ANNUAL DYNAMICS OF DISSOLVED AND PARTICULATE ORGANIC MATTER (C and N) IN A SUB-TROPICAL FLUVIAL-LACUSTRINE SYSTEM (CIMA LAKE - BRAZIL)

Claudia Calasans; Paulo Pedrosa & Carlos Eduardo Rezende[1]
Universidade Estadual do Norte Fluminense
Centro de Biociências e Biotecnologia
Laboratório de Ciências Ambientais
Av. Alberto Lamego, 2000 - Cep. 28015-620

RESUMO

O carbono e nitrogênio orgânico dissolvido e particulado (COD e COP; NOD e NOP, respectivamente) foram analisados em amostras d'água durante um ano no sistema rio Imbé - lagoa de Cima (Estado do Rio de Janeiro, Brasil). A dinâmica da matéria orgânica foi avaliada utilizando-se análise fatorial. As concentrações de COD e NOD variaram de 158 a 803 µM e de 3,3 a 109 µM, enquanto, o COP e o NOP apresentaram suas concentrações variando de 3,44 a 30,3% e de 0,32 a 4,65%, respectivamente. Os maiores valores de COP, NOP, pH e oxigênio dissolvido (OD) assim como as menores razões (C:N)a (Média= 8,2) foram encontradas no sistema lacustre. Comparativamente, nos tributários, as razões COD:COP, NOD:NOP e (C:N)a na fração particulada foram significativamente maiores do que as encontradas no ambiente lacustre, indicando uma importante participação quantitativa de matéria orgânica dissolvida em relação à particulada e uma relevante participação de material vascular no material particulado em suspensão. Nossos resultados sugerem que a porção de matéria orgânica particulada lábil, possui uma contribuição mais pronunciada na lagoa. Isto pode refletir uma importante contribuição de fontes de matéria orgânica autóctones não vasculares (ex. fitoplâncton) na lagoa de Cima. Nos tributários, no período úmido, a matéria orgânica dissolvida foi caracterizada por uma razão $(C:N)_a$ igual a 28, típica de substâncias húmicas, sugerindo uma importante contribuição de material refratário, de origem terrestre, no pool orgânico associado à fração dissolvida, indicando uma importante contribuição de material de origem terrestre para o sistema flúvio-lacustre. Estas relações indicam uma relevante participação da fração dissolvida e detritos de plantas vasculares nos material particulado para estes pontos. No período úmido o COD, NOD, total de sólidos em suspensão (TSS), temperatura (T), profundidade e condutividade elétrica (Cond) apresentaram valores mais elevados, enquanto a transparência (Tr) e o oxigênio dissolvido (OD) foram menores. Nossos resultados mostraram que dois principais fatores explicam a dinâmica da matéria orgânica no sistema: o tipo de ambiente (tributários ou lago) e a sazonalidade (período seco ou úmido).

PALAVRAS CHAVES: Lagoa , Matéria Orgânica, Tributários, Sistema Sub-Tropical.

ABSTRACT

Dissolved and particulate organic carbon and nitrogen (DOC, POC; DON, PON, respectively), were analyzed over an equivalent one-year period in the fluvial-Cima Lake system (Rio de Janeiro State, Brazil). In the system, the dynamic of the organic matter was evaluated on the light of factorial analysis. Overall, DOC and DON concentrations ranged from 158 to 803 µM and from 3.3 to 109 µM respectively. POC and PON concentrations also presented great homogeneities in the system, ranging, respectively, from 3.44 to 30.3% and from 0.32 to 4.65%. The highest values of POC, PON, pH and dissolved oxygen (DO) as well as the lowest particulate $(C:N)_a$ ratios (Avg. = 8.2) were found in the lacustrine system. The latter findings suggested that the proportion of labile particulate organic matter was, comparatively to the other sites, more pronounced in the lake. This likely reflects an important non-vascular autochthonous source of organic matter (e.g., phytoplankton) in Cima Lake. On the other side, in the streams organic matter was characterized by higher DOC:POC, DON:PON and particulate $(C:N)_a$ ratios. It indicated both a major participation of dissolved fraction and vascular plants in the bulk of the organic matter in those sampling sites. DOC, DON, total suspended solids (TSS), temperature (T), depth and electrical conductivity (Cond) presented higher values during the wet season while transparency (Tr) and dissolved oxygen (DO) presented the lower ones. Dissolved organic (C:N)a ratios (Avg. = 28) were characteristic of humic substances, specially in the streams during the wet season, and, thus, may indicate an important terrestrial contribution of refractory dissolved organic matter to the fluvial-lacustrine system. Our results showed that two major factors affect the organic matter dynamics in the system: the environment type (stream or lake) and the seasonality of the rainfall along the year (wet and dry periods).

KEY WORDS: Lake, Organic Matter, Streams, Sub-Tropical System.

INTRODUCTION

Organic matter is an important source of matter and energy, contributing to the maintenance and development of ecosystems (Buffle, 1988; Wetzel, 1993). Since carbon and nitrogen are the major constituents of the organisms, the organic form of these elements can be considered a proxy of organic matter in the ecosystems (e.g. Curtis & Adams, 1995; Heikkinen, 1994; Cadée, 1982).

Dissolved organic carbon and nitrogen (DOC and DON) are composed of complex mixtures of labile and recalcitrant materials, exhibiting a continuum of sizes and chemical characteristics (Hope *et al*., 1994; Schiff *et al*., 1990). DOC and DON plays an important role at ecological level since it can influence surface-water pH by buffering pH changes in acidified waters or by adding acidity to the system. Further, DOC (especially the humic fraction) can also affect nutrient dynamics and the toxicity of pollutants (Kullberg *et al*., 1993). Yet, DOC depletion has also been related to increases in the depth of UV-B penetration in aquatic systems (Yan *et al*., 1996).

Particulate organic matter (POM) is a combination of living organisms (phyto, zoo and bacterioplankton) and non-living organisms in different states of decomposition. Besides being a food resource to aquatic life, POM can be associated with inorganic matrices (e.g. minerals) and ions (e.g. trace metals; Stumm & Morgan, 1981). During the process of sinking toward bottom sediments POM can undergo a series of alterations (early diagenesis), to which typically affects the quality of the organic matter recently buried in the sediments.

In this case, elemental composition is a useful tool for evaluating source signatures and alteration stages of organic materials. This method is suitable for source analyses since there are distinct abundance patterns of biogenic elements in different living organism classes (Hedges, 1990). The relationship between the different constituents involved in the organic matter elemental composition, such as the (C:N)a ratio, can qualitatively indicate the sources involved. Although organic matter elemental composition can be modified by microbial activity during early diagenesis, the magnitude of these changes is not large enough to completely erase the difference between vascular and non-vascular plant debris (Meyers & Ishiwatari, 1993).

According to Wetzel (1993), the main source of dissolved and particulate organic matter in lakes is autochthonous production from the littoral zone (macrophytes and attached microflora) and pelagic autotrophs (primarily the phytoplankton), and allochthonous inputs of terrestrial origin. However, the relative importance of these sources largely depends on the characteristics of the lake and its drainage basin and is also time-dependent.

The present study aimed to provide a spatial and seasonal example of dissolved and particulate C and N in a fluvial-lacustrine system.

Material and Methods

Study Site

The fluvial Cima Lake - a shallow 14 km^2 system - is situated in northeastern Rio de

Janeiro State (41° 41´ - 42° W; 21° 45´ - 22° S). The lake hydrology is mostly regulated by the well-defined inflow of Imbé (principal component) and Urubu stream waters, and by the outflow of lake waters by the Ururaí channel (Fig. 1). Imbé stream flows through a relatively undisturbed and fertile area. Urubu stream drains mainly floodplain areas and in its lower reach it characterized by a sluggish water body.

Fluvial processes from the Quaternary period at the Holocene epoch formed the lake. Imbé watershed is formed on a mix of both Quaternary plains and gneissic-granitic Tertiary shields, with circa of 70% of its total area 100 m above sea level. These shields and plains were formerly dominated by Atlantic forest. About 85% (600 km^2) of the total watershed of the fluvial-lacustrine system is related to Imbé stream. In the last decades these areas have been deforested and replaced by pasture and sugar cane crops. As a result, in the present, there are only patches of the original vegetation. Nowadays the area has been target of a novel profound environmental changes since a series of projects of revitalization and urbanism have been proposed and even initiated by the municipal government, which wishes to improve tourism activities in the local. We hypothesize that land transformation is gradually modifying the organic matter dynamics in the system and the first signals can be seen in particulate and dissolved phases.

Sampling and chemical analyses

Water samples were collected monthly from October 1995 to September 1996. A total of six sites were considered for the present study (Fig. 1). All samples were obtained with a Teflon van Dorn bottle, but those for DOC analyses were collected with an ambar glass bottle. After

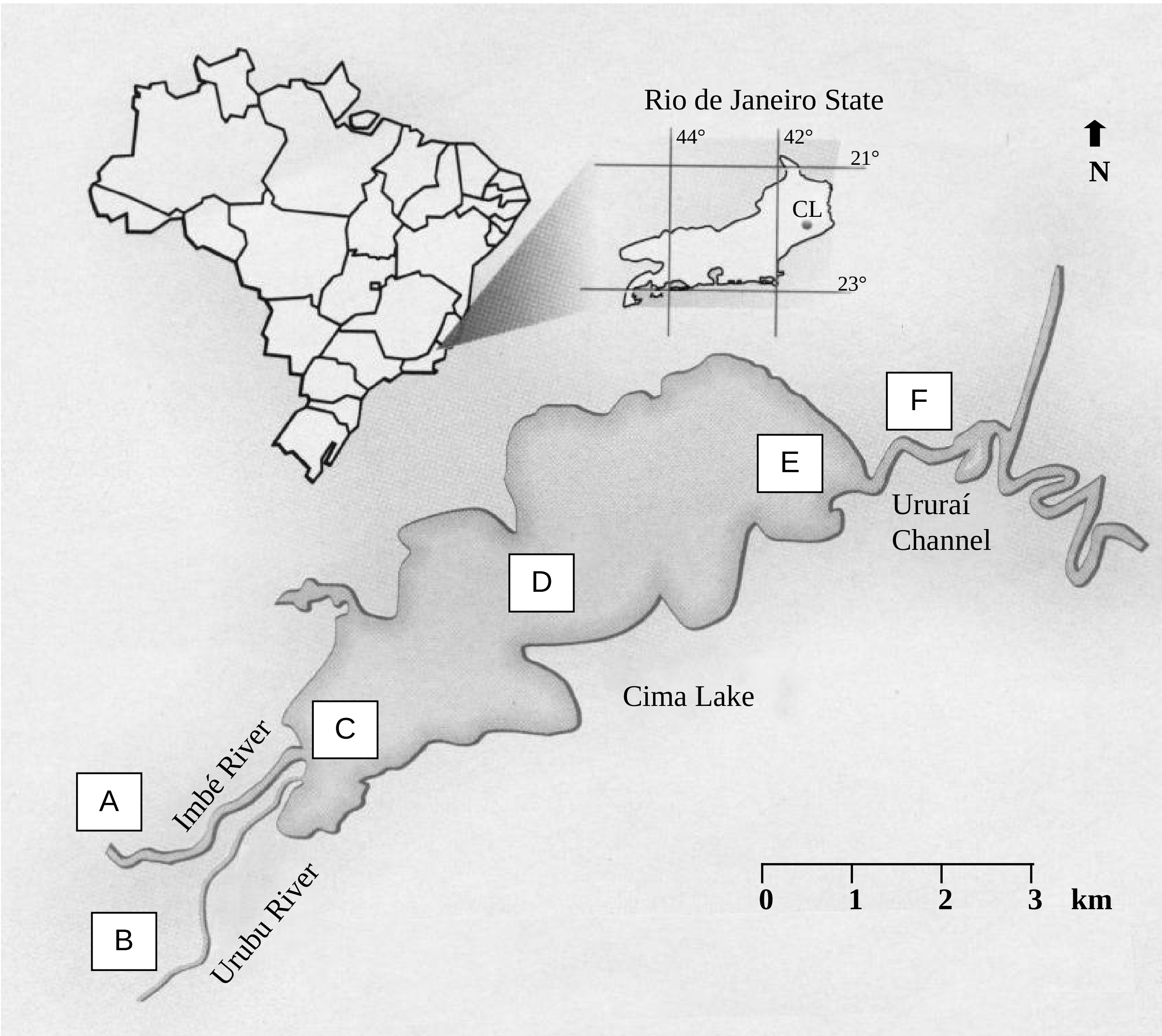

Figure 1 - Study area and sampling sites.

collection, the samples were kept refrigerated and in darkness until transported to the laboratory.

Physico-chemical variables such as dissolved oxygen (DO), temperature (T), conductivity (Cond) and pH were measured *in situ* by portable devices (DO/T - Horiba; Conductibity and pH - WTW/Digimed). Water transparency (Tr) was determined using a *Secchi* Disk.

Total suspended solids (TSS) were determined gravimetrically in samples filtered through GF/F membranes at low pressures (< 0.25 atm). For DOC every filtrate was transferred to amber bottles containing 10 % H_3PO_4 (final proportion of 50mL "H_3PO_4" : mL^{-1} "Water Sample") and stored in a refrigerator until the moment of analysis. Immediately before the DOC analysis samples were acidified (2N HCl) and sparged with ultra pure air, followed by high temperature catalytic oxidation (HTCO) in a TOC-5000 Analyzer (Shimadzu). The material for particulate organic carbon (POC) and nitrogen (PN) analyses was concentrated by centrifugation at 18,780 g for 90 minutes. Comparatively, this process was in average 87% of that obtained by GF/F filtration. Particulate nitrogen and organic carbon were measured in a CHNS/O Analyzer (Perkin Elmer). No acidification was carried out in the samples since carbonates are negligible in the system. Here PN was assumed to be equivalent to particulate organic nitrogen (PON) as the plotting of PN against POC showed a confident linear regression with the intercept close to the zero point. Analytical standard deviations (triplicate) were ± 8 % for TSS, ± 2 % for DOC, ± 2 % for POC and ± 7 % for PON.

Dissolved nitrogen (DN) and the nutrient ammonium (NH_4^+) were determined as described by Grasshoff *et al.*, (1983). Nitrate (NO_3^-) was measured by colorimeter as nitrite (NO_2^-) by flow injection analyses (FIA system, Asia-Ismatec) (Carmouze, 1994). DON concentrations were calculated by subtraction of the sum of inorganic forms (NO_3^- + NO_2^- and NH_4^+) from the DN. Analytical standard deviations (from duplicate or triplicate) were ± 2 % for DN, ± 10 % for (NO_3^- + NO_2^-) and ± 7 % for NH_4^+.

Data on precipitation in the Campos region were obtained from the climatologic station located in the " Universidade Federal Rural do Rio de Janeiro".

Principal component analyses were used to identify the main processes controlling the annual dynamic pathways. This technique has been proven as a useful toll introducing the distribution through their factors along the time and space.

RESULTS

Precipitation regime

The mean monthly precipitation from 1976 to 1996, ranged from 30 mm in June to 146 mm in December (Fig. 2). Typically, the wet season (Avg. = 108 mm) begins in September with the maximal rainfall values occurring in November and December. On the other side, the dry season typically occurs from May to August (Avg. = 35mm).

During the sampling period, precipitation varied from 7 mm in July to 173 mm in September (Fig. 2) and the wet season lasted from October to December (Avg. = 144 mm) with September raining more than usual (Fig. 2). We also observed dry (Avg. = 30 mm; May, June and August) and very dry (Avg. = 10 mm; January, February and July) conditions during the studied period (Fig. 2).

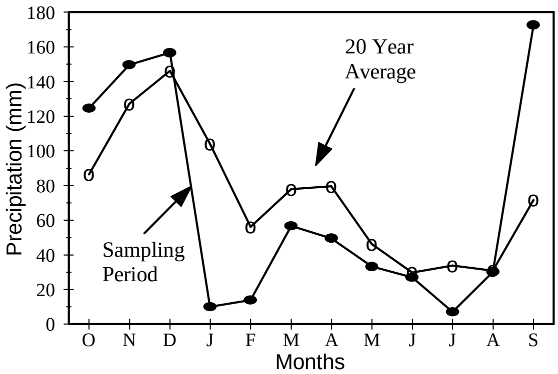

Figure 2 - Precipitation regime in a 20 years-temporal series (monthly mean) and in the sampling period.

Physico-Chemical Variables

Spatial and temporal changes of physico-chemical variables are shown in Tab. 1. Mean depths varied from 1.2 (site A, Imbé stream) to 3.2 m (site D, center of the lake) in the system. Spatial and temporal changes in *Secchi depths* occurred within a narrow intervals, the main exceptions were observed in the streams (A and B). Water temperature was quite similar for all sites, being slightly lower at Imbé stream. Dissolved oxygen showed a clear spatial gradient, with lower values in the streams (A and B) and increasing values toward the lake's center (D) and Ururaí channel (F). In the system DO ranged from 4.1 to 8.7 mg.L^{-1}, respectively, in the Urubu stream (B) and Ururaí channel (F). Seasonal variations were more pronounced in and near the streams (sites A, B and C). The pH values showed similar spatial gradients as described for DO, varying from acid (inlet region) to basic (center of the lake toward outlet). Therefore, pH values extended from 6.0 to 8.2, respectively, at Imbé stream (A) and Ururaí channel (F) (Tab. 1). For conductivity, the highest mean value was found in the Urubu stream (51.5 µS cm^{-1}); all the other sites were close to 30 µS cm^{-1}.

Table 1 - Spatial changes of physico-chemical variables (Average ± Standard Deviation) in Cima Lake water. Temporal variations for the sampling period are given by the standard deviation.

Sampling Sites	Depth (m)	Tr (m)	T (°C)	DO (mg.L^{-1})	pH	Cond (µS.cm^{-1})
A	1.2 ± 0.7	0.7 ± 0.2	23.4 ± 3.3	6.5 ± 1.2	6.0 ± 0.5	28.8 ± 4.1
B	1.9 ± 0.5	0.7 ± 0.3	24.7 ± 3.4	4.1 ± 1.8	6.2 ± 0.4	51.5 ± 11
C	1.9 ± 0.6	0.7 ± 0.1	24.8 ± 3.9	6.6 ± 1.3	6.6 ± 0.4	29.3 ± 3.4
D	3.2 ± 0.5	0.7 ± 0.1	25.7 ± 3.6	8.3 ± 1.1	7.5 ± 0.7	29.6 ± 3.0
E	2.5 ± 0.7	0.6 ± 0.1	25.5 ± 3.4	8.3 ± 0.7	7.7 ± 0.8	30.7 ± 4.6
F	2.0 ± 0.6	0.6 ± 0.1	25.7 ± 3.3	8.7 ± 0.7	8.2 ± 0.7	31.6 ± 5.6
Abbreviations: **Tr** = Transparency; **T** = Temperature and **DO** = Dissolved Oxygen						

Dissolved Organic Carbon

DOC concentrations ranged from 158 to 803 µM (Fig. 3a). The highest DOC concentrations were observed from November to April although a decrease occurred in January and February. From May to August the lowest DOC levels were found and a discrimination between two groups occurred; lower DOC concentrations were found at stations A, B and C compared to stations D, E and F. This spatial difference was also evident in September, but the DOC concentration trend was inverted.

DON concentrations varied from 3.3 to 109 µM (Fig. 3b). The main spatial and seasonal variations in DON concentrations were observed from January to April when sites B, C and E had the highest values. Most of the sites had the lowest DON concentrations in June and July.

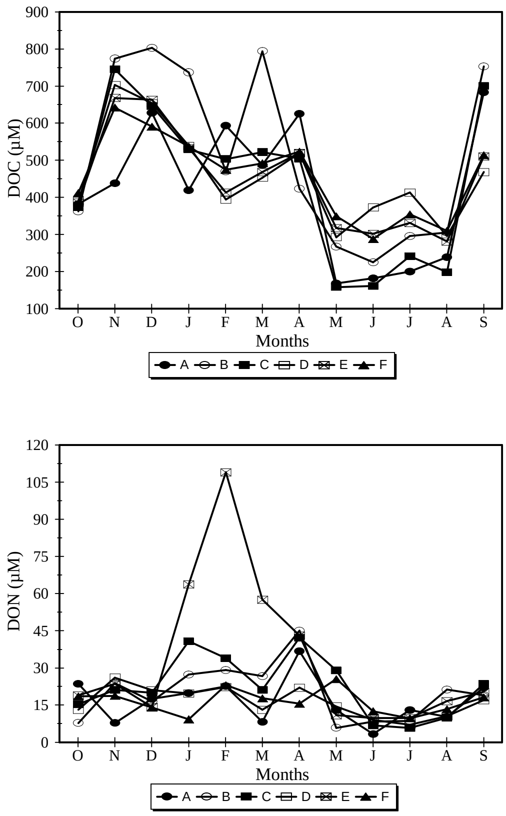

Figure 3 - Spatial and temporal variations of dissolved organic matter in Cima Lake: (a) dissolved organic carbon (b) dissolved organic nitrogen. Circles to streams, squares to lake and triangle to outlet.

Particulate Organic Carbon

TSS concentrations ranged from 2.3 to 50 mg.L^{-1} (Fig. 4a). The highest TSS values were found in December and March, except for sites A, B and E (stream inflows and outflow), which also had high values in August, September and October, respectively (Fig. 4a). The lowest TSS concentrations occurred from April to August.

POC and PON concentrations varied, respectively, from 3.44 to 30.3% and from 0.32 to 4.65% (Fig. 4b and Fig. 4c). The sites were clustered into two groups. Sites A to C (streams and stream-influenced site) had low POC and PON concentrations relative to sites D to F. Pedrosa *et al.* (1999) found a similar trend in the fluvial Cima Lake system, being the POC and PON, at sites D to F, associated to the phytoplankton. Imbé stream (A) had higher POC concentrations in November and January, whereas PON concentrations were fairly constant. In July POC and PON concentrations at site A were also high. Urubu stream (B) had high POC values in November, January and February and high PON concentrations in October, November, January, February and May.

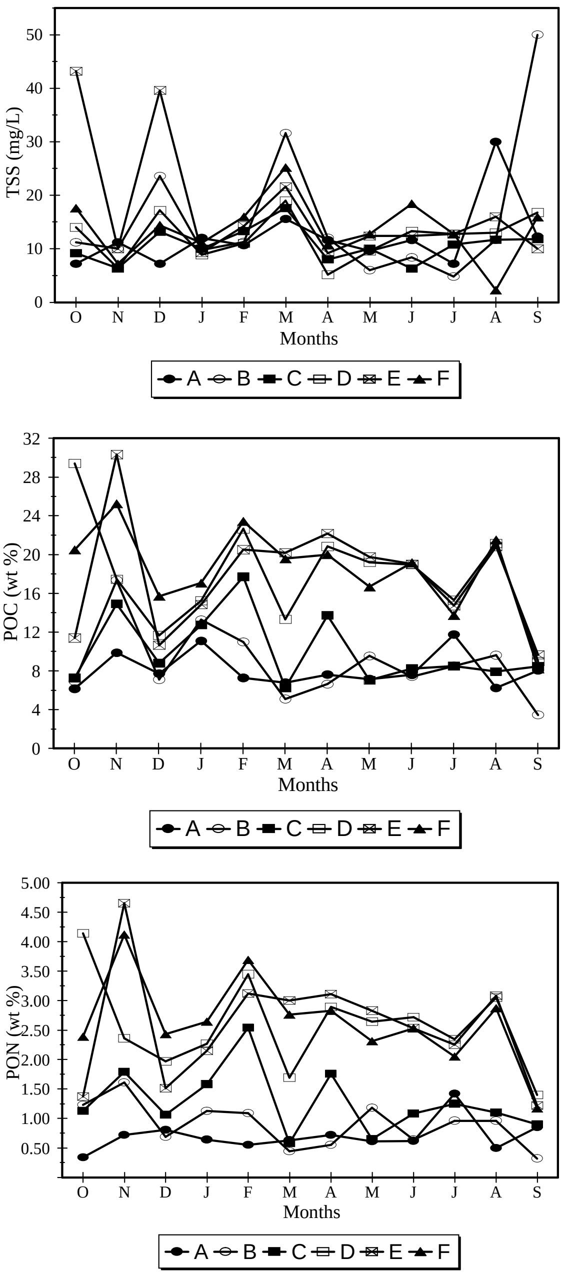

Figure 4 - Spatial and temporal variations of particulate organic matter in Cima Lake: (a) total suspended solids (b) particulate organic carbon (c) particulate organic nitrogen. Circles to streams, squares to lake and triangle to outlet.

In general, at sites D to F, POC and PON concentrations were high in November, February and August. Correlation of particulate organic carbon to particulate nitrogen (Fig. 5) showed that nearly all the nitrogen was in an organic form as the intercept upon extrapolation of the linear regression was close to zero (Hedges *et al.*, 1986).

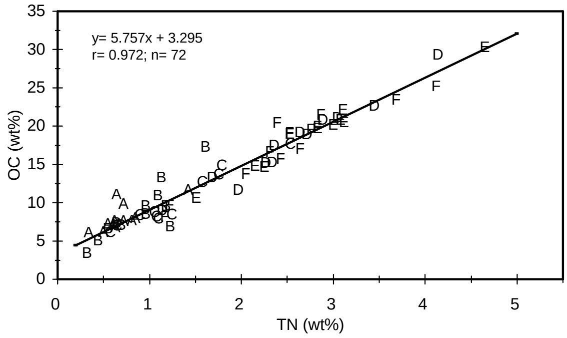

Figure 5 - Weight percent of organic carbon (OC) *vs.* total nitrogen (TN) for particulate matter from all sampled sites, from October, 1995 to September, 1996.

Elemental Composition {$(C:N)_a$ Ratios} and Dissolved *vs.* Particulate Organic Carbon

Elemental composition $(C:N)_a$, DOC:POC and DON:PON ratios are shown in Tab. 2. Mean $(C:N)_a$ ratios in dissolved fraction ranged from 22 to 31 and had a marked seasonal variation. The lowest ratios were observed at sites C and E. Particulate $(C:N)_a$ ratios varied from 8.1 to 14.4. Sites A to C presented the highest values and the most pronounced seasonal variation. Sites D to F showed similar ratios, which did not have a large seasonal change. Dissolved $(C:N)_a$ ratios were consistently higher than those found for the particulate fraction.

Table 2 - Spatial changes of (C:N)a, DOC:POC and DON:PON ratios (Average ± Standard Deviation) in Cima lake water. Temporal variations for the sampling period are given by the standard deviation.

Sampling Sites	(C:N)a Dissolved	(C:N) Particulate	DOC:POC	DON:PON
A	30.9 ± 17.3	14.4 ± 3.6	6.2 ± 3.8	3.8 ± 3.6
B	30.9 ± 13.0	11.9 ± 2.2	5.6 ± 1.4	2.8 ± 2.3
C	23.2 ± 10.8	9.6 ± 1.7	5.2 ± 2.3	2.6 ± 1.6
D	30.6 ± 10.7	8.1 ± 0.6	3.2 ± 2.0	0.9 ± 0.7
E	22.0 ± 12.7	8.3 ± 0.7	2.4 ± 1.6	1.4 ± 1.4
F	30.2 ± 11.7	8.2 ± 0.8	2.9 ± 1.9	0.9 ± 0.7

Mean DOC:POC and DON:PON ratios ranged, respectively, from 2.4 to 6.2 and from 0.9 to 3.8. For both DOC:POC and DON:PON ratios, sites A to C had the highest values compared to sites D to F. Seasonal variations in DOC:POC and DON:PON ratios were quite high for all sites although no definite pattern was observed.

DISCUSSION

We compare our findings from the fluvial Cima Lake system to other aquatic systems including non-tropical and larger fluvial and lacustrine systems. In fact, shallow tropical and sub-tropical lakes and also small streams are few studied for the parameters analyzed here. Del Giorgio & Peters (1994), working in northern temperate lakes (Quebec), found mean summer DOC concentrations ranging from 225 to 625 µM. Curtis & Adams (1995) observed DON values ranging from 71 to 250 µM for some freshwater temperate lakes. For riverine systems, Ertel *et al*. (1986) reported summer DOC concentrations varying from 298 to 900 µM in the Amazon River and its tributaries. In a time series study of two small streams (channel width £ 1 m) from contrasting catchments of the central Amazon basin, McClain *et al.* (1997) found DOC and DON averages, respectively, of 3,170 µM and 53 µM for Campina and of 371 µM and 13 µM for Barro Branco stations. Except for the DOC concentrations measured by McClain *et al.* (1997) for Campina station, DOC and DON concentrations found in the Cima Lake system were similar to those reported in the literature.

Mean annual POC and PON values found for Imbé (POC = 79 mM; PON = 5.8 mM) and Urubu (POC = 94 mM; PON = 8.0 mM) streams were more similar to fine (OC, Avg. = 151 mM; TN, Avg. = 14 mM) than to coarse (OC, Avg. = 26 mM; TN, Avg. = 1.2 mM) sedimentary or suspended particulate organic matter reported by Hedges *et al.* (1994) for the Amazon River. Hecky *et al.* (1993) reported extremely high values for some shallow tropical lakes (Kyoga Lake POC = 608 µM and PN = 58 µM; George Lake POC = 4,160 µM and PN = 210 µM). However, mean POC and PN values found by these authors for deep tropical lakes were 56 µM and 5 µM, respectively. For the Cima Lake itself and for site F, which is clearly influenced by the lake water, mean annual concentrations of POC (176 µM) and PON (21 µM) fell between those values found for other shallow and some deep tropical lakes.

Monthly precipitation was positively correlated with depth (r_s = 0.451; $p<0.01$) and TSS (r_s = 0.253; $p<0.05$). These correlations suggest that during the wet periods there was a clear input of allochthonous material to the aquatic system. This process, input of allochthonous material, seemed to be more important for the streams than to the lake.

DOC was positively correlated with precipitation (r_s = 0.569; $p<0.01$), depth (r_s = 0.598; $p<0.01$), conductivity (r_s = 0.290; $p<0.05$), and TSS (r_s = 0.235; $p<0.05$) and negatively correlated with DO (r_s = -0.489; $p<0.01$). It suggests a preferential leaching of soil organic matter during high precipitation events. The fact that DOC was also positively correlated to temperature (r_s = 0.489; $p<0.01$) and DON (r_s = 0.245; $p<0.05$) might indicate, at least for the lake sites, a DOC leaching from phytoplankton and some macrophytes. Heikkinen (1994) found some important autochthonous DOC sources in a Finnish humic river in the summer, when DOC was supposed to be partly composed by algae exudates.

DON was correlated to temperature (r_s = 0.499; $p<0.01$). We hypothesize that autochthonous production, especially during the summer (December to February), is an important DON source to the system. Maximal DON values have been reported for some lakes in the summer (e.g. Lawrence Lake, Wetzel, 1993). It has been reported in literature that algae may secrete several simple and complex organic nitrogen compounds. These compounds, such as polypeptides, have also been found to be secreted by large aquatic plants and in cases where the littoral zone is broadly developed; these secretions can be the major source of organic nitrogen to the lake (Wetzel, 1993 and references therein). Aquatic macrophytes are present at site B and close to site C, which might contribute with DON to the system. Sites C and E are also located near a sugar cane crop, and the agricultural use (fertilizer) of by-products derived from sugar cane industrialization may act as an anthropogenic DON source.

Dissolved (C:N)a ratios in the fluvial Cima Lake system fell within the range of 28 to 52 described by Hedges *et al*. (1994) and that of 25 to 73 reported by McClain *et al*. (1997) for the ultrafiltered dissolved organic matter in rivers of the Amazon region. Curtis & Adams (1995) observed that (C:N)a ratios of dissolved organic matter in some Canadian lakes ranged from 30 to 80. These values are characteristic of dissolved humic substances (e.g. Ertel *et al*., 1986) and, predominantly to the streams, suggest a significant contribution of these materials from soil leachates during the wet season and also from macrophyte debris. However, especially to the lake sites, where sedimentary organic matter contents are higher the participation of extensively degraded DOC fractions from sediments can not be disregarded (Calasans, 1996).

POC and PON were positively correlated with temperature (respectively, r_s = 0.379 and r_s = 0.350; p<0.01), pH (respectively, r_s = 0.754 and rs = 0.770; p<0.01), and dissolved oxygen (respectively, r_s = 0.430 and r_s = 0.502; p<0.01), likely reflecting a contribution of autochthonous primary production to particulate organic matter in the system. Spatial trends and the negative correlation of both POC and PON to particulate (C:N)a ratios (respectively, r_s = -0.537 and r_s = -0.682; p<0.01) reinforce our assumptions. For the lake sites (D and E) and site F, particulate (C:N)a ratios were within the range of 7.7 to 10.1 described by Holligan *et al*. (1984) as an indicator of phytoplanktonic source. Hecky *et al*. (1993) reported (C:N)a values for tropical lakes as ranging from 9.6 to 19.8. However, it is also important to emphasize the potential influence of N-limitation on the metabolism of phytoplankton which can result in higher (C:N)a ratios (Pedrosa *et al*., 1999).

Particulate (C:N)a ratios were also positively correlated with DOC:POC (r_s = 0.399; p<0.01). Particulate (C:N)a ratios for Imbé and Urubu streams were similar to the mean found for some soils of the region [(C:N)a = 13, unpublished data] reflecting a potential allochthonous contribution for the particulate organic matter, especially during storm events. In general, particulate (C:N)a ratios found in the Cima Lake system resembled the mean value for fine suspended or sedimentary particulate organic matter [(C:N)a = 11] rather than those for coarse particulate material [(C:N)a = 21] reported by Hedges *et al*. (1994) for the Amazon River. These findings suggest a major contribution of N-rich fine materials for the particulate matter of Imbé and Urubu streams.

It has been widely reported in the literature that the major fraction of organic carbon in most natural waters is in a dissolved rather than in a particulate form (e.g. Wetzel, 1993, Hope *et al*., 1994). DOC:POC ratios vary between 6 and 10; this range is typically for lacustrine and stream environments (Wetzel & Rich, 1973 *apud* Wetzel, 1993). DOC:POC ratios found for Imbé and Urubu streams usually fell within this range. During the dry periods these ratios decrease. This pattern was especially noteworthy for Imbé stream and it was attributed to bottom resuspension of sediments during the dry season. Since phytoplanktonic production seems to be markedly higher in the lake sites and Ururaí channel, POC becomes the dominant form of carbon as reflected by decreased DOC:POC ratios at these sites.

Similarly to carbon, DON:PON ratios ranges from 5 to 10 in lakes and streams (Wetzel, 1993 and references therein). DON:PON ratios, especially at sites D, E and F, were lower than these reported ranges, possibly reflecting rapid mineralization of DON and reassimilation by phytoplankton.

Principal components analysis (Fig. 6) indicates that two factors can explain 48 % of the observed variation. The first factor (I), responsible for 29 % of the variation, was assumed to be the type of the aquatic environment (stream or lake) because a clear differentiation was observed between the results from the streams and the lake. Thus, high positive values associated with factor I indicate lake sources while more negative values indicate fluvial origin. Sites C and F were grouped with either the streams or the lake since they were unambiguously influenced by them. POC, PON, pH and DO were strongly influenced by the environment, showing the highest values at the lake (Fig. 6). pH presented a strong relation to POC and PON reinforcing the influence of phytoplanktonic production at the lake. Slow flushing lake waters quite favor the development of the phytoplankton community in the lacustrine system. On the other hand, stream sources were strongly associated with higher conductivity, DOC:POC, DON:PON and particulate (C:N)a ratios, indicating a predominance of allochthonous organic matter inputs. Pedrosa *et al*. (1999) observed that chlorophyll a and carotenoids concentrations increase from streams (sites A and B) to site C towards Ururaí channel (site F). Moreover, microscopic observations showed that detritus dominated suspended particulate matter in the streams whereas in Cima Lake and Ururaí channel the particulate matter was virtually comprised by phytoplankters.

The second factor (II) accounted for 19 % of the variation and was attributed to rainfall. Positive and negative values to factor II are related, respectively, to wet and dry periods. DOC, DON, TSS, T, depth and Cond showed high values during the wet season with an opposite trend to Tr and DO.

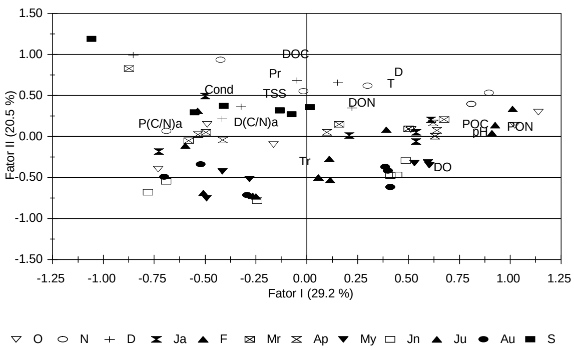

Figure 6 - Principal component analysis showing the main factors associated to the observed variations.

Organic matter composition and dynamics, especially in the streams, was the result of two processes; (1) leaching of highly degraded dissolved fractions (N-poor) from soil organic matter and (2) selective sorption of hydrophobic N-rich molecules onto soil minerals. This is consistent with the regional chromatography model described by Hedges *et al*. (1994) for the Amazon region. The coexistence of N-poor dissolved organic matter and N-rich fine particulate material at Cima Lake have supported the evidence to this model. However, we lack qualitative information (e.g. amino acid analyses) to evaluate this hypothesis in necessary and recently several works have been done to confirm the model existence (Silva & Rezende, 2002; Correia, 2001). In Cima Lake phytoplankton primary productivity is the dominant source of organic matter and thus POC must be strongly influenced by the ecological dynamic of these organisms (Pedrosa, *et al*. 1999). During the wet season, however, allochthonous inputs might also be an important source of organic matter to the lacustrine system (Calasans, 1998).

In summary, dissolved and particulate organic matter dynamics change spatially and seasonally. The relative importance of allochthonous and autochthonous sources changed between the streams and lake. The wet season was evidently the controlling factor of allochthonous inputs of extensively re-worked soil organic matter, especially to the fluvial sites. Autochthonous sources were related to phytoplankton production and this, in turn, reflected the environment's type (lacustrine sites). However, site peculiarities such as macrophyte colonization may act as an additional autochthonous source of dissolved and particulate organic matter during characteristic seasons.

ACKNOWLEDGMENTS

We are indebted to Arizolli Antônio Rosa Gobo, Mônica Aparecida Leite da Silva, Vitor Guimarães Correia and Wanderson Primo for sampling and analytical assistance. The authors would also like to thank Dr. Richard G. Keil and B.Sc. Dan Donato for reviewing drafts of this manuscript and an anonymous reviewer for the final comments. Financial support for this paper was provided by the FINEP, Universidade Estadual do Norte Fluminense, Fundação de Amparo a Pesquisa do Estado do Rio de Janeiro and Conselho Nacional de Desenvolvimento Científico e Tecnológico (Proc. 400300/95-8 to CCVC and Proc. 521965/96-9 to CER). This is a contribution 001 of the Ecology and Natural Resource Program of the Universidade Estadual do Norte Fluminense of Centro de Biociências e Biotecnologia.

REFERENCES

BUFFLE, J. (1988) Complexation Reactions in Aquatic Systems - an Analytical Approach. Ellis Horwood Limited, Chichester.

CADEÉ, G.C. (1982) Tidal and seasonal variation in particulate and dissolved organic carbon in the western dutch Wadden sea and Marsdiep tidal inlet. Nether. J. Sea Res. 15, 228-249.

CALASANS, C.F.; SILVA M.A.L.; REZENDE C.E. (1996) Elemental composition of sediments of a freshwater lagoon (Cima Lagoon - Brazil) and surrounding soils. *In*: Bottrell SH (Ed) Fourth International Symposium on the Geochemistry of the Earth's Surface (pp 275-279). 22-28 July, Ilkley, Yorkshire, England.

CALASANS, C. (1998) Origem e dinâmica da matéria orgânica em um sistema fluvio – lacustre da região Norte Fluminense. D.Sc. Thesis , Campos dos Goytacazes - RJ, Centro de Biociências e Biotecnologia, Universidade Estadual do Norte Fluminense - UENF; 100 pp.

CARMOUZE, J-P. (1994) O metabolismo dos ecossistemas aquáticos: fundamentos teóricos, métodos de estudo e análises químicas. Editora Edgard Blücher/Fapesp, São Paulo, 254 p.

CORREIA, V.G. (2001) O uso da análise da composição de aminoácidos na determinação de fontes e estado de alteração da matéria orgânica em um sistema Fluvio-Lacustre da região Norte Fluminense. M.Sc. Thesis , Campos dos Goytacazes - RJ, Centro de Biociências e Biotecnologia, Universidade Estadual do Norte Fluminense - UENF; 84 pp.

CURTIS, P.J. & ADAMS, H.E. (1995) Dissolved organic matter quantity and quality from freshwater and saltwater lakes in east-central Alberta. Biogeochemistry 30, 59-76.

DEL GIORGIO, P.A. & PETERS, R.H. (1994) Patterns in planktonic P:R ratios in lakes: influence of lake trophy and dissolved organic carbon. Limnol. Oceanogr. 39, 772-787.

ERTEL, J.R.; HEDGES, J.I,; DEVOL, A.H.; RICHEY, J.E.; RIBEIRO, M.N.G. (1986) Dissolved humic substances of the Amazon River system. Limnol. Oceanogr. 31, 739-754.

GRASSHOFF, K.A.; EHRHARDT, M.; KREMLING, K. (1983) Methods of Seawater Analysis. Verlag Chemie, Weinheim. 419p.

HECKY, R.E.; CAMPBELL, P.; HENDZEL, L.L. (1993) The stoichiometry of carbon, nitrogen, and phosphorus in particulate matter of lakes and oceans. Limnol. Oceanogr. 38, 709-724.

HEDGES, J.I.; CLARK, W.A.; QUAY, P.D.; RICHEY, J.E.; DEVOL, A.H.; SANTOS, U.M. (1986) Compositions and fluxes of particulate organic material in the Amazon River. Limnol. Oceanogr. 31, 717-738.

HEDGES, J.I. (1990) Compositional indicators of organic acid sources and reactions in natural environments. *In*: Organic Acids in Aquatic Ecosystems. E.M. Perdue. e E.T. Gjessing (Eds.). Dahlem Konferenzen, 1990; 43-63.

HEDGES, J.I.; COWIE, G.L.; RICHEY, J.E.; QUAY, P.D. (1994) Origins and processing of organic matter in the Amazon River as indicated by carbohydrates and amino acids. Limnol. Oceanogr. 39, 743-761.

HEIKKINEN, K. (1994) Organic matter, iron and nutrient transport and nature of dissolved organic matter in the drainage basin of a boreal humic river in northern Finland. The Sci. Tot. Environ. 152, 81-89.

HOPE, D.; BILLETT, M.F.; CRESSER, M.S. (1994) A review of the export of carbon in river water: fluxes and processes. Environ. Poll. 84, 301-324.

KULLBERG, A.; BISHOP, K.H.; HARGEBY, A.; JANSSON, M.; PETERSEN, R.C. (1993) The ecological significance of dissolved organic carbon in acidified waters. Ambio 22, 331-337.

McCLAIN, M.E.; RICHEY, J.E.; Brandes, J.A.; Pimentel, T.P. (1997) Dissolved organic matter and terrestrial-lotic linkages in the central Amazon basin of Brazil. Global Biogeoch. Cycles 11: 295-311.

MEYERS, P.A. & ISHIWATARI, R. (1993) The early diagenesis of organic matter in lacustrine sediments. *In*: Organic Geochemistry - Principles and Applications. M. H. Engel, S. A. Macko (Eds.), New York: Plenum Press, 1993; 861 pp.

PEDROSA, P.; CALASANS, C.V.C.; REZENDE, C.E. (1999) Particulate and dissolved phases as indicators of limnological and ecophysiological spatial variation in Cima Lake system, Brazil: A case study. Hydrobiologia 411 (1-3), 89-101.

SCHIFF, S.L.; ARAVENA, R.; TRUMBORE, S.E.; DILLON, P.J. (1990) Dissolved organic carbon cycling in forested watersheds: a carbon isotope approach. Wat. Resour. Res. 26, 2949-2957.

STUMM, W. & MORGAN, J. (1981) Aquatic Chemistry. 2nd Edition, John Wiley, New York. 780p

SILVA, M.A.L. & REZENDE, C.E. (2002) Behavior of selected micro and trace elements and organic matter in sediments of a freshwater system in south-east Brazil.

YAN, N.D.; KELLER, W.; SCULLY, N.M.; LEAN, D.R.S.; DILLON, P.J. (1996) Increased UV-B penetration in a lake owing to drought-induced acidification. Nature 381, 141-143.

WETZEL, R.G. (1993) Limnologia. Fundação Calouste Gulgenkian, 2ª Edição. 919p.

(Footnotes)

[1] To whom the correspondence should be sent: crezende@uenf.br;
Phone: 22 2726 1688; Fax: 22 2726 1472