# Synchrony among limnological variables in a lotic system (Meia Ponte River, Goiás, Brazil)

Sincronia entre variáveis limnologicas em um sistema lótico (Rio Meia Ponte, Goiás, Brasil)

Carneiro, FM.[1], Angelini, R.[2], Carvalho, AR.[2] and Bini, LM.[1]

[1]Programa de Pós-Graduação em Biologia (Ecologia e Evolução), Instituto de Ciências Biológicas, Universidade Federal de Goiás – UFG, CP 131, CEP 74001-970, Goiânia, GO, Brazil
e-mail: fermelcar2005@yahoo.com.br; lmbini@gmail.com

[2]Laboratório de Pesquisa Ecológica e Educação Científica, Universidade Estadual de Goiás – UEG, BR 153, Km 98, CP 459, CEP 75074-840, Goiânia, GO, Brazil
e-mail: ronangelini@yahoo.com.br; adriana.carvalho@pq.cnpq.br

**Abstract: Aim:** Recently, the homogeneity of spatial and temporal variations of ecosystem components has been assessed by synchrony. The present study aimed to assess the robustness and consistency of the changes in limnological variables along the lotic system, testing the spatial and inter-annual synchrony; **Methods:** The present study analyzed the synchrony of limnological variables recorded at nine sites in the Meia Ponte River in central Brazil, during a six-year period. Spatial synchrony was analyzed by Mantel test between the spatial matrix and the environmental variables correlation between points through the years. The inter-annual synchrony was tested by Procrustean analysis between the ordination produced for each year of study; **Results:** The different points analyzed were moderately coherent for some parameters (air temperature, color, chloride) and strongly coherent for others (water temperature, conductivity, dissolved oxygen concentration, Iron, pH, turbidity). However, there was not inter-annual pattern; **Conclusions:** This suggests that the climate conditions or even the human actions in this ecosystem influenced it in different ways in each year studied. The biological variables exhibited a more weak spatial synchrony than chemical variables.

**Keywords:** Meia Ponte River, lotic, synchrony, limnological variables.

**Resumo: Objetivo:** Atualmente, a homogeneidade espacial e temporal dos componentes do ecossistema tem sido avaliada através da sincronia. Dessa maneira, o objetivo desse estudo foi avaliar a consistência das mudanças de variáveis limnológicas através de um ecossistema lótico, através da sincronia espacial e inter-anual desse sistema; **Métodos:** O presente estudo analisa a sincronia das variáveis limnológicas de nove unidades amostrais no rio Meia Ponte localizado no Brasil central, durante o período de seis anos. A sincronia espacial foi testada com teste de Mantel entre a matriz espacial e a matriz de correlação das variáveis ambientais por ponto através dos anos. A sincronia interanual foi testada através de uma analise de Procrustes entre as ordenações geradas para os diferentes anos de estudo; **Resultados:** Os diferentes pontos amostrados foram moderadamente coerentes para alguns parâmetros (temperatura do ar, cor, cloretos) e fortemente coerentes para outros (temperatura da água, oxigênio dissolvido, ferro, pH, turbidez). Entretanto, não houve padrão interanual; **Conclusões:** Isto sugere que as condições climáticas ou até mesmo a ação humana influenciou esse ecossistema de forma diferente em cada ano estudado. Além disso, as variáveis mais associadas aos componentes biológicos exibiram uma sincronia espacial mais fraca do que as variáveis químicas.

**Palavras-chave:** Rio Meia Ponte, lótico, sincronia, variáveis limnológicas.

## 1. Introduction

Monitoring water quality in lotic ecosystems is important to define strategies for use, control, management and conservation (Cottingham and Carpenter, 1998). Moreover, knowledge of basic limnological parameters can guide the rational use of water resources and improve recovery by detecting the source of natural and (or) human disturbance (Valentin and Guimarães, 2004). Furthermore, studies of the interactions, interrelationships and covariation among different components of the aquatic ecosystem can provide the conceptual base necessary for the resolution of many problems in these systems (Tundisi, 2000).

One of the most important lines of ecological investigation consists in assessing whether descriptors of a system diverge over temporal and spatial scales (Kling et al., 2000). One former idea of spatial interrelationships for aquatic ecosystems was the river continuum concept, which hypothesizes that physical and biotic variables follow a continuous gradient from headwater to mouth, including changes in depth, temperature and general biological development along the length of a river (Vannote et al., 1980). Another concept recently applied to test spatial and temporal consistency is synchrony, which measures the similarity of inter-annual dynamics for limnological variables among different sampling points (Webster et al., 2000). This approach is useful to understand the contribution of determinism versus the stochastic events in ecological systems (Kent et al., 2007).

The present study aimed to assess the robustness and consistency of the changes in limnological variables along the Meia Ponte River in Goiás, Brazil, testing the temporal and spatial coherence among nine points sampled from 1999 to 2004. These questions were considered: i) Was there consistency in spatial patterns of limnological and microbiological variables? ii) Was there consistency in limnological pattern over time? iii) Was there greater similarity between geographically closer points? iv) Was synchrony lower at points subject to more intense human disturbance?

## 2. Material and Methods

### *2.1. Study area*

Meia Ponte River is one of the most important rivers in the state of Goiás in central Brazil. Its source lies 60 km north of the city of Goiânia at 983 m altitude, and the river flows southward through the city, joining the Paranaíba River on the border with the state of Minas Gerais. The Meia Ponte watershed is undergoing intense and diversified industrial development, and receives important inputs of pollutants from industrial, domestic, agricultural and cattle-ranching sources. The basin is located in south-central Goiás, between 48° 46'48"and 16º 44' 51" W, 16° 06' 38" and 18° 32' 53" S (Figure 1), and covers an area of approximately 12,349 km$^2$. The Meia Ponte River basin is bounded to the north by the Almas River basin, to the northeast by the Corumbá River basin, and to the south by the Paranaíba River basin. The Meia Ponte River is the main tributary of the latter.

### *2.2. Data collection*

Nine sampling sites were established in the Meia Ponte River. Six sites were located upstream from the water intake station for Goiânia's water supply. The seventh site was located at the water intake, and the remaining two sites were downstream from the water intake station, near the city (Figure 1). The samples were taken monthly from January/99 through December 2004, comprising six annual periods of each rainy season and dry season. The analyses were carried out according to Standard Methods (APHA, 1995). The water and air temperature, turbidity, total solids, color, pH, electrical conductivity (COND), dissolved oxygen concentration (DO), biochemical oxygen demand (BOD), iron (Fe), chloride (Cl), total and thermotolerant coliforms, nitrite ($NO_2^-$), manganese (Mn) and total phosphorus (P) were analyzed.

### *2.3. Data analysis*

The environmental variables were log-standardized (log ($X$+1)), exception for pH. A Pearson's correlation between precipitation and the limnological variables was carried out, as well as among these variables and the sampling points.

Spatial influence on the abiotic variables was assessed through the Mantel test, which calculates the degree of association between two distance matrices (Peres-Neto and Jackson, 2001). The correlation matrices among the points by variables were contrasted by the spatial matrix, which was previously calculated by the Euclidean distances among the points, using their geographical coordinates.

In order to assess the value of the synchrony without influence of space for each variable, a regression analysis was carried out between the spatial matrix (Euclidean distances among the points) and the correlation matrices for each point by variables. To perform the regression analysis those matrices were converted to Pearson correlation pair variables and Euclidian distances pairs, respectively. The intercept values from this regression represent the value of synchrony, without the influence of space (Krebs, 1998; Kling et al., 2000).

Detrended Correspondence Analysis (DCA) was carried out for each limnological matrix by year. DCA is a method of ordination proposed by Hill and Gauch (1980) to remove the arc effect of the correspondence analysis. To assess difference among the years in the ordination patterns produced by the DCA, a Procrustean analysis was carried out (Jackson, 1995; Peres-Neto and Jackson, 2001). In this analysis, a pair of data matrices is compared by using a rotational-fit algorithm that minimizes the sum of squares residuals between the two matrices, resulting in a badness-of-fit statistic called $m^2$-value (Jackson, 1995). The Protest was carried out between the matrices for different years at the same site, using 999 permutations in order to assess the statistical significance of $m^2$, which measures the level of concordance between the ordinations that are being compared. Therefore, the $m^2$ statistic reflects the lack of overlap between two ordinations, varying from 0 to 1. Values closer to 0 indicate total overlap between the matrices (i.e., results of two ordinations are the same) and values closer to 1 indicate a greater difference between ordination patterns (Jackson, 1995).

## 3. Results

The monthly mean precipitation for the period studied showed the same pattern rainy and dry season as presented for Galinkin (2002) to the same region (Figure 2). Consequently rainy-season months were defined as January through April, and October through December

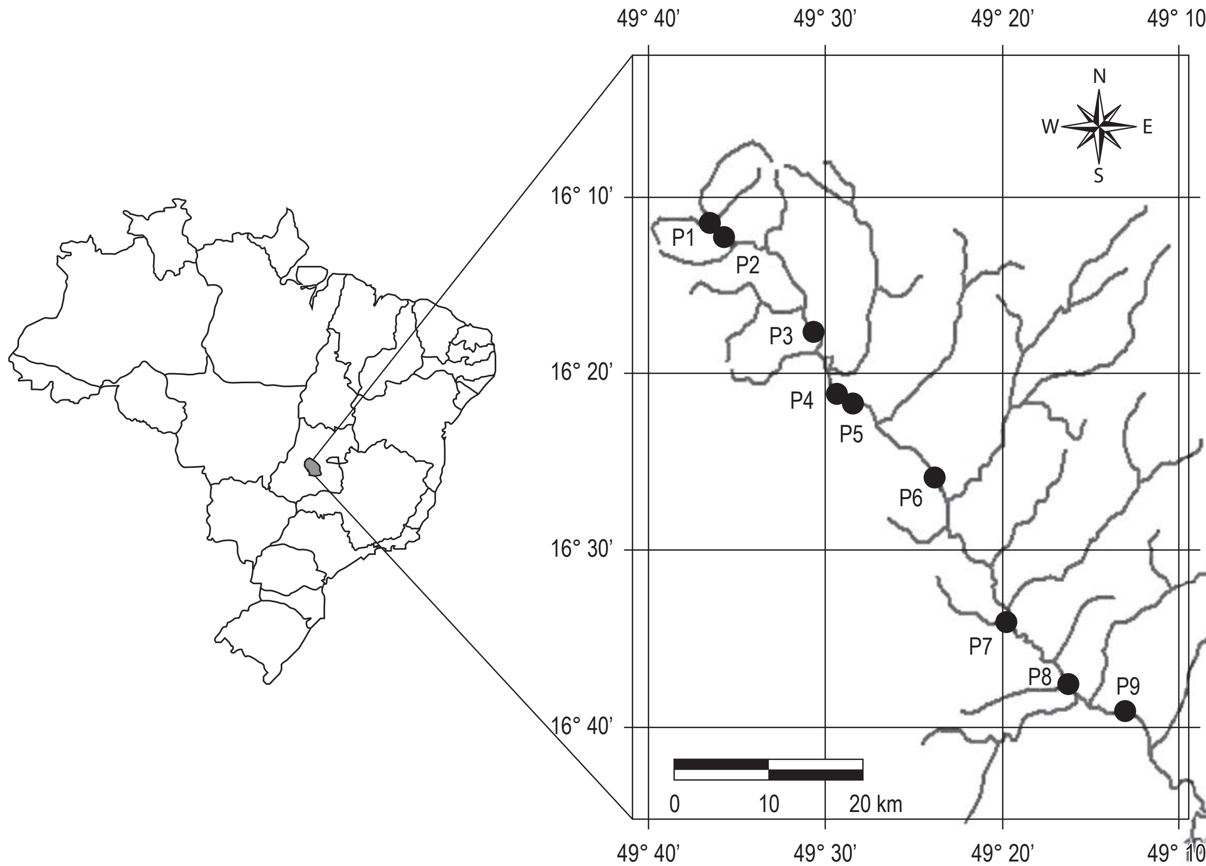


**Figure 1.** Meia Ponte River sub-basin and the nine sampling points (48° 46' 48"and 49° 44' 51" W, 16° 06' 38" and 18° 32' 53" S) in Goiás, central Brazil.

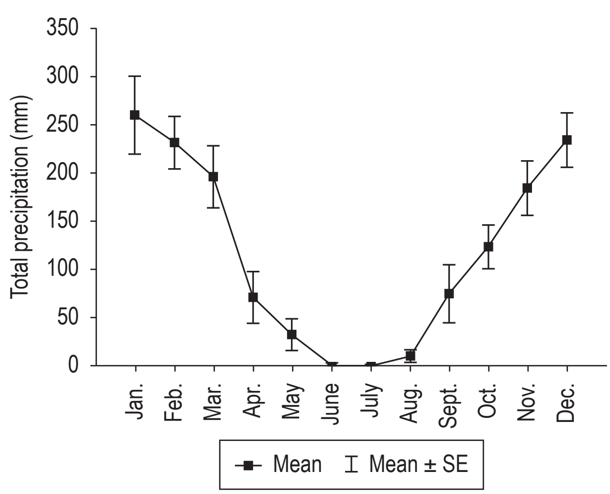


**Figure 2.** Means and standard deviations of monthly precipitation from 1999 through 2004 in the Meia Ponte River basin.

while dry season occurred from May through September. Limnological variables which were most strongly correlated with precipitation were water color ($r$ = 0.53, $P$ = 0.000, n = 626), turbidity ($r$ = 0.54 $r$ = 0.53, $P$ = 0.000, n = 624) and water temperature ($r$ = 0.48 $r$ = 0.53, $P$ = 0.000, n = 625).

According to the Mantel test (Table 1), the values of synchrony were negatively correlated with the spatial factor. This means that large distance among sampling points resulted in lower values of synchrony. Variables more structured in the space were air temperature (–0.80), chloride (–0.70), color (–0.56) and total phosphorus (–0.51; Table 1). When the spatial factor was removed, all variables exception to Manganese and Nitrite had significant values of synchrony (Table 2). Electric conductivity, iron, total solids and DO showed synchrony, but were not structured through the space (Table 2).

The majority of variables had high values of synchrony, but was not structured by space (e.g. water temperature; iron; total solids; DO). Conversely, color and air temperature showed high values of synchrony structured in the space (Table 2). Others variables did not reveal strong pattern of synchrony or were not synchronized (e.g. BOD, thermotolerant coliforms, total coliforms, Manganese, Nitrite respectively).

Higher inter-annual synchrony was during the 2001-2002 period ($m^2$ = 0.8167, $P$ = 0.0001; Table 2). It is important to stand out that values closer to 0 of the $m^2$ statistic indicate total overlap between the matrices and values closer to 1 indicate a greater difference between ordination patterns. In general, the values of temporal synchrony were very low for all years.

**Table 1.** Significant statistical values of limnological variables in the Meia Ponte River: *r*1 – value of Mantel's *r* among the spatial matrix and the environmental variables for 10,000 permutations; *P*1 – the probability value associated with *r*1; *r*2 – the synchrony value (intercept regression value between spatial matrix and correlation Pearson for variable); *P*2 – the probability value associated with *r*2 (significant values with $P < 0.05$ are in boldface).

| Variable | Synchrony | | | |
|---|---|---|---|---|
| | Spatial factor | | No spatial factor | |
| | *r*1 | *P*1 | *r*2 | *P*2 |
| Color | –0.5664 | 0.0008 | 0.6640 | 0.0000 |
| Turbidity | –0.4511 | 0.0052 | 0.6820 | 0.0000 |
| Water temperature | –0.3802 | 0.0003 | 0.8723 | 0.0000 |
| Air temperature | –0.8022 | 0.0003 | 0.8002 | 0.0000 |
| Electrical conductivity | –0.1647 | 0.1653 | 0.7526 | 0.0000 |
| pH | –0.4122 | 0.0282 | 0.5406 | 0.0000 |
| Iron | –0.2287 | 0.1030 | 0.6980 | 0.0000 |
| Manganese | 0.0210 | 0.4795 | 0.2157 | 0.0603 |
| Chloride | –0.7037 | 0.0029 | 0.6905 | 0.0000 |
| Total phosphorus | –0.5141 | 0.0022 | 0.2716 | 0.0036 |
| Nitrite | –0.2205 | 0.1094 | 0.1052 | 0.0663 |
| Total solids | –0.1380 | 0.2029 | 0.4130 | 0.0000 |
| DO | –0.2346 | 0.0974 | 0.5277 | 0.0000 |
| BOD | –0.4500 | 0.0082 | 0.2689 | 0.0000 |
| Thermotolerant coliforms | –0.4354 | 0.0139 | 0.3999 | 0.0000 |
| Total coliforms | –0.4401 | 0.0094 | 0.4268 | 0.0000 |

**Table 2.** Procrustean analysis of the limnological variables among the years. The $m^2$ values are showed below main diagonal and P values for 999 permutations are expressed above this main diagonal. Significant correlations are bolded.

| Years | *P* values (999 permutations) | | | | | |
|---|---|---|---|---|---|---|
| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
| 1999 | | 0.1686 | 0.0067 | 0.0010 | 0.0369 | 0.0517 |
| 2000 | 0.9747 | | 0.0001 | 0.0001 | 0.1256 | 0.0001 |
| 2001 | 0.9399 | **0.8704** | | 0.0001 | 0.3193 | 0.001 |
| 2002 | 0.9260 | **0.8496** | **0.8167** | | 0.0783 | 0.0001 |
| 2003 | **0.9527** | 0.9745 | 0.9813 | 0.9648 | | 0.1195 |
| 2004 | 0.9611 | **0.8352** | **0.915** | **0.8919** | 0.9708 | |
| | $m^2$ values | | | | | |

## 4. Discussion

As a result, all the variables showed negative values of Mantel's *r* when associated with the distance matrix, corroborating that the more distant the sampling points, the lower the similarity among them. Variables such as color, air temperature and chloride had spatially structured patterns, since at local biogeography scales; usually there is control of the same set of environmental variables, resulting in a high degree of congruence (Gaston, 1996; Paavola et al., 2006). Turbidity, water temperature, conductivity, pH, iron and dissolved oxygen followed a uniform spatial pattern, because these variables showed low association with the spatial factor, but had a relatively high synchrony. This pattern supports the influence of the regional factor like climate or geomorphic control, since the later homogenizes the flow of solute (Webster et al., 2000) and increases the uniformity of the system.

An important aspect in the characterization of freshwater systems is their seasonality, characterized in central Brazil by distinct rainy and dry seasons (Nimer, 1989; Galinkin, 2002). These seasons have a strong influence on the distribution of organic matter, due to the destabilization of the system by the increases in water volume and velocity during the rainy season (Markensten, 2006). In the present study, precipitation influenced the color, turbidity and water temperature. Precipitation is expected to increase the synchrony values among points (Webster et al., 2000). This suggests that aquatic system showed a similar response to a broad set of climate change or atmospheric deposition (Baron and Caine, 2000). On a macro-scale, the regular pattern characterized by environmental variables could have predictive power in other ecosystems, highlighting synchrony analysis as a useful tool for investigations in nutrient cycling and responses to climate changes (Weyhenmeyer, 2004; Kent et al., 2007).

In general, the microbiological communities available did not present the strongest spatial pattern, but also did not show an uniform pattern in the space. Other variables with reasonable biological response, such as phosphorus and nitrogen, had lower synchrony values and were weakly influenced by the spatial factor, likely due to the biological requirements for local primary productivity (Baron and Caine, 2000; George et al., 2000). Usually the dynamics of microorganisms depends on external factors, which results in values less idiosyncratic than the values of other variables through time (Kent et al., 2007).

In addition, the weak synchrony and the lack of the spatial pattern can indicate the existence of punctual source of pollution. This would imply in punctual inputs of nutrient from diffuse sources of pollution acting upon the biological community. Despite the belief that those sources could be easily controlled, worldwide punctual sources of pollution still are the main supplier of nutrient for the ecosystem (Carpenter et al., 1998). The weak synchrony in biological variables indicates sporadic alterations (e.g. occasional effluent discharge) and a concise characterization of such changes as well as continuous monitoring are required (Philippi et al., 1998; Lovet et al., 2007).

Phosphate concentration was strongly associated with the spatial factor and had low synchrony value as a whole, suggesting that similar values for this variable appeared only at point closer to each other. Higher values of phosphate were recorded at sampling points 8 and 9, which have higher human density occupation levels (closer to Goiânia metropolitan area). Therefore, the association of phosphorus with the spatial factor can be explained by human factors, since despite the natural sources of phosphorus in the environment (Tundisi, 2005), in regions with high population density, artificial sources of phosphate are more important than the natural sources (Esteves, 1998; George et al., 2000; Kratz and Frost, 2000). Human activities certainly influenced the low value of synchrony for this variable, since higher values of synchrony have been obtained in pristine areas near the stream headwater (Baron and Caine, 2000), underlining the influence of human actions upon synchrony (George et al., 2000; Kratz and Frost, 2000).

Sampling points were moderately coherent for some parameters (e.g. air temperature, color, chloride), and strongly coherent for others (e.g. water temperature, conductivity, dissolved oxygen concentration, Iron, pH, turbidity). Again this pattern could suggest higher uniformity trough the system and an expected synchrony of solute flow as a result from geomorphic and climate driving forces. Variables associated to or responsible for higher biological functions showed lower spatial synchrony values (e.g. coliforms, total phosphorus, nitrites, manganese and biochemical oxygen demand). Consequently these variables should be continuously monitored, because they supplied exclusive local information.

Microbiological community analyzed (thermotolerant coliforms) has anthropogenic cause and the lack of spatial synchrony as well as the high uniformity in all study sites reflects its origin and the anthropic influence in whole ecosystem. Additionally, nitrogen and phosphorus which can have human origin, showed low spatial synchrony indicating the influence of diffuse sources of pollution. Therefore spatial uniformity of fecal coliforms is an evidence of the effect of punctual source of pollution over the ecosystem. The low inter-annual coherence observed in limnological variables suggests that the climate conditions or even the human actions in the ecosystem had different effects at each year studied. Accordingly, Meia Ponte river do not show pattern through time (temporal synchrony) and had weak spatial pattern, since limnological variables related to anthropogenic activities are not structure at the space. Therefore, it seems that longer periods of limnological monitoring of the system and investigations concerning to human density effect upon it are required to achieve substantial knowledge about this lotic ecosystem.

## Acknowledgements

The authors are grateful to SANEAGO for providing the data used in this study. Carneiro FM was supported by a student grant from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). The other authors were supported by CNPq through research grants. Bini, LM was also supported by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and by FUNAPE (Fundação de Apoio a Pesquisa) at Universidade Federal de Goiás (UFG).

## References

American Public Health Association - APHA. *Standard methods for the examination of water and wastewater*. 19 ed. Washington: APHA, 1995. 1100 p.

BARON, JS. and CAINE, N. Temporal coherence of two alpine lake basins of the Colorado Front Range, USA. *Freshwater Biol*. 2000, vol. 43, no. 3, p. 463-476.

COTTINGHAM, KL. and CARPENTER, SR. Population, community, and ecosystem variates as ecological indicators: phytoplankton responses to whole-lake enrichment. *Ecol. Appl*. 1998, vol. 8, no. 2, p. 508-530.

ESTEVES, FA. *Fundamentos de limnologia*. 2 ed. Rio de Janeiro: Interciência, 1998. 545 p.

GALINKIN, M. *Geogoiás*. Goiânia: Agencia Ambiental de Goiás; Fundação CEBRAC; PNUMA; SEMARH, 2002. 272 p.

GASTON, KJ. Biodiversity-congruence. *Prog. Phys. Geo*. 1996, vol. 20, p. 105-112.

GEORGE, DG., TALLING, JF. and RIGG, E. Factors influencing the temporal coherence of five lakes in the English Lake District. *Freshwater Biol*. 2000, vol. 43, no. 3, p. 449-461.

KENT, AD., YANNARELL, AC., RUSAK, JA., TRIPLETT, EW. and MCMAHON, KD. Synchrony in aquatic microbial community dynamics. *The ISME Journal.* 2007, vol. 1, p. 38-47.

KING, GW., KIPPHUT, GW., MILLER, MM. and O'BRIEN, WJ. Integration of lakes and streams in a landscape perspective: the importance of material processing on spatial patterns and temporal coherence. *Freshwater Biol*. 2000, vol. 43, no. 3, p. 477-497.

KRATZ, TK. and FROST, TM. The ecological organisation of lake districts: general introduction. *Freshwater Biol*. 2000, vol. 43, no. 3, p. 297-299.

KREBS, CJ. *Ecological methodology.* 2 ed. New York: Addison Wesley Longman, 1998. 620 p.

LOVETT, GM., BURNS, DA., DRISCOLL, CT., JENKINS, JC., MITCHELL, MJ., RUSTAD, L., SHANLEY, JB., LIKENS, GE. and HAEUBER, R. Who needs environmental monitoring? *Front. Ecol. Environ*. 2007, vol. 5, no 5, p. 253-260.

MARKENSTEN, H. Climate effects on early phytoplankton biomass over three decades modified by the morphometry in connected lake basins. *Hydrobiologia*. 2006, vol. 559, no. 1, p. 319-329.

NABOUT, JC., NOGUEIRA, IS. and OLIVEIRA, LG. Phytoplankton community of floodplain lakes of the Araguaia River, Brazil, in the rainy and dry seasons. *J. Plank. Res.* 2006, vol. 28, no. 2, p. 181-193.

NIMER, E. *Climatologia do Brasil*. Rio de Janeiro: IBGE, 1989. 421 p.

PAAVOLA, R., MUOTKA, T., VIRTANEN, R., HEINO, J., JACKSON, D. and MAKI-PETAYS, A. Spatial scale affects community concordance among fishes, benthic macroinvertebrates, and bryophytes in streams. *Ecol. Appl*. 2006, vol. 16, no. 1, p. 368-379.

PERES-NETO, PR. and JACKSON, DA. How well do multivariate data sets match? The advantages of a Procrustean superimposition approach over the Mantel test. *Oecologia*. 2001, vol. 129, no. 2, p. 169-178.

PHILIPPI, TE., DIXON, PM. and TAYLOR, BE. Detecting trends in species composition. *Ecol. Appl.* 1998, vol. 8, no. 2, p. 300-308.

THOMAZ, SM. and BINI, LM. Limnologia: enfoques e importância para o manejo de recursos hídricos. *Cad. Biod*. 1999, vol. 2, no. 1, p. 11-25.

TUNDISI, JG. Limnologia no século XXI: perspectivas e desafios. In *Anais do VII Congresso Brasileiro de Limnologia*, 1999. São Carlos: Instituto Internacional de Ecologia, 1999. 24 p.

TUNDISI, JG. *Água no século XXI*: enfrentamento da escassez. 2 ed. São Carlos: Rima, 2005. 251 p.

VALENTIN, JL. and GUIMARÃES, MA. A modelagem ecológica em limnologia. In BICUDO, CEM. and BICUDO, DC. (Eds.). *Amostragem em limnologia*. São Carlos: Rima, 2004. p. 109-119.

VANNOTE, RL., MINSHALL, GW., CUMMINS, KW., SEDELL, JR. and CUSHING, CE. The river continuum concept. *Can. J. Fish. Aquat. Sci.* 1980, vol. 37, no. 1, p. 130-137.

WEBSTER, K. Structuring features of lake districts: landscape controls on lake chemical responses to drought. *Freshwater Biol*. 2000, vol. 43, no. 3, p. 499-515.

WEYHENMEYER, GA. Synchrony in relationships between the North Atlantic Oscillation and water chemistry among Sweden's largest lakes. *Limnol. Oceanogr.* 2004, vol. 49, no. 4, p. 1191-1201.

Received: 09 April 2009
Accepted: 12 October 2009