VERTICAL DISTRIBUTION OF NUTRIENTS IN THE SEDIMENT OF A BRAZILIAN COASTAL LAGOON (IMBOACICA LAGOON, RIO DE JANEIRO).

PETRUCIO, M.M.[1], ENRICH-PRAST, A.[1] & ESTEVES, F.A.

Lab. de Limnologia, Depto. de Ecologia, Inst. de Biologia, UFRJ
21941-590 - Rio de Janeiro - Brazil
e-mail: mmpetruc@acd.ufrj.br
1. Programa de Pós-Graduação em Ecologia - UFRJ

ABSTRACT: Vertical distribution of nutrients in the sediment of a brazilian costal lagoon (Imboacica Lagoon, Rio de Janeiro). Imboacica Lagoon, located in the north of the State of Rio de Janeiro, has been subjected to human influences such as landfills and discharge of domestic effluents for the past few decades. In order to evaluate possible changes caused by a large landfill in the 1970's, which reduced the lagoon area by about 20%, we took a 75 cm vertical profile of the sediment. The core was collected in August 1993 with an 8 cm diameter plexiglas tube, and sectioned every 2 cm for the first 30 cm and every 3 cm in the deeper part. Concentrations of available phosphate, total nitrogen, organic carbon, pheopigments and other elements including Al, Ca, Fe, K, Mg and Na were determined. The results showed considerable changes in organic carbon (8.88 to 0.77 mmol/g), nitrogen (0.15 to 0.01 mmol/g), available phosphate (1.11 to 0.59 mmol/g) and pheopigments (47.86 to 2.89 mg/g) during the period when the filling presumably occurred. These data, together with the results of other elements analyzed, allow us to infer that the large landfill in the littoral zone of Imboacica Lagoon had considerable influence on the nutrient dynamics of the ecosystem.

Key-words: sediment, vertical profile, human impact, nutrients, coastal lagoon.

RESUMO: Distribuição vertical de nutrientes no sedimento de uma lagoa costeira brasileira (Lagoa Imboacica, Rio de Janeiro). A lagoa Imboacica, localizada na região norte do Estado do Rio de Janeiro, vem sofrendo nas últimas décadas impactos antrópicos, tais como aterros e lançamento de efluentes domésticos. Com o objetivo de avaliar as possíveis alterações causadas por um aterro realizado na década de 70, que acarretou em uma redução de cerca de 20% do espelho d'água, foi coletado um perfil vertical de 75 cm do sedimento desta lagoa, próximo à área impactada. Este perfil foi coletado em agosto de 1993 com um core de 8 cm de diâmetro, posteriormente fracionada de 2 em 2 cm nos primeiros 30 cm e de 3 em 3 cm na fração posterior. Foram determinadas as concentrações de fosfato disponível, nitrogênio total, carbono orgânico, feopigmentos e alguns outros elementos (Al, Ca, Fe, K, Mg e Na). Os resultados demonstraram variações consideráveis de

carbono orgânico (8.88 a 0.77 mmol/g), de nitrogênio (0.15 a 0.01 mmol/g), de fosfato disponível (1.11 a 0.59 mmol/g) e feopigmentos (47.86 a 2.89 mg/g) na fração de 8 a 14 cm, que corresponde provavelmente ao período em que ocorreu o aterro. Estes dados, juntamente com o resultado da concentração dos outros elementos analisados, permitem inferir que o aterro nas margens da lagoa Imboacica deve ter influenciado a dinâmica dos nutrientes deste ecossistema.

Palavras-chave: sedimento, perfil vertical, ação antrópica, nutrientes, lagoa costeira.

INTRODUCTION

In many lacustrine ecosystems, the sediment can be considered as the most important compartment in energy and matter cycling, functioning as the chief nutrient stock (Nogueira & Esteves, 1994). According to Esteves (1983), this can be considered as a result of integration of all the processes occurring in lacustrine environments.

The sediment of coastal lagoons is a compartment derived from multiple sources, external ones such as rivers and oceans, as well as internal ones such as organic production, chemical precipitates and erosion of old deposits (Nichols & Bonn, 1994). In these environments, the sediment assumes greater importance since the lagoons are mostly shallow, resulting in a strong influence of this compartment on the water column in relation to other, deeper aquatic ecosystems.

According to Lacerda et al. (1986), understanding these processes controlling nutrient cycling at the level of abiotic compartments necessitates analysis of their distribution along the vertical sediment profile. Analysis of the sediment profile in aquatic ecosystems can furnish a history of past ecological conditions and variations, thus the sediment can be considered as an historical archive of a lake (Smol, 1992).

In the State of Rio de Janeiro there are a large number of coastal lagoons, of utmost importance to the local populace. Nevertheless these environments have been passing through a series of changes, principally because of human influences. For example we have Imboacica Lagoon, which has been subjected to discharge of domestic wastes and to landfills along its shores because of speculation in real estate.

This investigation had as its chief objective the evaluation of changes in concentrations of organic carbon, total nitrogen, available phosphorus and pheopigments, as well as concentrations of the elements K, Na, Ca, Fe, Al and Mg in a vertical profile of the sediments of a coastal lagoon subject to human impact.

STUDY AREA

Imboacica Lagoon is located in the State of Rio de Janeiro (Brazil), in the Municipality of Macaé (22° 50'S - 44° 42'W), about 190 km north of the city of Rio de Janeiro (figure 1). This environment has an area of 3.26 x $10^6 m^2$, maximum depth 2.2 m and mean depth 1.1 m.

The granulometry of the upper sediment layer varies from sand to clay. Near the sea, fine sand (22.29%) and very fine silt (19.28%) predominate. In the littoral zone near the area where the core was collected, very fine silt (24.7%) and clays (15.1%) were found in higher proportion (Gonçalves, pers. comm.).

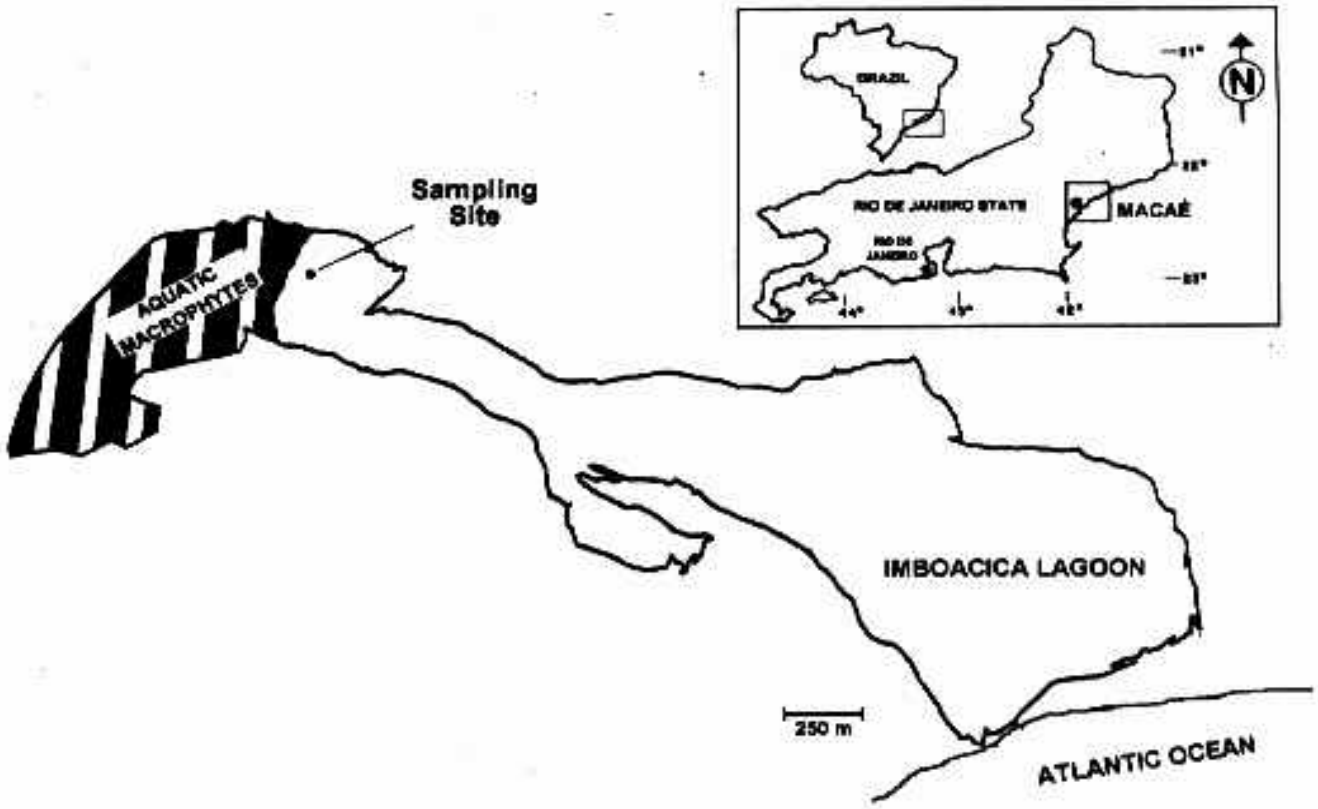

Figure 1. Location of Imboacica Lagoon and of the sediment sampling site.

The littoral zone near the collection point is densely colonized by aquatic macrophytes, chiefly *Typha domingensis* Pers. and *Eleocharis* cf. *fistulosa* (Poir.) Link (Furtado, 1994). At certain times of year, benthic macroalgae (Characeae) are also observed colonizing the limnetic sediment.

Since the end of the 1970's, Imboacica Lagoon has suffered a series of human impacts, such as the discharge of untreated domestic wastes and artificial breaches of the sandbar separating the lagoon from the sea. This environment has also had its water surface reduced about 20% by landfills along its shores. One of these landfills occurred near the area where the sediment was collected.

MATERIAL AND METHODS

The sediment profile was collected in August 1993, with an acrylic tube 1 m long and 8 cm in diameter. The profile was then fractioned every 2 cm in the upper 30 cm and the remainder was fractioned every 3 cm, over a total 75 cm. After collection, the samples were kiln-dried at 70°C, then ground and homogenized, 2 replicas being made in each sample.

The organic carbon content (mmol/g) was obtained by potassium dichromate oxidization (Embrapa, 1975) and that of the total nitrogen (mmol/g) by the Kjeldahl method (Allen et al. 1974). Available phosphate (mmol/g) was extracted with 0.5N HCl as proposed by Esteves (1983) and determined according to Golterman et al. (1978). The concentration of pheopigments (mg/g) in the sediment was determined according to Lorenzen (1974), with 90% acetone extraction.

The concentration of the ions Al, Ca, Fe, K, Mg and Na (ppm) was measured by

extracting in 0.5N HCl (Esteves, 1983)and obtained by atomic absorption spectrophotometry (Jarrel Ash model 975). For determination of the degree of linear association between the sediment constituents analyzed (Pearson's linear correlation), the concentrations obtained at each stratum were used.

RESULTS

The concentrations of the sediment constituents analyzed for the different layers of the profile of Imboacica Lagoon are graphically shown in figure 2. Except for iron, the lowest concentrations are between 10 and 12 cm depth. As with pheopigments, iron showed lowest concentrations below 57 cm.

Most sediment constituents were distributed similarly (figure 2), that is there was a distinct decrease from the 6 cm depth, followed by an increase below 16 cm. Another decrease can be observed beginning at 57 cm.

Available phosphorus and aluminum did not follow this pattern. Both elements showed a very similar distribution (figure 2), where the highest concentrations were found from 51 cm; while most of the other elements showed reduced concentrations.

The only element that did not show a definite pattern of distribution was sodium, differing from all other elements analyzed.

Comparing the concentrations of carbon, nitrogen, available phosphate and pheopigments found between 10 and 12 cm depth, with those found between 16 and 18 cm, a striking reduction of about 90% (C, N and pheopigments) and 45% (available phosphate) was observed.

Table I presents linear correlations between the sediment constituents analyzed. Of the macronutrients (C, N and P), available phosphorus was least correlated with other sediment constituents, except with aluminum where the highest linear correlation (0.9556) was observed. The micronutrients showed low correlations among each other, except for the high correlation between potassium and magnesium (0.8623).

Table I. Pearson's linear correlations of elements analyzed in the vertical profile of the sediments of Imboacica Lagoon. * indicates significant r.

	Carb.	Nitrog	Fosf.	Feop	Al	Ca	Fe	K	Mg
Nitrog	0.8628*								
Fosf.	-0.2123	-0.1074							
Feop	0.9157*	0.8671*	-0.4582						
Al	-0.0489	0.0309	0.9556*	-0.3060					
Ca	0.0515	0.3526	0.1533	0.0839	0.1183				
Fe	0.8375*	0.8962*	-0.3605	0.9096*	-0.2700	0.3188			
K	0.5010	0.5029	0.1860	0.2778	0.6886	-0.0042	0.2596		
Mg	0.8368*	0.7852*	0.1860	-0.0740	0.3201	-0.0280	0.6337	0.8623*	
Na	-0.3679	-0.2534	-0.0683	-0.2891	-0.1794	0.0794	-0.2011	-0.2395	-0.3455

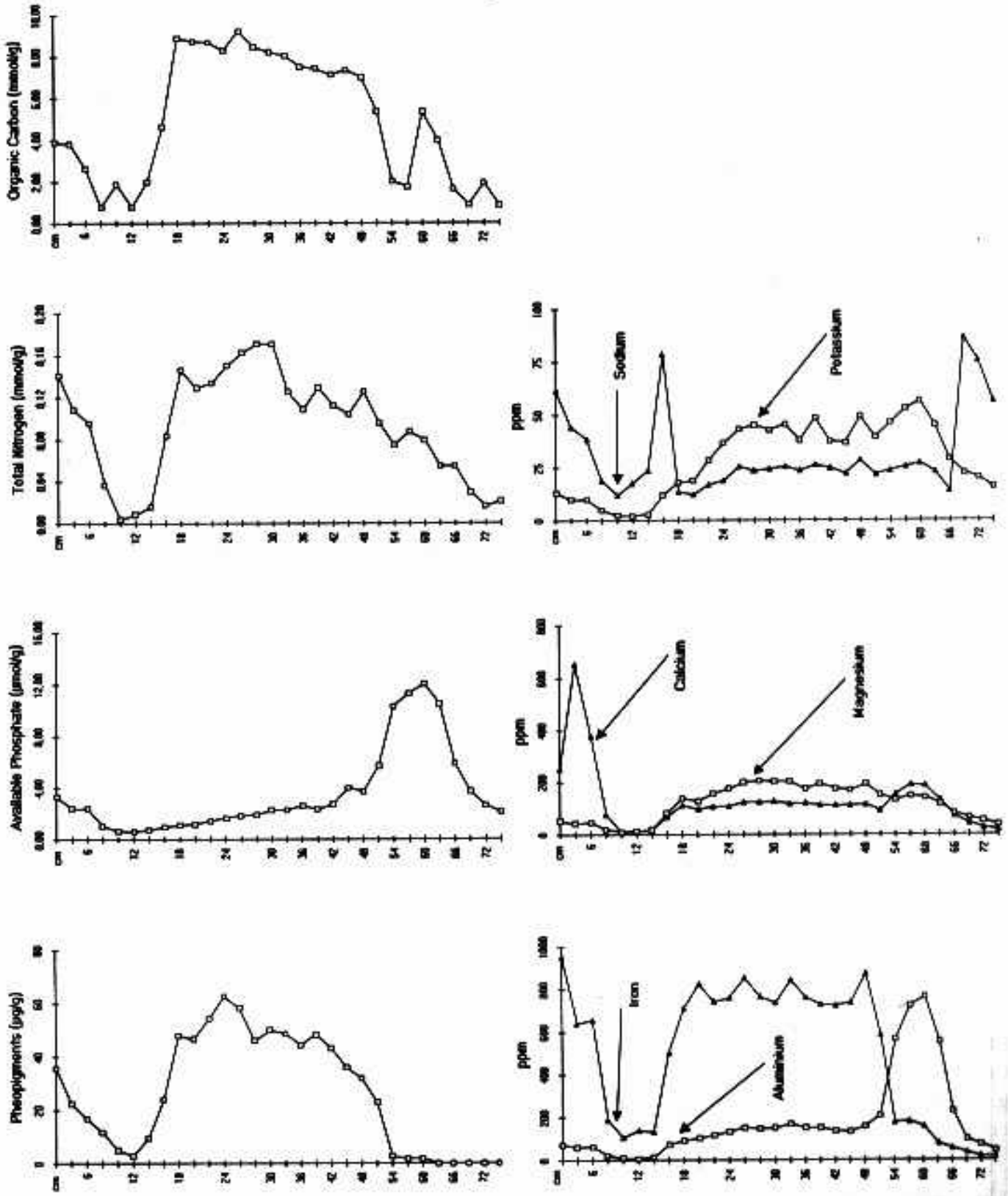

Figure 2. Vertical distribution (75cm) of elements analyzed in the sediment of Imboacica Lagoon.

DISCUSSION

As proposed by several authors, the role of the sediment in nutrient stocking (Margalef, 1986; Daelher et al., 1994; Esteves et al., 1995) may be suggested for Imboacica Lagoon, in view of the higher concentrations of the elements analyzed in the lower layers of the sediment profile.

The values found for the linear correlations between carbon, nitrogen, phosphorus and pheopigments in the profile are close to those found by Furtado et al. (1997), who studied the temporal and spatial variation in this environment for 17 months. Of the elements studied, phosphorus alone showed non-significant correlations. Thus, according to those authors, the principal source of carbon, nitrogen and pheopigments for the lagoon sediment is organic in origin.

The high correlations also found between the elements C, N and pheopigments with K, Mg and Fe may indicate that the origin of these elements is the biological community of the lagoon, principally the aquatic macrophytes present in the littoral region near the sampling point. According to James and Barko (1991), the sediment dynamics of these elements are greatly influenced by the presence of aquatic macrophytes.

Iron and aluminum are elements much associated with continental origin. The concentrations found along the profile may be a result of the influence of the Imboacica River, which carries products of weathering from the mountainous region of its source. A similar process was found in the Lake District, where the sediment is strongly influenced by input of materials derived from the drainage basin (Mackereth, 1965).

Tolentino et al. (1986), studying the chemical composition of 12 lakes in the north of the State of Rio de Janeiro, found comparatively lower concentrations of iron (162 ppm) for Imboacica Lagoon. This may be a function of the sampling point, which was nearer to the sandbar which separates this environment from the sea. This inference is also supported by the greater concentrations of K. Na and Ca (22.7, 3352 and 469 ppm respectively), which are elements typically of marine origin.

The surface concentrations of available phosphorus (0-10 cm) shown by the profile are much lower than the mean values obtained by Esteves (1983) in some reservoirs of the State of São Paulo (7.30 mmol/g). However the author considered the sediment of the reservoirs, with very low phosphorus concentrations. This leads us to believe that in Imboacica Lagoon the phosphorus is rapidly utilized by the primary producers, not premitting greater accumulation of this elements in the sediment. Efficient mineralization of the organic matter with less accumulation in the sediment was suggested by Span et al. (1990) to account for the low concentrations of organic carbon and total nitrogen (0.91 mmol/g and 0.07 mmol/g respectively) found in Lake Geneva. Kemp (1971) suggested the same process for carbon concentrations (0.38 - 1.74 mmol/g) in Lake Erie.

In the case of Imboacica Lagoon, the concentrations of carbon and nitrogen (3,89 and 0,14 mmol/g respectively) found in the first centimeters of the profile may be directly related to the presence of aquatic macrophytes in the littoral zone, an hypothesis also suggested by Lillie and Barko (1990), in Devil's Lake.

Pheopigments are degraded forms of chlorophyll, and if their origin is authochthonous they may be an indicator of the past history of the plant community of aquatic ecosystems (Rai, 1978). The concentrations of pheopigments in the Imboacica lagoon profile are close to those found by Esteves and Camargo (1982) in different reservoirs of the State of São Paulo (varying from 0.34 to 43.15 mg/g).

Esteves et al. (1995) in a study in some lacustrine ecosystems of Espírito Santo, found in Palminhas Lagoon, high concentrations of carbon (7.14 - 8.80 mmol/g), nitrogen (0.458 - 0.595 mmol/g) and pheopigments (153 - 283 mg/g), suggesting that these concentrations were a function of the presence of benthic macroalgae (Characeae). The higher values of these elements observed in the 18 - 48 cm section from Imboacica Lagoon, may also reflect the presence of bethic macroalgae (Characeae), since these are found sporadically in this part of the lagoon.

The results demonstrated a reduction in concentration of all the elements at about 8 to 14 cm depth. This section also showed a different granulometry, that is predominantly sandy sediment. These changes may be closely related to the fact that the shores of this environment underwent a landfill operation at the end of the 1970's, reducing the total lagoon surface by about 20% and bringing in a large amount of allochthonous material.

Rates of sedimentation in coastal lagoons vary according to each environment and often within the lagoon itself. Lagoons of the coast of the Gulf of Mexico (USA) have sedimentation rates from 2.8 to 4.0 mm/year, but the mean sedimentation rate in coastal lagoons is about 1.6 mm/year (Nichols and Boon, 1994). Considering a theoretical vālue of 4.0 mm/year for the sedimentation rate in this part of Imboacica Lagoon, because of the high human influences (landfills), we can propose that the marked reductions of all the elements analyzed in the sediment between 8 and 14 cm are a result of the 1970's landfill.

Imboacica Lagoon undergoes sporadic artificial breaches of the sandbar separating it from the sea, which results in changes in the environment which may influence the sedimentation rate. The existence of coastal lagoons is closely related to their sandbars (Martim and Dominguez, 1994). In order to better understand the formation and evolution of this lagoon, it is necessary to comprehend the mechanisms that produce and maintain the sandbar.

Studies of vertical profiles of the sediment of the coastal lagoons of this part of Rio de Janeiro State are extremely rare and of critical importance to obtain information about human impacts in these continental aquatic ecosystems. In the case of Imboacica Lagoon, the large reductions in the concentrations of certain elements in the 10 to 12 cm section, as well as the high sedimentation rate (theoretical) may result from the landfills of the late 1970's. However this hypothesis should be corroborated and better founded by geological dating of the sediment samples.

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REFERENCES

Allen, S.E.; Grimshaw, H.M.; Parkinson, J.A. and Quarmby, C. 1974. *Chemical Analysis of Ecological Materials*. Oxford, Blackwell Scientific Publications. 565p.

Dachler, C.C.; Baker, M.A.; Merkle, J. and Majumdar, S.K. 1994. Elemental processing in leaf litter and sediments in aquatic systems: effects of anthropogenic pollution. *International Journal of Ecology and Environmental Sciences*, 20: 287-302.

EMBRAPA. 1975. *Manual de análise de solos*. II. SNLCS. (mimeografado).

Esteves, F.A. 1983. Levels of phosphate, calcium, magnesium and organic matter in the sediments of some Brazilian reservoirs and implications for the metabolism of the ecosystems. *Arch. Hydrobiol.*, 96 (2): 129-138.

Esteves, F.A. and Camargo, A.F.M. 1982. Caracterização de sedimentos de 17 reservatórios do Estado de São Paulo com base no teor de feopigmentos, carbono orgânico e nitrogênio orgânico. *Ciência e Cultura*, 34 (5): 669-674.

Esteves, F.A.; Suzuki, M.S; Callisto, M.F.P. & Peres-Neto, P.R. 1995. Teores de matéria orgânica, carbono orgânico, nitrogênio, fósforo e feopigmentos de alguns ecossistemas lacustres do litoral do Estado do Espirito Santo. *Oecologia Brasiliensis*, vol. 1: p. 407-417.

Furtado, A.L.S. 1994. *Contribuição das macrófitas aquáticas Typha domingensis Pers. (Typhaceae) e Eleocharis cf. fistulosa (Poir.) Link (Cyperaceae) para o estoque de nutrientes e energia da lagoa Imboacica (Macaé, RJ)*. Rio de Janeiro, UFRJ. Dissertação de Mestrado. 104p.

Furtado, A.L.S.; Petrucio, M.M. & Esteves, F.A. (1997) C, N, P and pheopigments in the sediment of a Brazilian coastal lagoon (Macaé, Rio de Janeiro). *Rev. Brasil. Biol.* 57(1):127-134

Golterman, H.L.; Clymo, R.S. and Ohmstad, M.A.M. 1978. *Methods for Physical and Chemical Analysis of Fresh Water*. Blackwell Scientific Publ. Oxford. 214p.

James, W.F. and Barko, J.W. 1991. Littoral-pelagic phosphorus dynamics during nighttime convective circulation. *Limnol. Oceanogr.*, 36 (5): 949-960.

Kemp, A.L. 1971. Organic carbon and nitrogen in the surface sediments of lakes Ontario, Erie and Huron. *Journal of Sedimentary Petrology*. vol. 41, no 2, pp. 537-548.

Lacerda, L. D.; Cunha, C.T. e Seeliger, U. 1986. Distribuição de nutrientes em perfis de sedimentos em brejos costeiros tropicais e temperados. *Acta Limnol. Brasil.*, 1: 384-400.

Lillie, R.A. and Barko, J.W. 1990. Influence of sediment and groundwater on the distribution and biomass of *Myriophyllum spicatum* L. in Devil's Lake, Wisconsin. *Journal of Freshwater Ecology*, 5 (4): 417-426.

Lorenzen, C.F. 1974. Chlorophyll-degradation products in sediments of the Black Sea. The Black Sea - geology, chemistry and biology, memoir 20.

Mackereth, F.J.H. 1965. Chemical investigation of lake sediments and their interpretation. *Proc. of the Royal Scenerry*, B, vol. 161, pp. 295-309.

Margalef, R. 1986. *Limnología*. Ed. Omega, S. A., Barcelona.

Martin, L. and Dominguez, J.M.L. 1994. Geological history of coastal lagoons. In: Björn Kjerfve (ed). *Coastal Lagoon Processes.*, 41-68.

Nichols, M.N and Bonn, J.D. 1994. Sediment transport processes in coastal lagoons. In: Björn Kjerfve (ed). *Coastal Lagoon Processes.*, 157-219

Nogueira, F. and Esteves, F.A. 1994. Estoque de nitrogênio e fosfato em diferentes compartimentos de uma lagoa marginal do rio Mogi-Guaçu (SP). *An. Acad. bras. Ci.*, 66 (2): 237-242.

Rai, H., 1978. Distribution of carbon, chlorophyll-a and pheo-pigments in the black water lake ecosysten of the central amazon region. *Arch. Hydrobiol.* 82 1/4 74-87.

Smol, J.P. 1992. Paleolimnologycal: an important tool for effective ecosystem management. *Journal of Aquatic Ecosystem Health*, 1: 49-59.

Span, D.; Arbouille, D.; Howa, h. & Vernet, J.P.1990. Variation of nutrient stocks in the superficial sediments of Lake Geneva from 1978 to 1988. *Hydrobiologia* 207: 161-166.

Tolentino, M.; Esteves, F.A.; Roland, F. and Thomaz, S.M. 1986. Composição química do sedimento de doze lagoas do litoral fluminense e sua utilização na tipologia destes ecossistemas. *Acta Limnol. Brasil.*, 1: 431-447.