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DYNAMICS OF NITRIFICATION IN A OXBOW LAKE IN TROPICAL FLOODPLAIN RIVER

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Resumo

Foram estimadas taxas de nitrificação no sedimento e coluna de água de duas estações de coleta da Lagoa do Infernão, para dois períodos hidrológicos distintos (período seco e chuvoso). Este corpo de água corresponde a uma lagoa marginal rasa da planície de inundação do Rio Mogi Guaçu, localizada na Estação Ecológica de Jataí, Estado de São Paulo, Brasil. O método utilizado foi a incorporação de ^{14}C-bicarbonato, com e sem nitrapirina (N-Serve). Durante Fevereiro a Abril (período chuvoso) as taxas de nitrificação variaram entre 0,14 a 4,84 e de 0,02 a 0,68 mgN/m^3/h para amostras de sedimento e água, respectivamente. De Julho a Setembro (período seco) estas taxas variaram entre 1,93 a 8,04 e de 0,05 a 1,16 mgN/m^3/h para sedimento e amostras de água, respectivamente. Não foram observadas diferenças estatisticamente significativas das taxas de nitrificação entre as estações de coletas e entre as profundidades observadas; Entretanto, diferenças significativas foram observadas entre os períodos hidrológicos, independente da estação de coleta e profundidade observada. O aporte de nitrogênio inorgânico no período chuvoso não reverteu em taxas de nitrificação significativas, em decorrência de condições ambientais inadequadas (principalmente baixa oxigenação da coluna de água) e da assimilação de nutrientes pelos compartimentos produtores. A maior disponibilidade de N-NH_4^-, proveniente da mineralização da matéria orgânica, e condição de oxigenação adequada possibilitaram maiores taxas de nitrificação no período seco. A grandeza destes valores demonstram que o significado ecológico da nitrificação na Lagoa do Infernão, é quantitativamente mínimo, quando comparado com os processos de mineralização e assimilação de N-NH_4^-, a qual pode ser considerada o caminho preferencial da dinâmica dos compostos nitrogenados no sistema em questão.

Palavras-chave: nitrificação, dinâmica do nitrogênio, nitrapirina, lagoa marginal.

Abstract

Nitrification rates were estimated in the sediment and water column at two sampling stations in Infernão Lake, during two distinct hydrological periods (dry and wet seasons). This water body is a shallow oxbow lake of the Mogi Guaçu River floodplain, located at the Ecological Station of Jatai, in the State of São Paulo, Brazil. The method used was ^{14}C-bicarbonate incorporation with and without nitrapyrin (N-Serve). From February to April (wet season), these rates were 0.14 to 4.84 and 0.02 to 0.68 mgN/m^3/h, for sediments and water, respectively. From July to September (dry season), these rates were 1.93 to 8.04 and 0.05 to 1.16 mgN/m^3/h, for sediments and water, respectively. No statistically significant differences between nitrification rates for different depths and sampling stations were found; however, significant differences were observed between hydrological periods, independent of station and depth. Inorganic nitrogen input in the wet season was not reflected in significant nitrification rates, as a result of unfavorable environmental conditions (chiefly low oxygen) and of assimilation by producers. Greater availability of N-NH_4^-, from organic matter mineralization, and adequate environmental conditions permitted higher nitrification rates in 0the dry season. The magnitudes of these rates demonstrated that the ecological significance of this process in Infernão Lake is quantitatively minimal compared to the mineralization and ammonium assimilation processes, which can be considered the preferential pathways for transformation of nitrogen compounds in the system.

Key-words: nitrification, nitrogen dynamics, nitrapyrin, oxbow lake.

Introduction

Limnological studies of nitrogen dynamics have been concerned with determination of the concentrations of nitrogen compounds, assimilation of its inorganic forms, and ammonium regeneration (Klingensmith & Alexander, 1983), as well as with obtaining knowledge of the pathways and transformation rates of the nitrogen compounds participating in specific processes (Miller *et al.,* 1986).

Nitrate production, referred to as nitrification, is a primary consequence of biological oxidation of ammonium (Takahashi *et al.,* 1982). Nitrate concentration in the environment is a result of the balance between nitrification, assimilation and denitrification, with maximum levels occurring during periods of high oxygen concentrations and low organic productivity (Chen *et al.,* 1972). The ecological importance of nitrification lies in the potential oxygen consumption from the environment, in the supply of nitrogen for the biotic community, and mainly in constituting the link between the stages of oxidation (biological fixation) and reduction (denitrification) of the nitrogen cycle (Keeney, 1973; Downes, 1988).

Oxbow lakes of the Mogi Guaçu River floodplain are fundamentally characterized on the basis of the periodicity of their hydrological cycle, giving rise to contrasting ecological conditions, with, principally, more reducing conditions in the wet season than in the dry season (Ballester & Santos, 1997; Freitas, 1989; Krusche, 1989; Esteves *et al.,* 1991; Feresin, 1991; Obara & Santos, 1996), and greater nutrient consumption (Coutinho, 1990; Dias Jr., 1990; Silva, 1990), leading to different responses in some stages of the nitrogen dynamics in relation to the hydrological cycle (Ballester & Santos, 1997; Esteves *et al.,* 1991; Obara & Santos, 1996; Gianotti & Santos, 1997). In this context, the objective of the present work was to ascertain the qualitative and quantitative ecological significance of the nitrification process for nitrogen dynamics in one of these lakes (Infernão Lake), by estimating the nitrification activity in sediment and water samples.

Site Information

Infernão Lake is one of the group of 15 lakes on the floodplain of the Mogi Guaçu River within the boundaries of the Jataí Ecological Station, municipality of Luiz Antônio, São Paulo State, Brazil (Fig. 1). The lake is horseshoe-shaped, small (area 3.05 ha) and shallow (maximum depth 4.9 m in the low-water period), and is connected with the river only during high water periods. Its littoral supports dense growths of different species of aquatic macrophytes, 30% of the total lake area being occupied by a floating mixed stand formed mostly by *Scirpus cubensis* Poepp & Kunth and *Eichhornia azurea* Kunth. These macrophytes directly influence the thermal stratification and dissolved oxygen patterns of the littoral zone (Nogueira *et al.,* 1996).

Two sampling stations were established for the present study (Fig. 1), one in the littoral zone, covered by the bank of aquatic macrophytes (Station I), the other more central, without plant cover (Station II). Collections were made monthly, during two distinct hydrological periods according to the precipitation regime and the lake flooding

(Ballester, 1994), i.e. in months representative of the high-water season (February, March and April 1990) and the low-water season (July, August and September 1990).

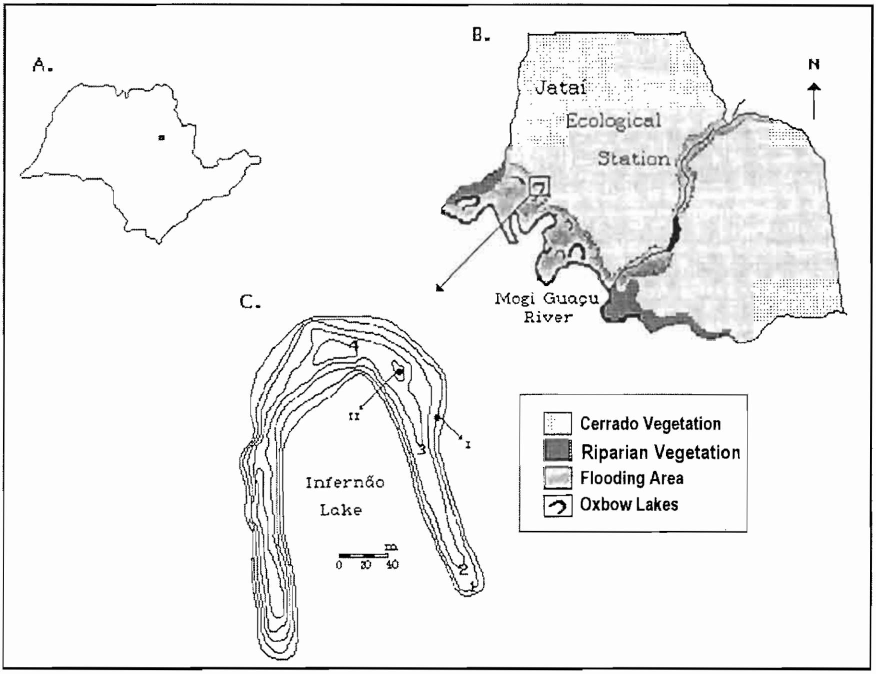

Figure 1. A. Location of the Jataí Ecological Station in the State of São Paulo. B. Vegetation and hydrographic map of the Jataí Ecological Station and locations of the oxbow lakes (approximate scale 1:95600). C. Morphometry of Infernão Lake showing depth intervals (1, 2, 3 and 4 m) and location of Sampling Stations I and II.

Material and Methods

Sediment samples were obtained with a modified collector as described by Ambuhl & Buhrer (1975), and the upper 5 cm used, part for determination of organic matter by weight loss after ignition, and part for determination of in situ nitrifying activity. The interstitial water was extracted to a depth of 5 cm, using minipiezometers attached to a manual vacuum pump, and alkalinity (Gran, 1952) and concentrations of $N\text{-}NH_4^-$ (Krug *et al.,* 1983), $N\text{-}NO_3^-$ and $N\text{-}NO_2^-$ (Giné, 1980) were determined. The pH and temperature at the sediment-water interface were also determined.

Samples from the water surface and at 0.5 m above the sediment were collected with a Van Dorn bottle and used for determination of pH, temperature, dissolved oxygen (Golterman *et al.,* 1978), alkalinity, and inorganic-N ($N\text{-}NH_4^+$, $N\text{-}NO_3^-$ and $N\text{-}NO_2^-$), and estimation of in situ nitrifying activity. The concentration of dissolved inorganic carbon was calculated from the total alkalinity of the samples from the water column and the sediment interstitial water (Mackereth *et al.,* 1978).

Nitrification rates were estimated from dark uptake of ^{14}C-HCO_3^- in samples with and without nitrapyrin (Billen, 1976; Somville, 1978; Vincent & Downes, 1981). Triplicate samples from the water column and the sediment (sediment samples were suspended in water from the sampling site, in a 1:50 proportion), from both sampling stations, were preincubated with nitrapyrin dissolved in acetone (5mg/l nitrapyrin final concentration) or an equal volume of acetone (control) for 1 hour. Next, $NaH^{14}CO_3^-$ (activity 7.9 mCi/ml) was added to the samples and these were incubated in situ for four more hours. At the end of the experiment, the samples were vacuum-filtered (30 ml for water column samples and 5 ml for sediment samples) through 0.45 mm cellulose-acetate membranes. After being dried, the membranes were read in a liquid scintillation counter. The results, expressed as $mgC/m^3/h$, were calculated as a function of the following factors: difference between samples not inhibited and inhibited with nitrapyrin, concentration of dissolved inorganic carbon and ^{14}C-HCO_3^- added, and volume and incubation time of samples (Vincent & Downes, 1981). From these values, the nitrification rate ($mgN/m^3/h$) was calculated using a conversion factor (Belser, 1984). The results were compared statistically by the Mann-Whitney Test.

Results and Discussion

The results of the physical and chemical variables of the sediment and interstitial water, and of the water column, respectively, at different depths, for both sampling stations, and for each hydrological period studied, are shown in Tables I and II. During the rainy season, for the system as a whole, independent of sampling station, and sample type (sediment or water column), more reducing conditions (as indicated by lower dissolved oxygen levels and higher pH values), reduced water transparency and lower concentrations of inorganic N were evident. The predominant form of inorganic N in the interstitial water and in the water column was N-NH_4^+, independent of sampling station and hydrological period. N-NO_2^- sampled quantitatively in the interstitial water was detected when N-NO_3^- and N-NH_4^+ also showed higher concentrations during the dry period.

Sediment and water column nitrification rates (Tables I and II, respectively) showed different behavior during each hydrological period, independent of sampling stations and collection depths, with higher values during the dry period. The rates varied from 0.14 to 4.84 and 0.02 to 0.68 $mgN/m^3/h$ for the sediment and water column, respectively, during the rainy season, and from 1.93 to 8.04 and 0.05 to 1.16 $mgN/m^3/h$ for the sediment and water column, respectively, during the dry season. The sediment as well as the water column showed statistically significant differences (95% confidence level) in measured nitrification rates between the different hydrological periods; however, no such difference was observed between the stations and water depths.

Higher nitrification rates during the dry period for the sediment (Fig. 2) and water column (Fig. 3), at both sampling stations, resulted from the better oxygenation conditions and greater availability of N-NH_4^+ in the system at that time. Lower nitrification rates in the rainy season suggest a greater ecological significance, in quantitative terms, of this process during the dry season, when the system is more dependent on its own dynamics with relation to nitrogen cycling.

Table I. Physical and chemical variables of sediment and intersticial water (*) and sediment nitrification rate for the two sampling stations (St.), during wet (Feb. – Apr.) and dry (July – Sept.) periods.

Month	St.	Temp. (°C)	pH	%OM	ALK. mEq/l	$N\text{-}NH_4^{+(*)}$ mg/l	$N\text{-}NO_2^{-(*)}$ mg/l	$N\text{-}NO_3^{-(*)}$ mg/l	Nitrification $mgN/m^3/h$
Feb.	I	28	6.25	30.9	-	1160.0	<	21.5	2.01
	II	26	6.19	25.6	-	984.4	<	30.9	4.84
Mar.	I	27	6.54	23.4	-	1450.4	<	16.8	0.14
	II	25	6.12	23.6	-	1382.6	<	15.4	0.28
Mar.	I	25	6.36	20.7	482.5	779.9	<	10.3	0.84
	II	25	6.24	21.4	379.2	850.3	<	10.3	0.34
Apr.	I	24	6.65	25.0	560.8	1130.6	<	34.4	1.45
	II	24	6.48	25.1	274.2	987.5	<	26.4	1.46
July	I	19	5.79	26.4	735.0	6075.0	329.7	576.1	3.16
	II	18	5.35	26.8	778.3	4139.0	239.9	425.5	4.46
Aug.	I	19	5.25	25.4	375.0	7520.0	214.3	1194.6	2.03
	II	19	5.58	27.4	547.5	5409.5	332.9	1305.6	1.93
Sept.	I	22	5.74	26.5	279.2	7450.0	240.7	1510.7	8.04
	II	21	5.82	27.5	128.3	6336.0	124.4	1342.2	7.39

(<) Value lower than detection level of method (10mg/l).
(-) No data.
(% OM) Percentage organic matter
(ALK) Total alkalinity.

The preliminary conceptual model, represented in Fig. 4, was proposed in an attempt to illustrate the nitrification behavior in relation to nitrogen dynamics and periodicity of the hydrological cycle in Infernão Lake.

Input of water in the rainy season and consequent contribution of inorganic-N and organic matter caused a reduction in transparency and oxygenation of the water column. However, the lower availability of inorganic-N observed in the rainy season is explained by increases in phytoplankton productivity (Dias Jr., 1990; Silva, 1990) and biomass of aquatic macrophytes (Nogueira *et al.,* 1996) via assimilation from their roots (Coutinho, 1990), which appear to function as veritable pumps extracting the nutrients from the sediment (Santos *et al.,* 1986). Responses of biotic and abiotic structural and functional parameters similar to those observed in Infernão Lake are considered typical of ecosystems maintained by pulse mechanisms, which are represented by the periodic fluctuation in water levels, and are considered a principal driving force in the productivity of these systems (Junk *et al.,* 1989). However, it must be emphasized that the change in ecological conditions in Infernão Lake in relation to the addition of water in the rainy season is, basically, much more a consequence of the processes of infiltration and surface drainage, than of the nature of the waters of the main floodplain channel.

Table II. Physical and chemical variables in the water column and nitrification rate for the two sampling stations (St.), during wet (Feb. – Apr.) and dry (July – Sept.) periods.

Month	St.	Depth	Secchi (m)	Temp. (°C)	pH	D.O. % sat.	Alk. mEq/l	$N\text{-}NH_4^+$ mg/l	$N\text{-}NO_2^-$ mg/l	$N\text{-}NO_3^-$ mg/l	Nitrification $mgN/m^3/h$
Feb.	I	0.0	0.85	30	6.7	35	-	11.5	<	<	0.52
		1.5		28	6.6	45	-	29.9	<	<	0.43
	II	0.0	1.25	28	6.5	115	-	15.2	<	<	0.19
		3.0		26	6.3	15	-	40.9	<	<	0.23
Mar.	I	0.0	1.25	32	6.8	-	-	20.7	<	<	0.03
		2.5		29	6.3	-	-	64.4	<	<	0.03
	II	0.0	1.5	28	6.4	55	-	9.6	<	<	0.02
		4.0		27	6.7	-	-	48.2	<	<	0.03
Mar.	I	0.0	0.75	30	6.8	46	266	9.6	<	<	0.05
		2.5		28	6.6	16	148	15.2	<	<	0.04
	II	0.0	1.25	31	6.5	115	171	28.0	<	<	0.02
		3.5		28	6.5	15	57.5	18.8	<	<	0.03
Apr.	I	0.0	0.5	27	6.8	34	153	39.1	<	<	0.68
		2.0		25	6.7	-	179	17.0	<	<	0.66
	II	0.0	0.75	25	6.7	28	94.2	26.2	<	<	0.34
		3.5		24	6.6	21	158	33.5	<	<	0.44
July	I	0.0	1.5	21	5.9	140	108	104.2	<	<	0.05
		1.2		19	5.6	110	156	88.2	<	<	0.38
	II	0.0	2.5	19	5.4	128	203	92.6	<	<	0.29
		2.7		18	5.7	115	50.1	83.8	<	<	0.09
Aug.	I	0.0	1.25	20	5.7	135	214	99.3	<	<	0.21
		1.5		19	5.9	85	147	108.2	<	<	0.16
	II	0.0	2.25	20	5.9	140	65.1	88.2	<	<	1.03
		3.0		19	5.6	95	450	94.9	<	<	0.18
Sept.	I	0.0	1.75	21	6.1	140	50.7	104.5	<	<	0.26
		2.5		20	5.8	95	70.5	94.7	<	<	1.16
	II	0.0	1.75	20	6.2	140	137	54.2	<	<	0.69
		3.0		19	5.9	85	193	89.8	<	<	0.77

(<) Value lower than detection level of method (10mg/l).
(-) No data.
(D.O.) Dissolved oxygen.
(ALK) Total alkalinity.

Regarding the influence of the hydrological cycle, the Mogi Guaçu River has a unimodal inundation period, which occurs in rapid pulses (Krusche, 1989). However, the influence of the invasion of the main channel water on Infernão Lake is minimized by the distance between these two ecosystems, so that the latter can be characterized as an infiltration lake. During sampling in the rainy season, we verified that the water level of the lake fluctuated considerably over a short period of time (a few days); because of this fluctuation, some samples may have reflected more direct influences than those of the hydrological period as a whole. Thus, the higher nitrification rates observed in February at the two sampling stations, for both water column and sediment, may have resulted from the entrance of $N\text{-}NH_4^+$ and of nitrifying bacteria from adjacent areas as a result of a period of intense rain, similar to that observed by Freitas (1989) for total heterotrophic bacteria.

In view of the ecological conditions established by the low levels of oxygen saturation and $N\text{-}NH_4^+$ availability, nitrification was of minimal ecological significance in the rainy season, in supplying nitrate to the producer component. The low nutrient concentrations in the water column (Albuquerque & Mozeto, 1997; Nogueira *et al.,* 1996) have indicated the sediment to be the principal storage compartment of the system. In this context, it was established that heterotrophic biological nitrogen fixation contributes only 2% to the stock of this element in Infernão Lake (Ballester & Santos, 1997). Moreover, these same ecological conditions make possible higher rates of denitrification (Gianotti & Santos, 1997), permitting us to consider this process the preferential pathway of $N\text{-}NO_3^-$ reduction during the period in question.

The greater availability of $N\text{-}NH_4^+$, derived from mineralization of organic matter accumulated in the rainy season or from decomposition of aquatic macrophytes, associated with better oxygenation conditions, may have influenced the increase in nitrification rates observed for the dry season. The presence, although in a low quantity, of oxidized forms ($N\text{-}NO_2^-$ and $N\text{-}NO_3^-$) in the sediment (Table I) may

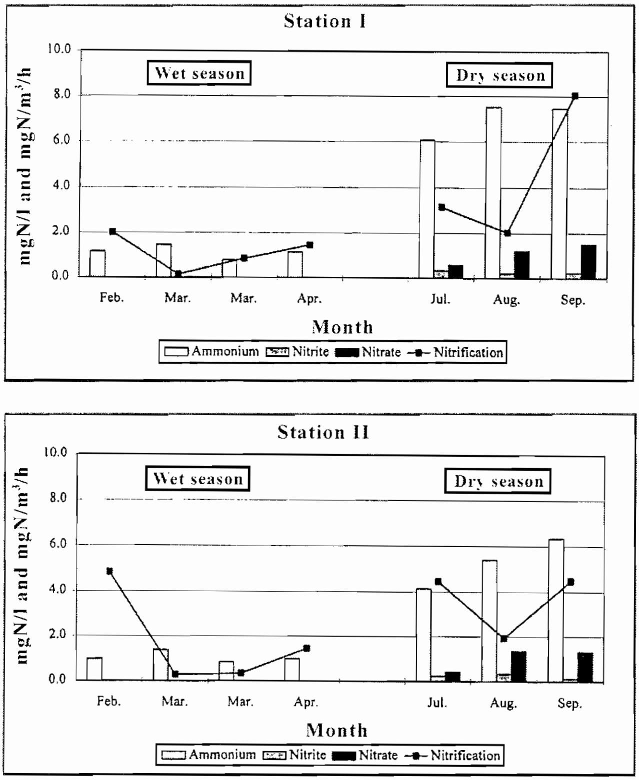

Figure 2. Variation of nitrification rates and concentration of inorganic forms of nitrogen in the sediment of Stations I and II during wet (Feb. – Apr.) and dry (July – Sept.) periods.

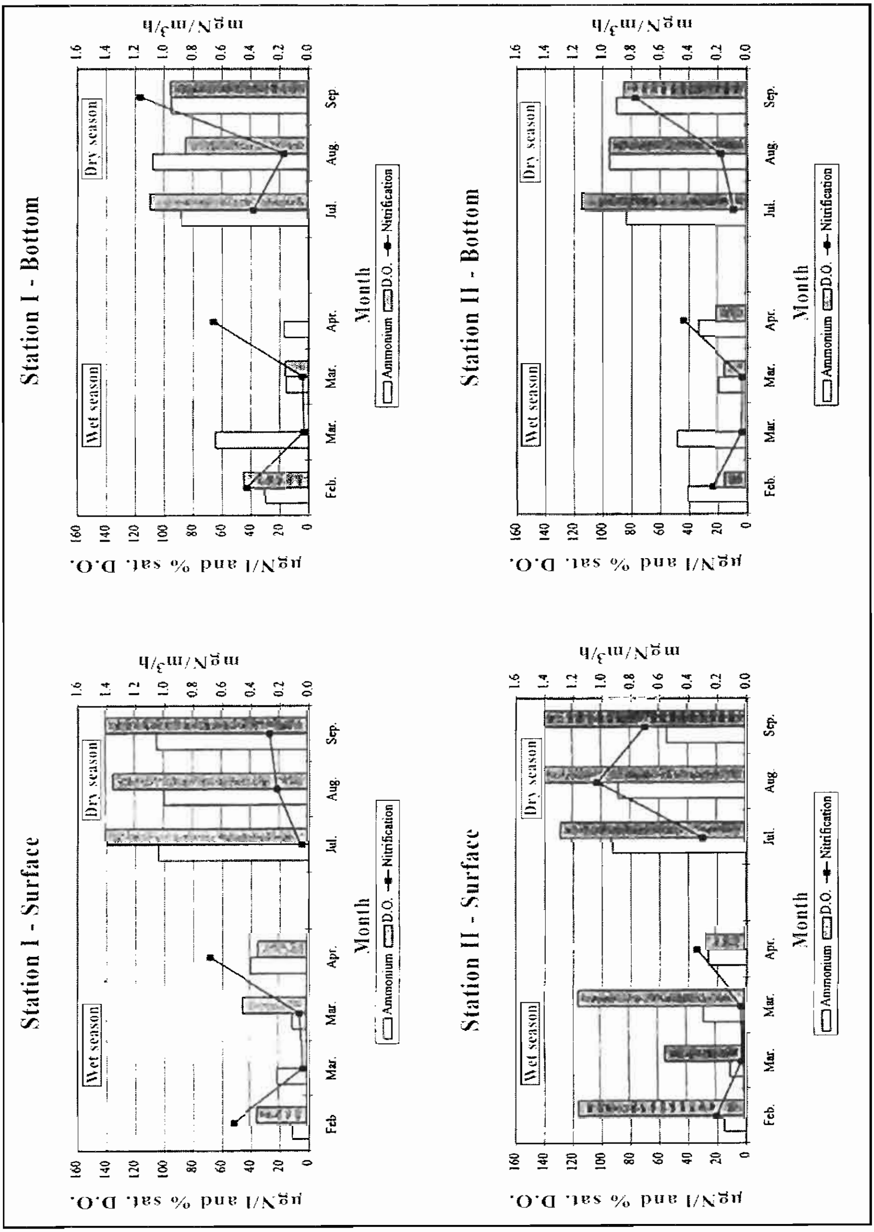

Figure 3. Variation of nitrification rates, ammonium concentration and dissolved oxygen saturation levels for the surface and near-bottom of the water column at Stations I and II, during wet (Feb. – Apr.) and dry (July – Sept.) periods.

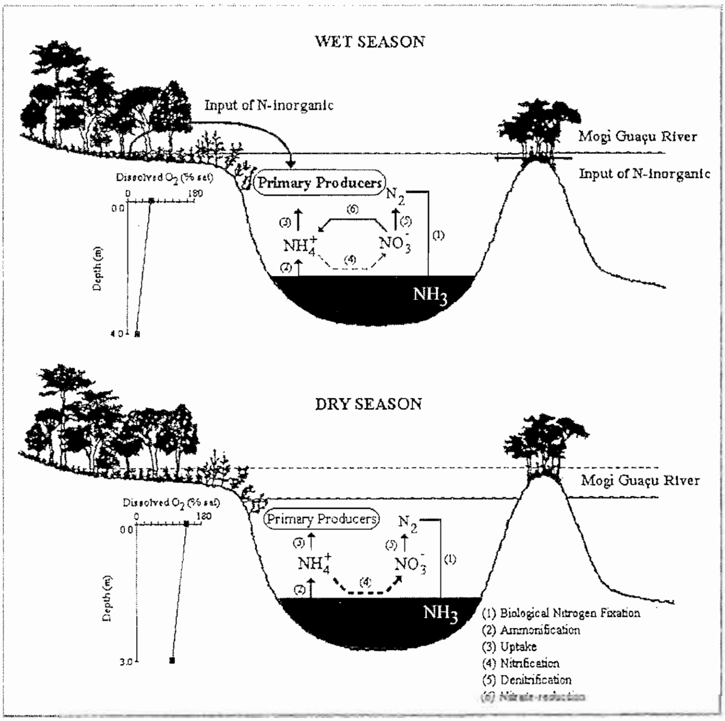

Figure 4. Preliminary simplified conceptual model of the processes of formation and utilization of nitrogen compounds in Infernão Lake during the two hydrological periods studied, in relation to environmental oxygenation conditions and nutrient input. Width of arrows indicates intensity of process.

be a result of this activity. In spite of the presence of N-NO_3^- in the sediment, the rates of denitrification (Gianoti, 1994) and biological fixation of the element (Ballester & Santos, 1997) have been found to be lower for the dry period, probably as a result of inhibition by high oxygen concentrations of these processes. Sediment resuspension by wind action, together with the shallower depths at that time, could probably have contributed to the greater availability of N-NH_4^- during the dry period. For some temperate zone lakes, peak nitrifying activity has been observed during the winter, due to the influence of these factors (Cavari, 1977; Christofi *et al.,* 1981).

In environments characterized by changes in ecological conditions because of influences from the floodplain, and with a high density of aquatic macrophytes, such as Infernão Lake, the most significant stages of the nitrogen cycle are related to ammonification and consequent uptake of N-NH_4^- by the lake biota (Howard-Williams *et al.,* 1989). In this context, the nitrification rate is quantitatively most significant, during the dry season, in furnishing part of the N-NO_3^- requirement for the autotrophic community of Infernão Lake, while the sediment always occupies the role of the largest storage component and supplier of nutrients in this system. In the rainy season, the ecological significance of nitrification is limited by the input of inorganic-N coming from adjacent areas and by the ecological conditions established in the system.

References

ALBUQUERQUE, A.L.S. & A.A. MOZETO 1997. C:N:P ratios and stable carbon isotope composition as indicators of organic matter sources in a riverine wetland system (Mogi-Guaçu River, São Paulo, Brazil). *Wetlands*, **17**: 1–9.

AMBUHL, H. & H. BUHRER 1975. Zur tecnick der entnahme ungestorer grosse proben von sedimenten; ein verbesserters bohrlot. *Schweiz. Z. Hydrol.*, **37**: 175-186.

BALLESTER, M.V.R. 1994. *Dinâmica de gases biogênicos (CH_4, CO_2 e O_2) na planície de inundação do RioMogi Guaçu (Estação Ecológica de Jataí, Luiz Antonio, SP).* São Carlos, UFSCar. Dissertation, 172p.

BALLESTER, M.V.R. & J.E. SANTOS 1997. Fixação biológica do nitrogênio no sedimento de uma lagoa marginal do Rio Mogi Guaçu (Lagoa do Infernão, SP). *Anais VIII Sem. Reg. Ecologia,* **I**: 209-219.

BELSER, L.W. 1984, Bicarbonate uptake by nitrifiers: effects of growth rate, pH, substrate concentration, and metabolic inhibitors. *Appl. Environ. Microbiol.*, **48**: 1100-1104.

BILLEN, G. 1976. Evaluation of nitrifying activity in sediments by dark ^{14}C-bicarbonate incorporation. *Water Res.*, **10**: 51-57.

CAVARI, B.Z. 1977. Nitrification potential and factors governing the rate of nitrification in Lake Kinneret. *Oikos*, **28**: 285-290.

CHEN, R.L.; D.R. KEENEY & J.G. KONRAD 1972. Nitrification in sediments of selected Wisconsin lakes. *J. Environ. Quality,* **1**: 151-154.

CHRISTOFI, N.; T. PRESTON & W.D.P. STEWART 1981. Endogeneous nitrate production in an experimental enclosure during summer stratification. *Water Res.*, **15**: 343-349.

COUTINHO, M.E. 1990. *Ecologia populacional de* Eichhornia azurea *Kunth e sua participação na dinâmica da vegetação aquática da Lagoa do Infernão, SP).* São Carlos, UFSCar, MsC Dissertação,145p.

DIAS Jr., C. 1990. *Ciclo anual do fitoplâncton e algumas variáveis ambientais na Lagoa do Infernão (SP).* São Carlos, UFSCar, MSc. Dissertation,108p.

DOWNES, M.T. 1988. Aquatic nitrogen transformations at low oxygen concentrations. *Appl. Environ. Microbiol.*, **54**: 172-175.

ESTEVES, M.R.; M.C.F. PONTES; M.V.R. BALLESTER & J.E. SANTOS 1991. Fixação do nitrogênio (redução do acetileno) em filosfera de *Nymphoides indica* (L.) O. Kuntze. *Acta Limnol. Brasiliensia*, **III**: 517–543.

FERESIN, E.G. 1991. *Nitrificação em uma lagoa marginal do Rio Mogi Guaçu (Lagoa do Infernão, Estação Ecológica de Jataí, Luiz Antônio, SP)*. São Carlos, UFSCar, MSc. Dissertation, 77p.

FREITAS, E.A.C. 1989. *Bactérias do sedimento da Lagoa do Infernão (Luiz Antonio, SP): distribuição temporal e composição por grupos produtores de exoenzimas.* São Carlos, UFSCar, MSc. Dissertation,100p.

GIANOTTI, E.P. 1994. *Desnitrificação em uma lagoa marginal do Rio Mogi-Guaçu, Lagoa do Infernão, Estação Ecológica do Jataí, Luiz Antônio - SP.* São Carlos, UFSCar, PhD Thesis.

GIANOTTI, E.P. & J.E. SANTOS 1997. Denitrification in a oxbow lake in the floodplain of the Mogi-Guaçu River : Infernão Lake, Jatai Ecological Station, State of São Paulo, Brazil. *Verh. Internat. Verein. Limnol.*, **26**: 305–308.

GINÉ, M.F. 1980. Simultaneous determination of nitrate and nitrite by flow injection analyses. *Anal. Chem. Acta*, **114**: 191-197.

GOLTERMAN, H.L.; R.S. CLYMO & M.A.M. OHNSTAD 1978. *Methods for physical and chemical analyses of freshwaters.* 2nd ed. IBP 8. Blackwell Scientific Publications. Oxford, 215p.

GRAN, G. 1952. Determination of the equivalence point in potentiometric tritations. Part II. *Analyst*, **77**: 661-671.

HOWARD-WILLIAMS, C.; F.A. ESTEVES; J.E. SANTOS & M.T. DOWNES 1989. Short term nitrogen dynamics in a small Brazilian wetland lake (Lago Infernão, São Paulo). *J. Tropical Ecology*, **5**: 323-335.

JUNK, W.J. P.B. BAYLEY & R.E. SPARKS 1989. The flood pulse concept in river-floodplain systems. pp.: 110-127. In: DODGE, D.P. (ed.): *Proceedings of The International Large River Symposium (LARS)*. Can. Spec. Publ. Fish. Aquat. Sci. Vol. 106.

KEENEY, D.R. 1973. The nitrogen cycle in sediment-water systems. *J. Environ Quality*, **1**: 15-29.

KLINGENSMITH, K.M. & V. ALEXANDER 1983. Sediment nitrification, denitrification and nitrous oxide production in a deep arctic lake. *Appl. Environ. Microbiol.*, **46**: 1084-1092.

KRUG, F.J.; B.F. REIS; M.F. GINÉ; E.A.G. ZAGATTO; J.R. FERREIRA & A.O. JACINTHO 1983. Zone trapping in flow injection analysis. *Anal. Chem. Acta*, **151**: 39-48.

KRUSHE, A.V. 1989. *Caracterização biogeoquímica da Lagoa do Diogo, uma lagoa marginal do Rio Mogi Guaçu (Estação Ecológica de Jataí, Luiz Antonio, SP).* São Carlos, UFSCar, MSc. Dissertation, 79p.

MACKERETH, F.J.H.; J. HERON & J.F. TALLING 1978. *Water analyses: some revised methods for limnologists.* Biol. Assoc. Scientific Publications, vol. 36. 121 p.

MILLER, L.G.; R.S. OREMLAND & S. PAULSEN 1986. Measurement of nitrous oxide reductase activity in aquatic sediments. *Appl. Environ. Microbiol.*, **51**(1): 18-24.

NOGUEIRA, F.; F.A. ESTEVES & A.E. PRAST 1996. Nitrogen and phosphorus concentration of different structures of the aquatic macrophytes *Eichhornia azurea* Kunth e *Scirpus cubensis* Poepp in relation to water level variation in Lagoa do Infernão (São Paulo, Brazil). *Hydrobiologia*, **328**: 199–205.

OBARA, A.T. & J.E. SANTO, 1996. Fixação do nitrogênio via diazotróficos perifíticos em raízes de *Scirpus cubenis* (Lagoa do Infernão, Estação Ecológica de Jataí, Luiz Antônio, SP). *Anais VII Sem. Reg. Ecologia,* **I**: 1-13.

SANTOS, J.E.; F.A. ESTEVES; C.F. MENEZES & R. BARBIERI 1986. Fixação de nitrogênio em rizosfera de macrófitas aquáticas. *Acta Limnol. Brasil.*, **1**: 341-362.

SILVA, A.C. 1990. *Produção primária e excreção da matéria orgânica dissolvida de populações fitoplanctônicas da Lagoa do Infernão-Estação Ecológica de Jataí -SP-Variação anual e diurna.* São Carlos, UFSCar, MSc. Dissertation, 102p.

SOMVILLE, M. 1978. A method for the measurement of nitrification rates in water. *Water Res.*, **12**: 843-848.

TAKAHASHI, M.; T. YOSHIOKA & Y. SAIJO 1982. Nitrogen metabolism in Lake Kisaki, Japan III. Active nitrification in early summer. *Arch. Hydrobiol.*, **93**: 272-286.

VINCENT, W.F. & M.T. DOWNES 1981. Nitrate accumulation in aerobic hypolimnia: relative importance of benthic and planktonic nitrifiers in an oligotrophic lake. *Appl. Environ. Microbiol.* **42**: 565-573.

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