sediments, except for phosphorus. Caieira and Peixoto lakes have by far the highest phosphorus concentrations. If only the upper 2 cm of sediment is compared, a pronounced change in the patterns is observed regarding nitrogen and calcium concentrations. Caieira Lake showed the highest nitrogen and calcium levels in the superficial sediments. Porteira Lake, followed by Emboaba Lake, presented superficial calcium enrichment in the upper sediment strata. Although at low proportions, sodium concentrations in the latter also showed a slight increase, if compared to the other lakes.

Heavy metal distributions in sediment cores of littoral zones in some coastal lakes reflect naturally occurring processes and, in some cases, weak atmospheric inputs are noted. Analysis performed during summer in the sediments of the littoral zone suggest that only cadmium and lead in Barros-Solidão Lake and lead in Tarumã Lake were lower than those obtained in other coastal lakes, in the same period (Tab 3).

Table 3: Heavy metal contents (ppm) in sediment cores of the littoral zone. Means and standard deviations are based on triplicate determinations, including surface (0 to 1 cm depth) and each 2 cm interval up to 20 cm depth (n= 33).

Lake	Zn	Cu	C	Pb
Palmital	0.87(0.28)	1.38(0.94)	0.03(0.06)	0.45(0.48)
Caieira	0.97(0.59)	1.36(1.02)	0.17(0.27)	1.63(2.29)
Peixoto	0.81(0.53)	1.44(1.09)	0.19(0.22)	0.67(1.50)
Barros	0.72(0.27)	1.15(0.56)	0.06(0.08)	0.18(0.25)
Emboaba	1.07(1.21)	0.90(0.33)	0.14(0.19)	1.55(2.17)
R. Éguas	0.99(0.34)	0.97(0.83)	0.04(0.06)	0.32(0.35)
Porteira	1.53(1.00)	2.75(1.43)	0.20(0.12)	0.24(0.14)
B. Solidão	0.42(0.24)	0.84(0.39)	0.02(0.03)	0.06(0.06)
Tarumã	0.48(0.29)	1.38(0.75)	0.08(0.14)	0.03(0.04)

The highest heavy metal accumulations were observed in sediments of Porteira, Emboaba, Peixoto and Caieira lakes. Such results are primarily dependent on the localization of the lakes, their inputs, and on the littoral zone sampled. Littoral sediments of Emboaba Lake are likely to suffer direct inputs from heavy traffic, since the lake is located near the main road used to reach the resort towns near the beach. The levels showed by lead in sediment strata of Peixoto Lake may result from its proximity to a town and to roads. This lake is used during summer as a recreational area. Caieira Lake may be influenced by nearly mechanized plantation areas and also by roads. It is well known that lead is widely scattered throughout the environment by the combustion of gasoline and other fossil fuels (OLIVER, 1968; ENK &

MATHIS, 1977) and increasing lead concentrations in sediments of natural waters could be explained by proximity to roadways. It is important to mention that in the studied coastal region, the wind direction may also play an important role regarding heavy metal inputs and accumulations. A high positive correlation between the content of organic matter and metal concentrations has often been observed in lake sediments (GROTH, 1971). But such correlation does not imply preferable metal bonding by organic substances (FÖRSTNER, 1977). On the other hand, high lead concentrations in sediments may also be related to the presence of hydrous iron oxides. Co-precipitation and sorption of metal on hydrous oxides are the principal mechanisms controlling the heavy metal distribution in aerated water systems, and the uptake or release of these metals depends on the pH, the metal ion concentration, the concentrations of other heavy metals present in solution, and the amount and type of organic and inorganic complexes (JENNE, 1968; FÖRSTNER, 1977, 1982; FÖRSTNER & WITTMANN, 1981, SALOMONS & FÖRSTNER, 1984).

Although chemical and physical variables contribute to some heavy metal redistribution, a relation between grain size and concentrations of heavy metals with depth was also observed by CLINE & CHAMBERS (1977). They stated that sediments showing an upward concentration gradient of heavy metals may indicate that biochemical factors and biological activity in the upper strata are effective in causing the gradients, but the concentration gradients are not entirely grain size dependent.

The values obtained in this work are low if compared to cadmium and lead levels in sediments of eutrophic lakes (MATHIS & KEVERN, 1975), lagoons (KNOPPERS *et al.*, 1990) and reservoirs (ESTEVES *et al.* , 1981). Nevertheless, cadmium was slightly higher than the mean concentration mentioned by FÖRSTNER (1977) for the Amazon lakes.

In order to compare the heavy metal concentrations in the profile and in the uppermost 2 cm of sediment the relative mean deviation of each heavy metal was computed (Fig. 3). Lead was the only heavy metal whose mean levels did not differ greatly between the sediment profiles and the upper strata. This element showed higher concentrations in both Caieira and Emboaba lakes. All the other heavy metals showed different trends among the littoral zone, and delineated some peculiarities. Zinc accumulated especially in the upper sediment layers of Emboaba Lake, whereas in a gradient, Porteira Lake was more differentiated. Copper was also more concentrated in this lake, but no special accumulations were observed in the superficial strata of sediments among all coastal lakes. The cadmium gradient differentiated Porteira, Peixoto, Caieira, and Emboaba lakes from the others. Barros Lake presented cadmium enrichment in the upper strata. This fact is probably related to the high silty-clay suspended particles content of the lake (ARAÚJO DE OLIVEIRA, 1983).

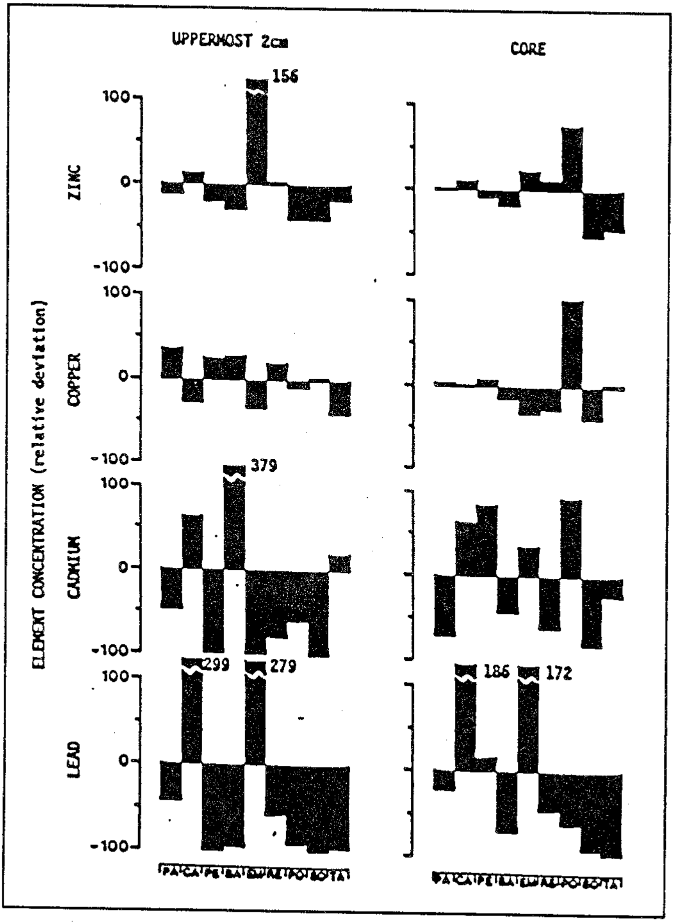

Figure 3: Mean heavy metal concentrations in the sediments expressed as percent deviation from the littoral zone mean concentration. Columns show the superficial sediments (left) and the sediment cores (right) for each lake.

PA= Palmital; CA= Caieira; PE= Peixoto; BA= Barros; EM=Emboaba; RE= Rincão das Éguas; PO= Porteira; SO= Barros-Solidão e TA= Tarumã

The inter-relationships of the chemical parameters along the sediment cores and in the uppermost strata showed that naturally occurring processes differentiated the littoral zones of lakes when treated separately. Principal components analysis based on the correlation among nutrient elements and heavy metals present in the sediment profile (up to 20 cm depth) indicated a tendency of nutrients to cluster strongly on the positive pole of the first axis (Fig. 4). This component accounted for 66.7% of the total variation, suggesting common trends of increasing or decreasing along the sediment gradient. Phosphorus and cadmium grouped on the positive pole of the second component, that accounted for 23.8% of the total variance, whereas lead occurred alone on the third componed. Such results show that approximately 29.6% of the variance in the sediment profile is not explained by patterns of increase or decrease in nutrients. Other mechanisms are responsible for the gradient in the littoral zone, not determined by the factors analyzed, but that can be reasonably related to anomalous strata in the sediment cores.

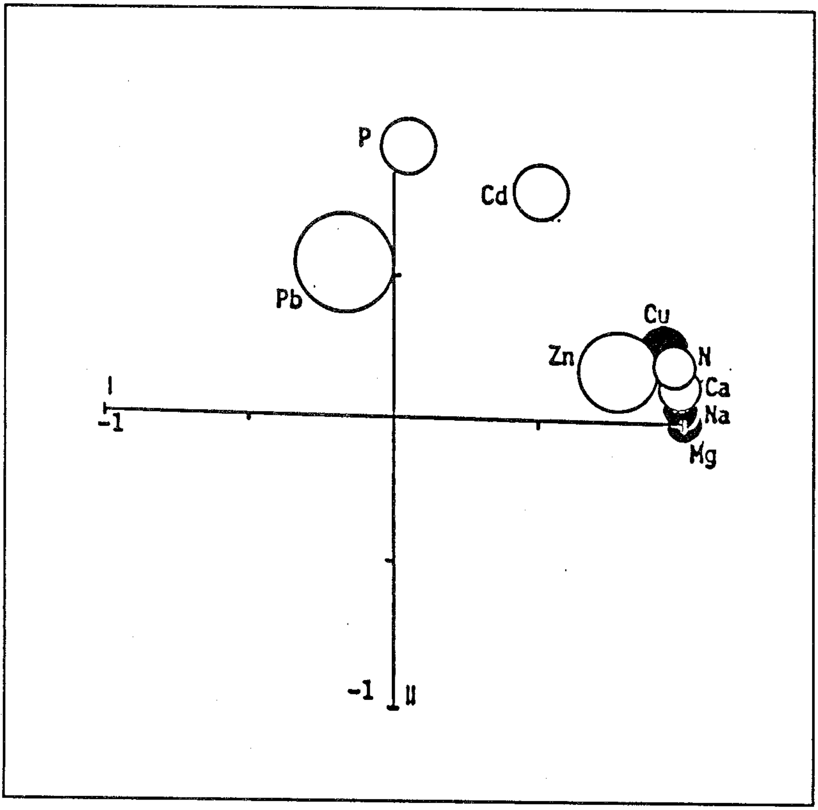

Figure 4 - Principal component analysis of nutrients and heavy metal concentrations in sediment profiles. Components I and II accounted for 66.7 and 23.8% of total variation. Component III (5.8% of total variation) is represented by the circle diameter where open circles represent positive values and closed circles negative values.

From the uppermost sediment strata four components were extracted by the principal components analysis (Fig. 5). On the positive pole of the first component, that accounted for 40.9% of the total variation, phosphorus, nitrogen and calcium grouped together, which suggests similar chemical relations. Another grouping was shown by sodium and magnesium on the second component, as well as by zinc, copper and lead on the third one. Cadmium grouped alone on the fourth component, which accounted for 9.5% of the total variance. This means that only this heavy metal showed great differences in accumulation patterns among the coastal lakes. Similar trends of both zinc/lead and nitrogen/phosphorus concentrations are said to indicate that these substances originate in the urban system, and cadmium within the upper layers of sediments may be related to industrial emissions (FÖRSTNER, 1976).

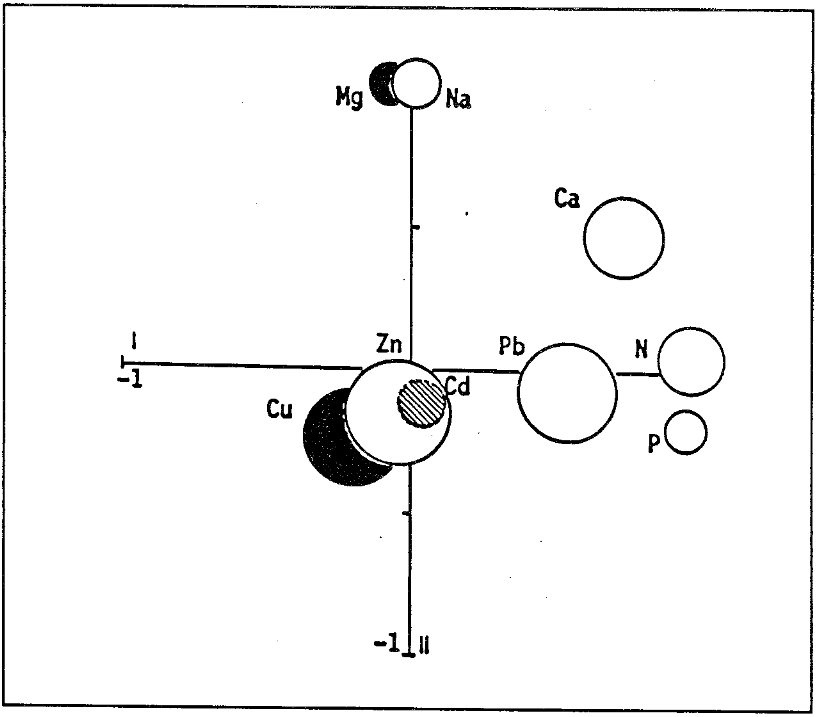

Figure 5: Principal component analysis of nutrients and heavy metal concentrations in the uppermost sediment strata. Components I and II accounted for 40.9 and 25.5% of total variation. Component III (16.7% of total variation) is represented by the circle diameter where open circles represent positive values and closed circles negative values. Component IV (9.5% of total variation) is represented by dotted circles.

As expected by the results above, the coastal lakes also showed different trends regarding the variables analyzed, and according to the sediment gradient. The principal components analysis based on the correlation among the lakes, and taking into account the nutrients and heavy metals present in the sediment cores of the littoral zones, grouped Palmital, Rincão das Éguas, Barros-Solidão and Barros lakes on the positive pole of the first component (Fig. 6). This component alone accounted for 63.3% of the total variance. Caieira and Emboaba lakes grouped on the positive pole of the second axis, and Porteira Lake on the opposite pole of the same component, that accounted for 24.0% of the total variance. This shows that Caieira and Emboaba lakes had a similar pattern of heavy metal and nutrient accumulations, opposite to Porteira Lake, but whose variations grouped them together, although distinct from those that grouped lakes on the first axis. Tarumã and Peixoto lakes grouped on the third component, but the latter showed no defined pattern and was also associated with the second component.

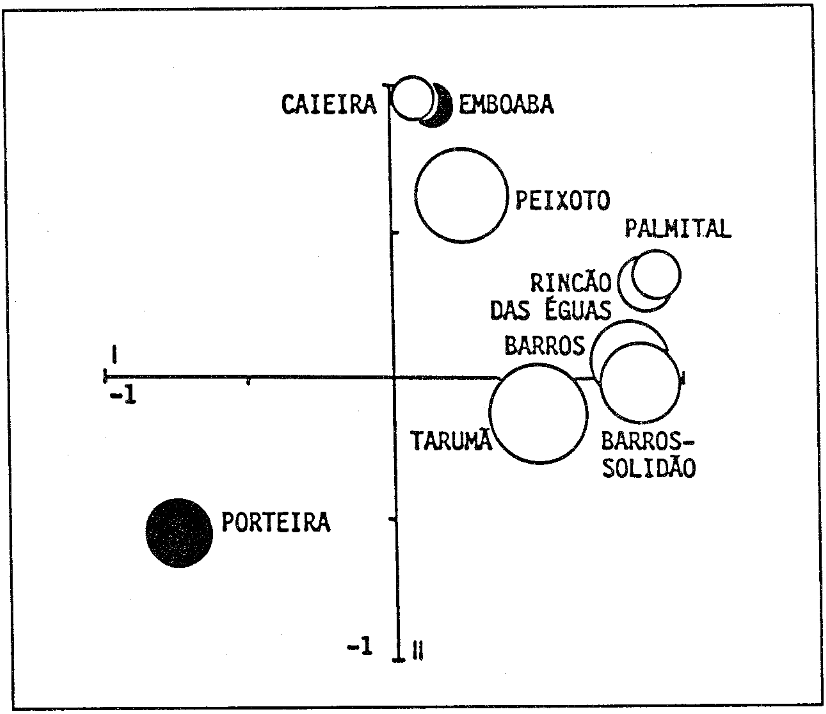

Figure 6: Components I (63.3% of total variation), II (24.0% of total variation) and III (7.3% of total variation) of a principal component analysis based on mean element concentrations in sediment profiles. Component III magnitude is represented by the circle diameter where open circles represent positive values and closed circles negative values.

Comparing the uppermost sediment strata by principal component analysis, clear differences are still noted among the littoral zones (Fig. 7). Rincão das Éguas, Palmital and Barros-Solidão lakes, as observed in a sediment gradient, grouped together on the positive pole of the first component, that accounted for only 37.9% of the total variance. Barros Lake grouped on the second component, together with Tarumã Lake. Porteira and Caieira lakes, showed opposite trends on the third axis, whereas Peixoto and Emboaba lakes showed opposite trends on the fourth component. The results obtained show a marked separation between littoral zones of Rincão das Éguas, Palmital and Barros-Solidão lakes and the others.

Although in some sediment cores of the coastal lakes cadmium appears with slightly higher values, the background concentrations of heavy metals in some lacustrine sediments listed by SALOMONS & FÖRSTNER (1984) are by far higher than the levels found. On the other hand, it may be taken into account that pre-established background levels vary according to the geographical position of the lake, the geology of the lake basin, the suspended material present in the water, the grain size and type of sediment, the accumulation zones (highly dependent on wind direction), and the seasonality of lake parameters. For these reasons, the background levels generally cited for lacustrine sediments are not useful for interpretation and comparison of the heavy metal levels measured in the sediments of the littoral zone of coastal lakes in southern Brazil.

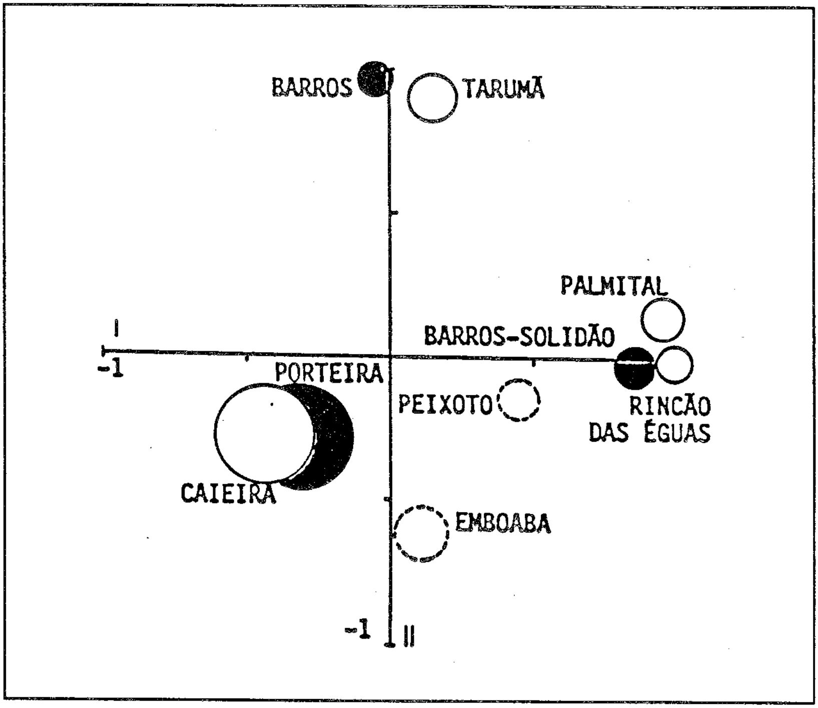

Figure 7: Components I (37.9% of total variation), II (25.0% of total variation), III (17.6% of total variation) and IV (13.2% of total variation) of a principal component analysis based on mean element concentrations in the uppermost sediment strata. Component III magnitude is represented by the circle diameter where open circles represent positive values and closed circles negative values. Component IV is represented by dotted circles.

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