The effect of temperature on the glucose cycling and oxygen uptake rates in the Infernão Lagoon water, state of São Paulo, Brazil

Rogério Marchetto Antonio[1]* and Irineu Bianchini Junior[2]

*[1]Programa de Pós-Graduação em Ecologia e Recursos Naturais (PPG-ERN), Universidade Federal de São Carlos C.P. 676, 13565-905, São Carlos, São Paulo, Brasil. [2]Departamento de Hidrobiologia, PPGERN, Universidade Federal de São Carlos, C.P. 676, 13565-905, São Carlos, São Paulo, Brasil. *Author for correspondence. e-mail: pantonio@iris.ufscar.br and rogermarchetto@ig.com.br*

ABSTRACT. Experiments were carried out to verify the temperature effect on the mineralization process of an artificial source of organic matter. Incubations were prepared with water samples from the Infernão Lagoon (21º35'S and 47º51'W), enriched with glucose (20 mg.L^{-1}). Bottles were kept with and without aeration for 8 days. Glucose and oxygen concentrations were registered; the results were adjusted to first order kinetic models. The Q_{10} of each process was estimated by the reaction coefficients obtained. Temperature had greater influence on the process of oxygen consumption (Q_{10}=6.23) than on glucose decay. For glucose consumption, the anaerobic process was more sensitive (Q_{10}=3.30) to temperature than the aerobic one (Q_{10}=1.12). Results suggest that in the Infernão Lagoon the anaerobic cycling processes are favored in warmer seasons whereas, in colder months, the aerobic process may prevail.

Key words: temperature, aerobic and anaerobic mineralization, glucose, oxygen uptake, decay rates.

RESUMO. O efeito da temperatura sobre as taxas de ciclagem de glicose e do consumo de oxigênio na água da Lagoa do Infernão, Estado de São Paulo, Brasil. Experimentos foram realizados para verificar o efeito da temperatura sobre os processos de mineralização de uma fonte artificial de matéria orgânica. Para tanto, prepararam-se incubações com amostras de água da lagoa do Infernão (21º35'S e 47º51'W) enriquecidas com glicose (20mg.L^{-1}). As garrafas foram mantidas com e sem aeração durante 8 dias. As concentrações de glicose e de oxigênio dissolvidos foram registradas; os resultados foram ajustados a modelos cinéticos de primeira ordem. Através dos coeficientes de reação obtidos, o Q_{10} de cada processo foi estimado. A temperatura influenciou mais os processos de consumo de oxigênio (Q_{10}=6,23) que os de desaparecimento da glicose. Para o consumo de glicose, o processo anaeróbio foi mais sensível (Q_{10}=3,30) à variação de temperatura que o aeróbio (Q_{10}=1,12). Os resultados sugerem que, na lagoa do Infernão, os processos anaeróbios de ciclagem são favorecidos nos meses mais quentes; nos meses mais frios, os processos aeróbios podem predominar.

Palavras chave: temperatura, mineralização aeróbia e anaeróbia, glicose, assimilação de oxigênio, coeficientes de decaimento.

Introduction

Microorganisms of the aquatic environment play an important role in the mineralization process and nutrient regeneration, as well as in the creation of the basic food resources (Sorokin and Kadota, 1972). Bacteria, fungi and certain yeasts are included in this category and their main function in the ecosystem is to mineralize the organic matter back into simple inorganic compounds, which are then recycled (Golterman, 1975). Microorganisms are not only responsible for the nutrient cycling but, through the microbial loop, they represent an exceptional trophic link between detritus and classical food chain. Therefore, nutrients, carbon and energy are efficiently transferred from a lower level of the food chain to its higher levels (Biddanda, 1985; Pomeroy and Wiebe, 1988).

Bacterial decomposition may occur aerobically or anaerobically (Golterman, 1975). Aerobic bacteria require oxygen as electron receptors, while

anaerobic bacteria act only in the complete absence of molecular oxygen; a third class of bacteria, facultative bacteria, uses free oxygen when available and another substance as electron receptors (oxidants) in the absence of molecular oxygen (Manahan, 1994). Heterotrophic bacteria are primarily responsible microorganisms for the breakdown of pollutant organic matter in waters and of organic wastes in biological waste-treatment processes (Manahan, 1994). Thus, heterotrophic bacteria are probably the most ecologically important types of bacteria in most lakes. However, the rates at which they transform organic matter are virtually unknown (Cairns Jr., 1969).

Bacterial metabolic reactions are mediated by enzymes, biochemical catalysts endogenous to living organisms (Manahan, 1994). The degradation rates of the organic matter will depend on the enzymatic capacity as much as on the environmental conditions (Wetzel and Likens, 1991). In accordance to Swift *et al*. (1979), the abiotic factors determine range limits to the potential decomposition rates and it is also known that microorganisms can respond to environmental changes in a matter of seconds or minutes. The basis for these mechanisms lies at molecular level (Cairns Jr. 1969). Abiotic factors on aquatic systems include physical phenomena such as radiant energy, temperature and other physical-chemical aspects of water. They also include the chemical elements and compounds, dissolved or suspended in the water, which enable most natural waters to support life (Golterman, 1975).

Studies on terrestrial and aquatic ecosystems have shown that immobilization (biotic assimilation) and mineralization depend basically on the following abiotic factors: a) temperature (Sorokin and Kadota, 1972; Carpenter and Adams, 1979; Davis and Cornell, 1991; Brezonik, 1994); b) nutrient concentration in the environment and in its detritus (Coulson and Butterfield, 1978; Enríques *et al*., 1993; Hohmann and Neely, 1993); c) kind of detritus and quantity of their refractory compounds (Mindermann, 1968; Rice and Tenore, 1981); d) pH and salinity (Chan, 1985; Ogburn *et al*., 1988; Kok and Van Der Velde, 1991); e) dissolved oxygen concentration (Jewell, 1971; Twilley *et al*., 1986; Moore Jr. *et al*., 1992; Gale *et al*., 1992); f) detritus particle size (Lush and Hynes, 1973; Swift *et al*., 1979.

Tropical water bodies respond to short-term environmental changes (Souza and Couto, 1999). Climate and meteorological forces, such as anomalous episodes of intense precipitation or drought, river and tidal cycles, strong wind action, and front formation, act physically or take an indirect role on the system, and rapidly affect the biogeochemical processes (Knoppers, 1994). The temperature variation range tends to be more determinant in water than on land and aquatic organisms usually present narrower ranges of thermal tolerance than their inland equivalent (Odum, 1988). Therefore, temperature is the most important one among all abiotic factors; frequently it is a limiting factor. In this context, bacterial production and average growth rates frequently correlate with temperature (Kirchman and Rich, 1996).

The relation in which the reaction rate changes at each 10ºC of temperature rise is the Q_{10} or "temperature coefficient" (Harper, 1977). Temperature increase results in the rise of kinetic energy of the enzyme system in reaction. Otherwise, if the temperature is too high, the enzyme kinetic energy becomes so high that it surpasses the energetic barrier for the breaking of secondary links that maintain the enzyme in its native state or active catalytic (Harper, 1977). According to Levenspiel (1972), the rate expression may be written for many reactions and particularly for elementary reactions as a product of a temperature-dependent term and of a substrate composition term. For such reactions, being the reaction rate constant, the temperature dependent term has been found in practically all cases to be well represented by Arrheniu's law (Levenspiel, 1972).

Apart from the species involved, one may suppose that the decomposition process in tropical systems occurs at other rates than those observed in temperate zones. Such difference has an important role for mineral cycling in the mentioned areas, by promoting the mineralization instead of humidification. Experiments on nutrient and organic matter cycling may still contribute to restore original chemical element routes and it also might contribute towards energy conservation for the use of sustainable ecosystems. Current research aims at investigating the effects of temperature on the rates of organic matter mineralization by the microorganism's community in samples from a lagoon situated at the Mogi-Guaçu River floodplain named *Infernão*. Experiments with glucose as a source of organic matter were carried out in laboratory so that its heterotrophic capacity could be described.

Material and methods

The sampling point lies at the Infernão Lagoon (21º 35' S and 47º 51' W) and the samplings occurred from June to July 1994. The oxbow-shaped lagoon is

located in the Mogi-Guaçu River basin, inside the Jataí Ecological Station, one of the conservation units in the state of São Paulo (Brazil) and it is one of the few regions with native forest (Santos and Mozeto, 1992). Water samples were taken from the surface, medium and bottom of the lagoon through a van Dorn bottle, integrated (mixed) and filtered in glass wool. In the laboratory, glucose was added to the water at an approximated concentration of 20 $mg.L^{-1}$. Aliquots of approximately 1 liter of this enriched sample were poured into glass bottles (mineralization chambers). Two bottles were incubated in each temperature: one was conditioned to aerobic media by bubbling air into it and the other was conditioned to anaerobic media by bubbling nitrogen; each of them was accompanied by a blank bottle (without glucose) to obtain, through their difference, the consumption result due only to the added glucose. Therefore, there were four bottles at each temperature, half of them aerobic and half anaerobic. These bottles were kept in the dark at controlled temperatures of 17.4; 20.6 and 25.9ºC, which correspond to the Infernão annual temperature range (Antonio, 1996).

To describe the oxygen decay rates, two bottles were incubated at each temperature; one of them was blank and the different controlled temperatures were: 17.2; 20.0; 20.8; 23.7 and 26.0ºC. The difference among the temperatures of this experiment and the one above was due to the repetition of this one so that, at the second time, more temperatures could be established.

Aliquots were collected every day, and the determination of glucose concentration was made through the colorimetric method (Dubois *et. al*., 1956), until the stabilization of glucose and oxygen decay were observed (≈ 8 - 9 days). Oxygen concentrations and temperatures of the samples were also daily measured with an oxymeter (Metrohm, mod. E-627). When oxygen concentration was below 3 $mg.L^{-1}$, the samples were aerated again until the oxygen reached saturation value.

The time variation of glucose decay and oxygen uptake were adjusted to a first order kinetic model through a nonlinear regression method (based on the Levenberg-Marquardt algorithm) to estimate rates (k). Q_{10} was estimated from the graphic method by the formula: $Q_{10}=e^{10\alpha}$; where α=angular coefficient obtained from the linear relation between the T (temperature) *versus* ln k (decay rate)

Results

The results of the glucose concentration decay during aerobic and anaerobic mineralization under the three different temperatures are exposed in Table 1. Glucose kinetic variation had different rates for each temperature. Adjusting the obtained kinetic rates through Equations 1 and 2, which are temperature dependent models (USEPA, 1985), it was possible to estimate the Q_{10} (figure 1A, B) in order to describe the glucose decay rates according to the temperature under both conditions. It was possible to verify the increment of rate values as the temperature increased. The glucose uptake rate was incremented 1.12 times for each 10ºC of temperature elevation (Q_{10}), with regard to the aerobic process and 3.3 times with regard to the anaerobic one.

$$k_{(T)} = k_{ref}\,\theta^{(T-T_{ref})} \qquad (1)$$

where:
$k_{(T)}$ = variation of decay rates (glucose and D.O. concentration) according to the temperature;
k_{ref} = mineralization rate at reference temperature (T_{ref});
T = temperature;
T_{ref} = reference temperature (20ºC);
θ = temperature adjustment coefficient (= $Q_{10}^{0.1}$) ….. Equation (2)

Table 1. Glucose concentration decay ($mg.L^{-1}$) in Infernão Lagoon water samples incubations, at different temperatures, for aerobic and anaerobic conditions, with their respective rates (k)

Temperature (ºC)	17.4		20.6		25.9	
Condition	Aerobic	Anaerobic	Aerobic	Anaerobic	Aerobic	Anaerobic
Days						
0	20.65	20.65	20.65	20.65	20.65	20.65
1	⋆	⋆	6.20	8.86	11.90	9.62
2	7.34	11.14	6.96	6.39	10.76	6.20
3	5.63	12.28	8.86	10.00	10.00	5.82
4	7.15	8.67	7.53	⋆	4.30	3.92
5	10.00	9.81	9.24	12.47	3.35	2.78
7	⋆	⋆	4.68	2.40	2.40	2.40
k (day^{-1})	0.307	0.196	0.326	0.295	0.340	0.519

⋆ datum not used due to methodological error

Table 2 exhibits changes in dissolved oxygen concentration during the aerobic mineralization of glucose under five different temperatures; these results were also adjusted to obtain oxygen uptake rates in function of temperature variation (Figure 1C). Rate increment in this case was 6.23 for each 10ºC of temperature elevation.

Table 2. Decay of oxygen concentration ($mg.L^{-1}$) in incubations of water samples from the Infernão Lagoon at different temperatures, for aerobic condition, with their respective rates (k)

Temperature (ºC)	17.2	20.0	20.8	23.7	26.0
Days					
0	8.6	8.6	8.4	8.6	7.6
1	9.3	8.5	8.4	8.0	7.0
2	9.0	8.1	7.6	7.0	6.8
3	9.0	7.9	7.9	6.9	6.8

4	9.2	8.2	7.9	6.8	6.5
5	8.9	7.6	⋆	6.7	5.7
6	8.8	7.5	⋆	6.0	5.5
k (day^{-1})	0.00059	0.01911	0.0183	0.05208	0.0485

⋆ datum not used due to methodological error

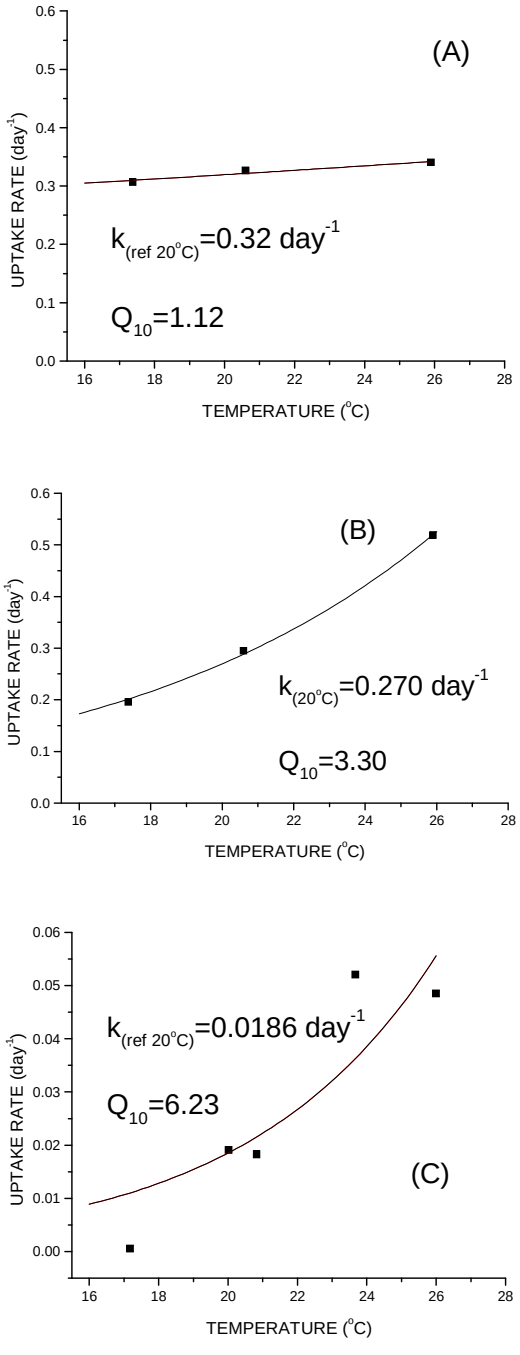

Figure 1. Variation of glucose decay rates in the lagoon water samples under aerobic (A) and anaerobic (B) conditions and the deoxygenation rates at different temperatures (C)

Discussion

Observing the results obtained from the glucose consumption (aerobic and anaerobic) and oxygen uptake processes, it was possible to verify, through Q_{10} and reference rate at 20°C (k_{ref}), that the temperature variation influenced differently the three processes.

The influence of temperature variation on the glucose decay was more sensitive under anaerobic condition (Q_{10}=3.30). Under aerobic condition Q_{10} =1.12, which means that under this condition the process is less affected by temperature variation and its rates do not considerably change. The two coefficients show that an elevation of 10°C in the Infernão Lagoon water, the anaerobic cycling rate increases about 3.3 times, while the aerobic uptake increases only about 1.1 times. However, during the Summer, when the water temperature is about 30°C (Antonio, 1996), one should expect to find faster dissolved organic matter consumption by bacteria in the water column of this lagoon, specially the anaerobic consumption. That reflects indirectly the sensitivity of anaerobic microbial community regarding dissolved organic matter consumption when the Infernão Lagoon undergoes temperature variation.

Comparing Figure 1A and 1B, it was possible to verify that the aerobic rates were higher than the anaerobic rates below 22°C; however, above 22°C the anaerobic rates were higher. In accordance to the water physical characteristics, as temperature increases, its oxygen saturation decreases, which may disfavor the oxygen-dependent organisms; on the other hand, anaerobic organisms may benefit from the fact. Considering that the average temperature of this ecosystem is around 23°C, one may suppose that the anaerobic and/or facultative anaerobic organisms are well adapted to it. Another point that should be considered refers to the routine of dissolved oxygen low concentrations in the Infernão Lagoon, around 1.12 mg.L^{-1} (Antonio, 1996), which favors the presence and maintenance of facultative anaerobic communities. This observation might indicate a physical-chemical expression of an intrinsic metabolic behavior of the communities involved on the mineralization process where the aerobic communities are not so affected by temperature variation as the anaerobic ones, which are probably more adapted to this environment.

With reference to the oxygen consumption, it has been observed that when there is a temperature elevation of 10°C, the oxygen uptake rate increases in approximately 6.2 times (Q_{10}=6,23). It was the process most affected by temperature variation found in the current research. This means that the

oxygen uptake process is highly affected by temperature and that it does not have any direct relation to the aerobic glucose uptake (1.1 times), which may be either assimilated or used as an energy source for respiration. It is still possible, for this environment, that under higher temperatures the aerobic processes are unfavorable, considering the small concentration of dissolved oxygen saturation.

Conclusion

Based on the results obtained and on the methodology applied, it was possible to verify that:

i) Generally speaking, dissolved oxygen and dissolved glucose consumption rates increased with temperature elevation;
ii) In what concerns of glucose consumption, the anaerobic process was more sensitive (Q_{10}=3.3) to temperature variation than the aerobic one (Q_{10}=1.1);
iii) The dissolved glucose aerobic consumption prevailed in water samples with temperature below 22ºC; the anaerobic process was favored in higher temperatures;
iv) Temperature had greater influence on the process of oxygen consumption (Q_{10}=6.2) than on glucose decay;
v) In the Infernão Lagoon the anaerobic cycling processes may be more favored in the warmer seasons; in colder months, the aerobic process may prevail.

Acknowledgements

The authors would like to thank Coordenadoria de Aperfeiçoamento de Pessoal de Nível Superior (Capes) and Fundação de Amparo à Pesquisa do Estado de São Paulo (Fapesp, process. number 91/1301-3) for the financial support.

References

ANTONIO, R. M. *Estimativa da capacidade heterotrófica do Lago Infernão (Estação Ecológica de Jataí, SP).* 1996. Dissertação (Mestrado em Ecologia e Recursos Naturais) - Universidade Federal de São Carlos, São Carlos, 1996.

BIDDANDA, B. Microbial synthesis of macroparticulate matter. *Mar. Ecol. Prog. Ser.*, Oldendorff, v. 20, p. 241-251, 1985.

BREZONIK, P. L. *Chemical kinetics and process dynamics in aquatic systems*. Boca Raton: Lewis, 1994.

CAIRNS JR., J. *The structure and function of fresh water microbial communities*. Blacksburg: Virginia Polytechnic Institute, 1969. (Research Division Monograph, 3)

CARPENTER, S. R.; ADAMS, M. S. Effects of nutrients and temperature on decomposition of *Myriophylum spicatum* L. in a hard water eutrophic lake. *Limnol. Oceanogr.*, Waco, v. 24, p. 520-528, 1979.

CHAN, K. Aerobic decomposition of *Chlorella salina* in freshwater and saline conditions. *Hydrobiologia,* The Hague, v. 122, p. 35-44, 1985.

COULSON, J. C.; BUTTERFIELD, J. An investigation of the biotic factors determining the rates of decomposition on a blanket bog. *J. Ecol.*, Paris, v. 66, p. 631-650, 1978.

DAVIS, M. L.; CORNELL, D. *An introduction to environmental engineering*. New York: McGraw-Hill, 1991.

DUBOIS, M. *et al*. Colorimetric method for determination of sugar and related substances. *Anal. Chem.*, Washington, DC, v. 28, p. 350-356, 1956.

ENRÍQUES, S. *et al*. Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C:N:P content. *Oecologia*, Berlin, v. 94, p. 457-471, 1993.

GALE, P. M. *et al*. Mineralization of sediment organic matter under anoxic conditions. *J. Environ. Qual.*, Madison, v. 21, p. 394-400, 1992.

GOLTERMAN, H. L. *Physiological Limnology*. Amsterdam: Elsevier, 1975.

HARPER, H. A. *Manual de Química Fisiológica*. São Paulo: Atheneu, 1977.

HOHMANN, J.; NEELY, R. K. Decomposition of *Sparganium eurycarpum* under controlled pH and nitrogen regimes. *Aqua. Bot.*, v. 46, p. 17-33, 1993.

JEWELL, W. J. Aquatic weed decay: dissolved oxygen utilization and nitrogen and phosphorus regeneration. *J. Wat. Poll. Contr. Fed.*, v. 43, p. 1457-1467, 1971.

KIRCHMAN, D.L.; RICH, J. H. Regulation of bacterial growth rates by dissolved organic carbon and temperature in the Equatorial Pacific Ocean. *Microb. Ecol.*, Sendai-shi, v. 33, p. 11-20, 1996.

KNOPPERS, B. *Aquatic primary production in coastal lagoons*. *In*: KJERFVE, B. (Ed.). *Coastal lagoon processes*, Amsterdam: Elsevier Science Publishers, Chapter 9, 1994.

KOK, C. J.; VAN DER VELDE, G. The influence of selected water quality parameters on the decay rate and exoenzymatic activity of detritus of *Nymphaea alba* L. floating leaf blades in laboratory experiments. *Oecologia*, Berlin, v. 88, p. 311-316, 1991.

LEVENSPIEL, O. *Chemical Reaction Engineering*. Singapore: John Wiley and Sons, 1972.

LUSH, D. L.; HYNES, H. B. N. The formation of particles in freshwater lecheates of dead leaves. *Limnol. Oceanogr.*, Waco, v. 18, p. 968 – 977, 1973.

MANAHAN, S. E. *Environmental chemistry*. Boca Raton: Lewis, 1994.

MINDERMANN, G. Addition, decomposition and accumulation of organic matter in forests. *J. Ecol.*, Paris, v. 56, p. 355-562, 1968.

MOORE, JR., P. A. *et al*. Nutrient transformations in sediments influenced by oxygen supply. *J. Environ. Qual.*, Madison, v. 21, p. 387-393, 1992.

ODUM, E. P. *Ecologia.* Rio de Janeiro: Guanabara, 1988.

OGBURN, R. W. *et al*. Effect of pH on phosphorus release during macrophyte (*Eleocharis sp*) decomposition. *Water Resour. Bull*., Urbana, v. 23, p. 829-832, 1988.

POMEROY, L. R.; WIEBE, W. J. Energetic of microbial food webs. *Hydrobiologia*, The Hague, v. 156, p. 7-18, 1988.

RICE, D. L.; TENORE, K. R. Dynamics of carbon and nitrogen during the decomposition of detritus derived from estuarine macrophytes. *Estuar. Coast. Shelf Sci.*, London, v. 13, p. 681-690, 1981.

SANTOS, J. E.; MOZETO, A. A. *Ecologia de áreas alagáveis da planície de inundação do Rio Mogi Guaçú*. São Carlos: UFSCar, 1992.

SOROKIN, Y. I.; KADOTA, H. *Techniques for the assessment of microbial production and decomposition in fresh waters*. Oxford: Blackwell, 1972. (IBP nº 23)

SOUZA, M. F. L. de; COUTO, E. C. G. Short-term changes and longitudinal distribution of carbon metabolism in the Piauí river estuary (Sergipe, Brazil). *Rev. Brasil. Biol.*, São Carlos, v. 59, p. 195-202, 1999.

SWIFT, M. J. *et al. Studies in ecology decomposition in terrestrial ecosystems.* Oxford: Blackwell, 1979.

TWILLEY, R. R. *et al*. Comparative study of decomposition and nutrient release for selected aquatic plants occurring in an estuarine environment. *Oikos,* Copenhagen, v. 47, p. 190-198, 1986.

USEPA - UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. *Rates, Constants and Kinetics Formulation in Surface Water Quality Modeling.* Athens: U.S. Government Printing Office, 1985.

WETZEL, R. G.; LIKENS, G. E. *Limnological Analyses*. New York: Springer-Verlag, 1991.

Received on May 23, 2001.
Accepted on February 04, 2002.