Temporal variation of biomass and status nutrient of periphyton in shallow Amazonian Lake (Rio Branco, Brazil)

Variação temporal da biomassa e estado nutricional do perifíton em lago raso amazônico (Rio Branco, Brasil)

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Biological Limnology

Abstract: Aim: The present study evaluated periphyton biomass and status nutrient variation during colonization period in Viveiro Lake (Acre, Brazil) during dry and rainy season; **Methods:** Samplings were performed in 4 day intervals until day 20 and, afterwards at 5 day intervals over 35 days. Water sampling for physical, chemical and biological analysis was conducted during the dry and rainy season. Glass slides were the artificial substrates used for periphyton colonization; **Results:** Dry season was characterized mainly by highest water transparency values. Biomass and content of nitrogen (N) and phosphorus (P) increased over the course of colonization period, but phosphorus limitation also increased. Although N and P content increased with colonization time, nutrient partition was not good. Ratio N:P was not representative of biomass increment during colonization period. Periphyton N and P content was on average higher in rainy than dry season and, was considered significantly different between seasons. Periphyton was limited primarily by phosphorus. Periphyton dry mass (DM) and ash free dry mass (AFDM) presented the highest increment in dry season; **Conclusions:** Periphyton N and P content uncoupled the availability of TN and TP of the water, but the ratio N:P of the water and periphyton indicated high P-limitation. The variation in status nutrient and biomass accumulation was influenced by colonization time (autogenic process) and scale seasonal.

Keywords: periphyton, status nutrients, biomass, colonization, seasonal.

Resumo: Objetivo: O presente estudo avaliou a variação da biomassa e estado de nutrientes do perifíton durante período de colonização na estação seca e chuvosa no Lago Viveiro (Acre, Brasil); **Métodos:** Amostragens foram realizadas em intervalos de 4 dias até 20º dia e posteriormente a cada 5 dias, totalizando 35 dias de colonização. Foram coletadas amostras de água para análise física, química e biológica no período seco e chuvoso. O substrato artificial utilizado para colonização do perifíton foi lâmina de vidro; **Resultados:** Período seco foi caracterizado principalmente pelos maiores valores de transparência de água. Biomassa e conteúdo de N e P aumentaram durante o tempo de colonização, mas a limitação por P também aumentou. Apesar do aumento do conteúdo de nitrogênio e fósforo ao longo da colonização, a repartição dos nutrientes não foi ótima. Razão molar N:P não foi representativa de incremento de biomassa durante período de colonização. O conteúdo de N e P foram em média maiores no período chuvoso do que no seco e, foram significativamente diferentes entre os períodos climáticos. O perifíton foi considerado primariamente limitado por fósforo. Massa seca e massa seca livre de cinzas apresentaram os maiores valores no período seco; **Conclusões:** O conteúdo de N e P foi desacoplado da disponibilidade do nitrogênio e fósforo da água, mas a razão N:P da água e do perifíton indicaram alta limitação por P. A variação do estado de nutrientes e da biomassa do perifíton foi influenciada pelo tempo de colonização e pela escala sazonal.

Palavras-chave: perifíton, estado nutricional, biomassa, colonização, sazonal.

1. Introduction

Periphyton communities present great ecologic importance due to their participation in primary production, food web interactions and nutrient cycling (Vadeboncoeur and Steinman, 2002), mainly of phosphorus in shallow lakes (Dodds, 2003). Periphyton play the important role as a bioindicador, which can be used in early detection of eutrophication and establishment of restoration targets (McCormick et al., 2001; Pan et al., 2000; Gaiser et al., 2006). The periphytic community can also facilitate the understanding of ecological processes, such as the succession of community, colonization patterns and effects of pulses (Tundisi, 1999).

The dramatic effects of nitrogen and phosphorus overload in the aquatic ecosystems are well known (Smith, 1998). Phosphorus and nitrogen are the most commonly investigated nutrients and, these two nutrients are the most likely to be limitant of algal growth in the periphyton (Borchardt, 1996). Studies have established positive relationships between periphyton biomass and water-column nutrients (Havens et al., 1999; Gaiser et al., 2006), while others showed that nutrient concentrations alone are poor predictors of the standing biomass (Liboriussen and Jeppesen, 2006). Therefore, there is little consensus on the role nutrients play relative to other factors that may regulate periphytic community in aquatic systems (Lowe, 1996; Luttenton and Lowe, 2006).

Research on status nutrients (absence or presence of growth limitation by N or P; surplus of N or P) of periphyton were focused principally on understanding the relationship between status nutrients, biomass of community and trophy of ecosystem (Kahlert, 2002; Kahlert and Pettersson, 2002; Rier and Stevenson, 2006). Studies have shown that periphyton nutrient content increases with water nutrient availability (Gaiser et al., 2004; Stelzer and Lamberti, 2001), while others showed that periphyton status nutrients were uncoupled (Cattaneo, 1987; Liboriussen and Jeppesen, 2006; Borduqui et al., 2009).

In Brazil, experiments and field observations in lakes and reservoirs showed that status nutrients and biomass of periphyton varied in function of nutrient availability (Engle and Melack, 1993; Moschini-Carlos et al., 1998; Ferragut, 1999; Fermino, 2006). Experimentally, Ferragut (1999) and Fermino (2006) evidenced biomass positive response to increased water nutrients availability, considering status nutrient of periphyton a good predictor. At the Jurumirin reservoir, Moschini-Carlos et al. (1998) reveal influence of annual variation on epiphyton chemical composition. In the Amazon region, Engle and Melack (1993) report on influence of seasonal flooding on the periphyton N and P content in Calado Lake. Preliminary synthesis of the evaluation of nutrient limitation to algal growth pointed to phosphorus as the most common limiting element in lentic ecosystems (Huszar et al., 2005).

Knowledge of mechanisms that control the temporal variation of periphyton can improve the understanding of community dynamics and, in general, can contribute to explain the function of ecosystem. Nevertheless, few investigations analyzed to changes of the periphyton along the colonization process (Sekar et al., 2002; Vercellino and Bicudo, 2006), mainly approaching the status nutrient (Stelzer and Lamberti, 2001).

The aim of this study was to evaluate periphyton biomass and status nutrient variation during colonization period in the dry and rainy season in Viveiro Lake (Rio Branco, Acre). Secondarily, the objective was to examine the relationship between status nutrients of periphyton and total nutrient concentration of lake water and, with the increment in community biomass.

2. Material and Methods

This study was conducted in a shallow, urban, tropical lake, Viveiro Lake (09° 57' S and 67° 57' W), located in the Parque Zoobotânico of the Universidade Federal do Acre (Rio Branco, Brazil) (Figure 1). Locally called Viveiro Lake, it is actually the reservoir formed by damming of a narrow river. It has a mean depth of about 1.75 m and a maximum depth of 2.7 m. The regional climate presents two distinct seasons: rainy (October-May, on average accumulated precipitation about 240 mm) and dry (June-September, on average accumulated precipitation about 61.7 mm). The accumulated precipitation data was provided by Instituto Nacional de Meteorologia (INMET, www.inmet.gov.br).

Water sampling for physical, chemical and biological analysis was conducted during dry season (August 19 to September 19, 2006) and rainy (February 3 to March 8, 2007). Samplings were always performed in the morning at 4 day intervals until day 20 and, afterwards, at 5 day intervals, totaling 35 days. Abiotic and biological samplings were carried out simultaneously in the pelagic region.

Surface water and periphyton samples were transported in Styrofoam boxes with ice to the Limnology Laboratory of the Department of Natural Sciences of the Universidade Federal do Acre. Abiotics variables analyzed include water transparency (Secchi disc), temperature, electrical conductivity, pH, dissolved oxygen (DO), (Yellow Spring Instr.), alkalinity (Golterman and Clymo, 1971), carbon dioxide (free CO_2) (Mackereth et al., 1978), total nitrogen (TN) and total phosphorus (TP) (Valderrama, 1981) and silicate (Golterman et al., 1978).

Artificial substrata used were glass slides (76 × 26 mm). Hundred-fifty glass slides were fixed in the wood bases, which were submerged to 20 cm of depth in each study period. The sampling of the periphyton was performed randomly through a drawing of the colonized slides.

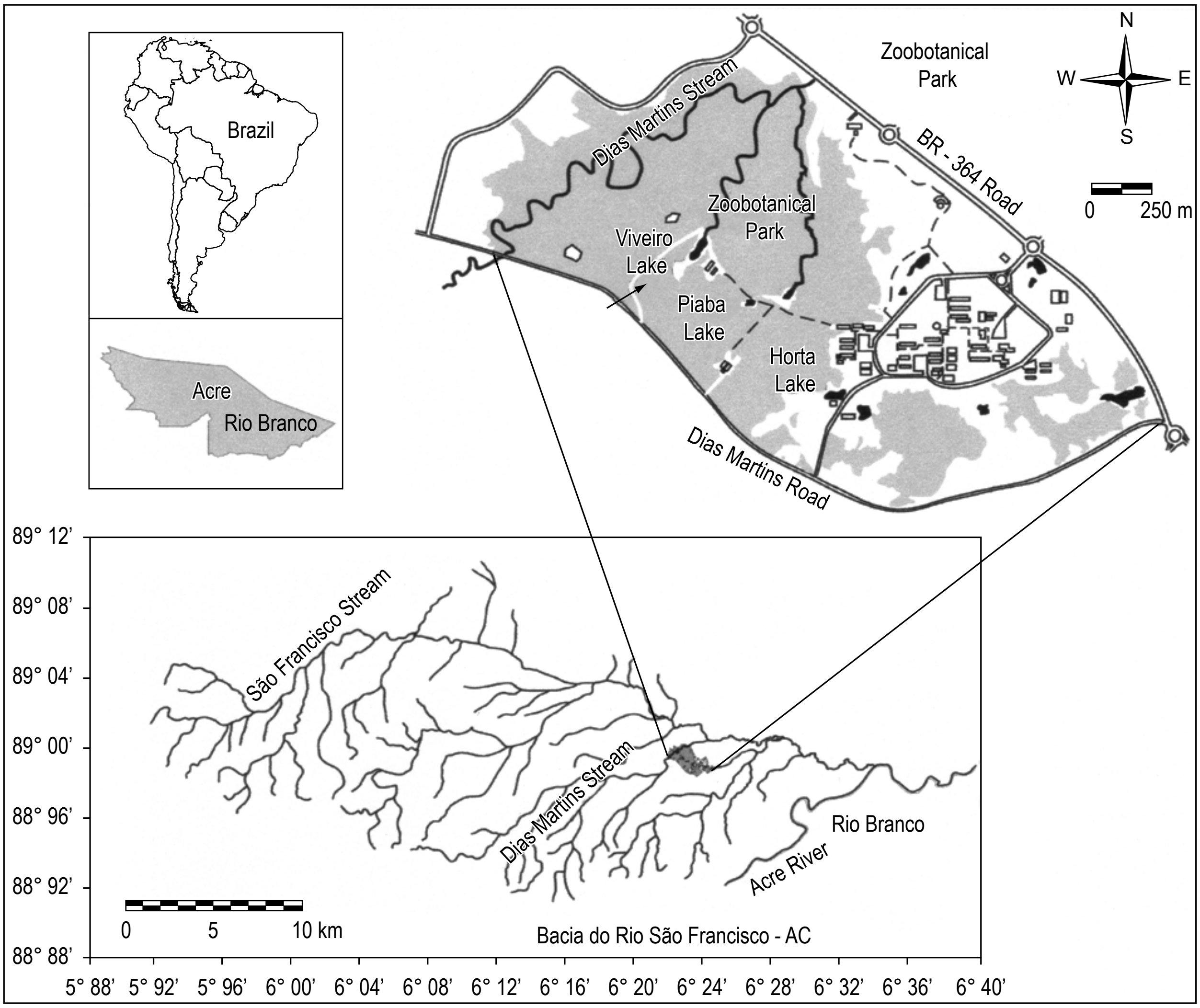

Figure 1. Map of Viveiro Lake with the location of sampling station (arrow).

Periphyton dry mass (DM) and ash free dry mass (AFDM) were determined according to APHA (1995). Triplicate samples for periphyton chemical composition analyses were obtained through scraping and washing of substratum with known volume of ultra-pure water. Later, the samples were frozen until determination of total phosphorus content (Pompêo and Moschini-Carlos, 2003) and total nitrogen (Umbreit et al., 1964) in the periphytic community.

The determination of limitation potential for nutrient of periphytic community was based on the ratio molar ideal 18N:1P proposed by Kahlert (1998) and, on the threshold of 5 and 0.5% for unit of ash free dry mass of periphyton, respectively, nitrogen and phosphorus content according to Biggs (1995). The N:P ratio was calculated based on nitrogen and phosphate molar concentrations.

Coefficient of variation (CV) was used to compare the degree of variation of environmental variables and N and P content of periphytic community studied over time. The Pearson coefficient correlation (r) was used to measure the degree of the relationship between the total nitrogen (NT) and total phosphorus (PT) concentrations and the water and nutrient content of the periphyton. Mean value comparisons between dry and rainy season were made by variance analysis (one-way ANOVA) using Minitab 13.0 for Windows.

3. Results

Mean surface water temperature in dry and rainy season was practically equal (Table 1) and, presented small temporal variability (CV: dry = 2.9%; rainy = 3.6%). The mean values of pH in each season were also very similar (Table 1) and presented small temporal variability (CV: dry = 2.1%; rainy = 2.8%). Electric conductivity presented low values and temporal variability was always small (CV: dry = 6.2%; rainy = 10.6%; Table 1). In contrast, water transparency was higher in the dry season, but presented low temporal variability in both seasons (CV: dry = 28.8%; rainy = 27.8%). The highest values free CO_2 were registered

Table 1. Limnological parameter ranges and, in between parenthesis, mean and standard deviation (n = 8) in the Viveiro Lake during dry and rainy season. Last column refers to one-way ANOVA results (α = 0.05).

Variables	Dry season	Rainy season	Anova
Alkalinity	0.22-0.40	0.17-0.30	F = 4.60
	(0.29 + 0.05)	(0.24 + 0.05)	p = 0.050
Dissolved oxygen ($mg.L^{-1}$)	0.1-1.4	0.1-0.6	F = 2.00
	(0.5 ± 0.48)	(0.3 ± 0.13)	p = 0.179
Electric conductivity ($\mu S.cm^{-1}$)	17-20	15-21	F = 1.76
	(18 ± 1.1)	(17 ± 1.8)	p = 0.205
Free CO_2 ($mg.L^{-1}$)	6.1-11.7	4.2-8.6	F = 7.39
	(8.5 ± 1.9)	(6.2 ±1.4)	p = 0.019
Silicate ($mg.L^{-1}$)	0.1-0.6	0.6-1.9	F = 60.98
	(0.3 ± 0.2)	(1.6 ± 0.4)	p = 0.000
pH	6.6-7.0	6.6-7.3	F = 5.34
	(6.9 ± 0.2)	(7.1 ± 0.2)	p =0.370
Temperature (°C)	25.6-27.8	25.5-27.9	F = 0.07
	(26.6 ± 0.8)	(26.5 ± 0.9)	p = 0.793
Total nitrogen ($\mu gPT.L^{-1}$)	88-1,662	464-843	F = 0.01
	(657 ± 493.2)	(641 ± 131.1)	p = 0.933
Total phosphorus ($\mu gPT.L^{-1}$)	1.0-40	2.5-8.0	F = 1.73
	(11.6 ± 14.8)	(5.0 ± 1.8)	p = 0.209
Transparency (Secchi Disc-m)	0.4-0.9	0.2-0.5	F = 19.44
	(0.7 ± 0.2)	(0.4 ± 0.1)	p = 0.001
TN:TP Ratio (molar)	18.5-770	162.1-581.4	F = 0.06
	(304 ± 267)	(300 ± 144)	p = 0.973

during dry season and, the temporal variability was similar in the studied periods (CV: dry = 22.7%; rainy = 22.9%). Alkalinity, free CO_2, pH, transparency and silicate differed significantly between dry and rainy season (Table 1).

Highest values of TP in the water were registered in the dry season, which also presented the largest temporary variability (CV: dry = 128.3%; rainy = 36.5%; Figure 2). NT concentration also presented larger temporal variability and the highest values in dry season (CV: dry = 75.1%; rainy = 20.5%; Figure 2). TN:TP molar ratio was highest during dry and rainy season (dry = 304 and rainy = 300 on average), indicated P limitation according Redfield ratio (16N:1P). TP and TN were not significantly different between dry and rainy season (Table 1).

3.1 Periphytic community

The maximum value of P content was registered in the advanced stages of the colonization, on days 25 and 30, respectively dry and rainy seasons (Figure 3 and Table 2). P content of periphyton varied during colonization time in dry and rainy seasons (CV: dry = 80%, rainy = 51%). Periphyton P content was significantly different between dry and rainy seasons (ANOVA: F = 5.39, p = 0.039) and, the highest value was verified in rainy season (Figure 3 and Table 2). P content and TP concentration of water had negative correlation in both seasons, but was significant

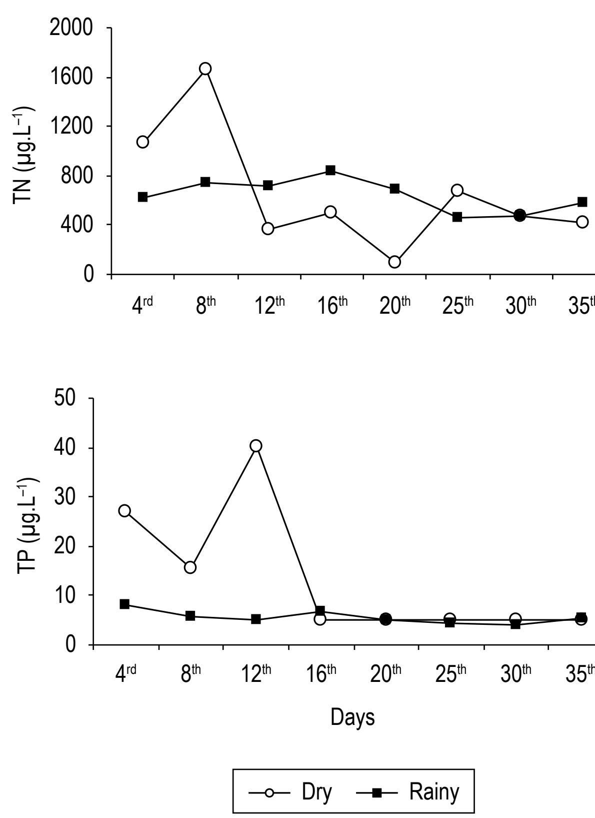

Figure 2. Temporal variation of total phosphorus and total nitrogen concentration in the Viveiro Lake.

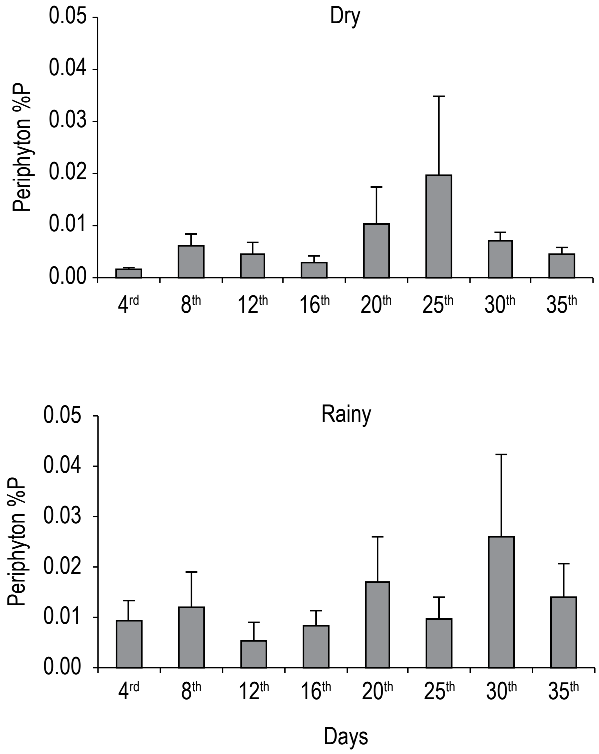

Figure 3. Variation of periphyton P content (%P.AFDM) mean values (n = 3; ±SD) during colonization period in dry and rainy season.

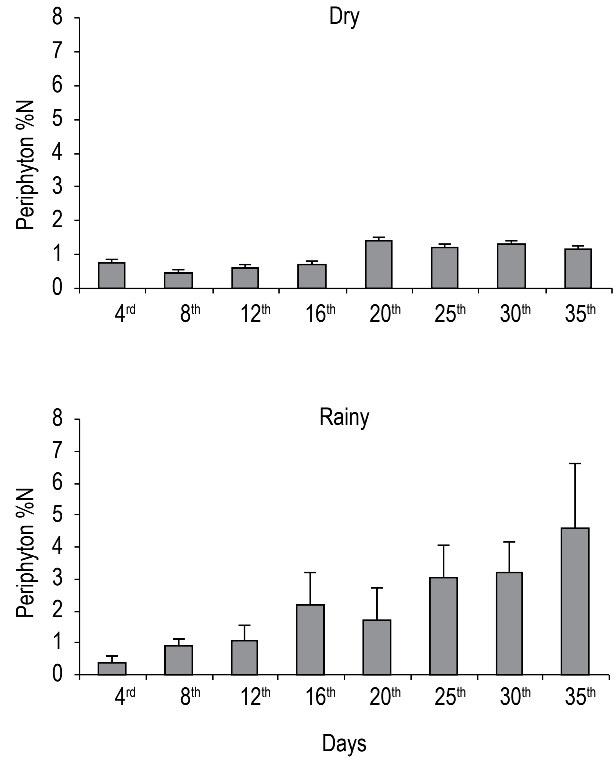

Figure 4. Periphyton N content (%N.AFDM) mean values (n = 3; ±SD) during colonization period in dry and rainy season.

Table 2. Minimum, maximum, mean, standard deviation (SD) and coefficient of variation (CV) values of phosphorus content, nitrogen content, N:P molar ratio, dry matter (DM) and ash-free dry matter (AFDM) of periphytic community measured in Viveiro Lake during the dry and rainy season.

	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
	%P		%N		N:P		DM		AFDM	
Minimum	0.00	0.01	0.5	0.4	125.4	86.5	0.1	0.02	0.1	0.01
Maximum	0.02	0.03	1.4	4.6	918.5	679.3	1.4	0.80	0.8	0.70
Mean	0.01	0.01	1.0	2.1	396.2	374.9	0.4	0.20	0.3	0.10
SD	0.01	0.01	0.4	1.4	253.9	230.1	0.5	0.30	0.2	0.20
CV (%)	80.20	51.10	36.8	65.6	64.1	61.4	104.5	165.80	94.4	206.7

only in dry season (dry: r = –0.743, p = 0.035; rainy: r = –0.178, p = 0.674).

Maximum value of N content was also registered in the advanced stages of the colonization, on the 20th day in the dry season and the 35th day in the rainy season (Figure 4 and Table 2). Periphyton N content was on average 2.3 times higher in rainy than dry seasons and, was considered significantly different between seasons (ANOVA: F = 4.06, p = 0.053). Temporal variability of N content was higher in rainy than dry seasons (CV: dry = 36.8%, rainy = 65.6%). In both seasons, the correlation between periphyton N content and TN concentration in the water was not significant (dry: r = 0.110, p = 0.796; rainy: r = –0.411, p = 0.312).

According to threshold of limitation proposed by Biggs (1995), N content of the periphyton was lower than 1.4% during colonization period in dry season, while in rainy season the N content was larger and close to limitation absence (4.6%). P content was smaller than threshold of 0.5%, therefore indicating always P limitation extreme.

Based on ratio molar 18N:1P optima for periphytic community (Kahlert, 1998), it was observed that community growth was extremely P limited during colonization period in dry and rainy seasons (Figure 5 and Table 2). Maximum value of N:P ratio was registered on the 35th day of the colonization in rainy season, while in the rainy season it occurred on the 4th day. Except for day 4 in dry season, the ratio N:P tended to increase throughout the colonization

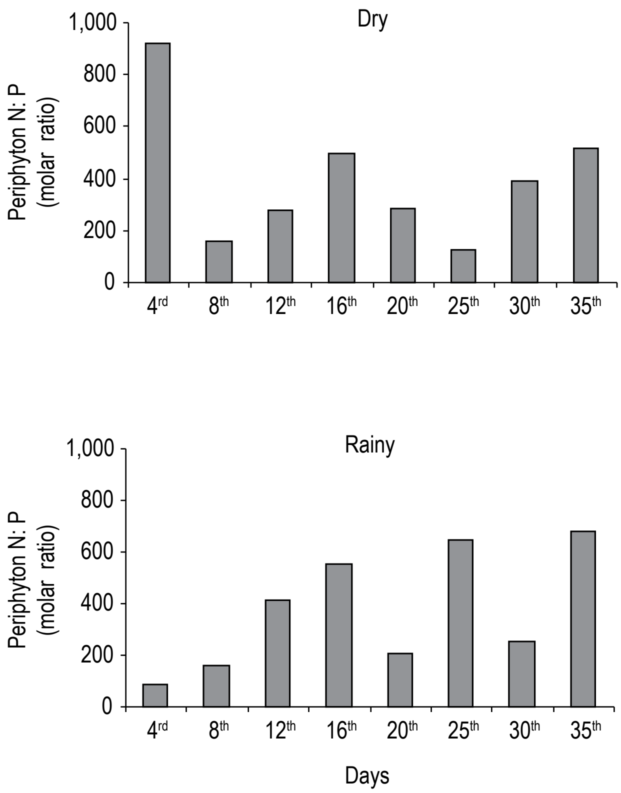

Figure 5. N:P ratio molar of periphyton during colonization period in dry and rainy season.

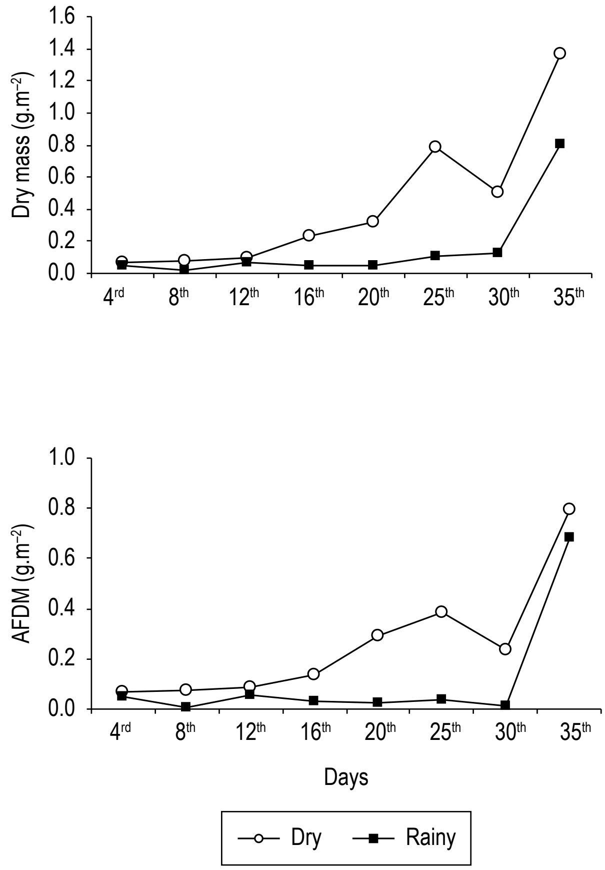

Figure 6. Periphytic dry mass (DM) and ash-free dry mass (AFDM) during colonization period in dry and rainy season.

period during both seasons (increase P limitation). Variation N:P ratio of periphyton during colonization period was high, but the coefficient of variation was similar among dry and rainy seasons (CV: dry = 64.1%, rainy = 61.4%). Periphyton N:P ratio was not significantly different between dry and rainy seasons (ANOVA: F = 0.03, p = 0.854).

Periphyton DM and AFDM presented the highest increment in the dry season (Figure 6). Dry season had increment of DM and AFDM on average of 2.7 and 2.3 times higher in the dry season than rainy, respectively. DM and AFDM tended to present an exponential increase during colonization period in dry and rainy seasons. The increment maxim of AFDM was reached on the 35th day in dry and rainy seasons. The temporal variability of AFDM was higher in the rainy season (CV: dry = 94%; rainy = 207%).

4. Discussion

Considering that periphyton colonization and development in any substratum depend on various physical, chemical and biological factors, characteristic of a particular aquatic habitat (Stevenson, 1996), the Viveiro Lake presented favorable limnological conditions for community development during the study period. In general, the lake presents differentiated limnological conditions during the study period. According to analyzed environmental variables, the dry season was characterized mainly by the highest values of water transparency, while the rainy season was characterized by the highest silicate concentration.

The researchers frequently apply N:P stoichiometry of periphyton to predict the nutrient limiters for algal growth (e.g. Hillebrand and Sommer, 1999), as measure of status nutrients (Kahlert and Pettersson, 2002) and, sometimes as a tool for nutrient abatement efforts (McCormick et al., 2001; Gaiser et al., 2006). Most of the predictions of nutrient limitation have used the ratio of Redfield 16N:1P, which was determined empirically for the oceanic seston (Redfield, 1958). Recently, Kahlert (1998) proposed, based on compiled data, 18N:1P as the ideal ratio for periphytic algae community.

Presently, the N:P ratio of the periphyton was higher than 32 during colonization period in dry and rainy seasons, indicating extreme P limitation according to Kahlert (1998). Another way to evaluate the limitation potential of periphyton is through N and P content. The limitation threshold proposed by Biggs (1995) used in a stream ecosystem, therefore, should be used with caution for lentic ecosystems. The application of limitation threshold N and P for Viveiro Lake showed that periphyton was co-limited for N and P in the dry season. Nevertheless, community was primarily limited for P in the rainy season, because the N:P ratio was very close to the limitation absence for N (≥5%). Based on the content of N and P and N:P stoichiometry, the periphyton developed at the Viveiro Lake was considered limited primarily for phosphorus and secondarily for N.

Considering limitation potential of the periphyton in Brazil, experimental (Ferragut, 1999) and observational (Vercellino and Bicudo, 2006; Borduqui et al., 2009) studies indicate phosphorus as principle nutrient limiting in community development. Preliminary synthesis of the evaluation of nutrient limitation to growth pointed to phosphorus as the most common limiting element (Huszar et al., 2005). On the other hand, Engle and Melack (1993), using the Redfield ratio (16N:1P), identified N-limited periphyton in Lake Calado (Amazonian) during rainy and dry seasons.

Previous studies have also found seasonal variations in the status nutrients of periphyton in tropical systems (Fermino, 2006; Moschini-Carlos et al., 1998; Borduqui et al., 2009). Fermino (2006) reported influences of seasonal scale on the periphyton status nutrients and, found better status nutrients in the spring. Moschini-Carlos et al. (1998) reported high N:P ratio variation on an annual scale, however, they found the community P-limited in most months.

The status nutrients of periphyton also varied during colonization time in the present study. N and P content tended to increase with the progress of colonization period. In the temperate region, Sekar et al. (2002) observed that N:P ratio in the interstitial water of biofilm was relatively high in the early periods of biofilm development, but decreased sharply by the fourth day.

This study did not detect significant correlation between TP and TN concentration of water and nutrient content of periphyton. Thus, periphyton content of N and P uncoupled the availability of TN and TP of the water, however the ratio N:P of the water and periphyton indicated high limitation equally for P. The relationship between periphyton nutrient content and available water nutrients is controversial, there are studies that reported a weak relationship (Cattaneo, 1987; Liboriussen and Jeppesen, 2006), while others found good correlation (Havens et al., 1999; Gaiser et al., 2006; Borduqui et al, 2009). In a tropical reservoir, Moschini-Carlos et al. (1998) found no positive correlation between dissolved nutrient concentration and periphyton nutrient content, but the variation was in function of nutrient availability. Borduqui et al. (2009) reported that P contents of periphyton were conditioned to availability of nutrients in the water column. According to Kahlert and Pettersson (2002) is needed to unravel the causes for the uncoupling of lake trophy, periphytic algal status nutrients, status nutrients and algal biomass.

Periphyton biomass varied during colonization period in the dry and rainy seasons and peaked on the last day of the study period. Thus, biomass increment increases during colonization time. According to Biggs (1996), during periphyton development there is an initial phase of rapid growth, biomass increase and productivity and a second phase with maximum increment of biomass and productivity. In tropical ecosystems, previous studies have also reported exponential increase accrual of biomass during colonization and succession processes (Vercellino and Bicudo, 2006; Felisberto, 2007).

In seasonal scale, development of biomass (AFDM) was the most favorable in dry season, which had the highest transparency values and, the difference was significant between seasons. Probably, the seasonal variation of biomass was more influenced by water transparency. Another study of Viveiro Lake during the same period found that low water transparency in rainy season was due to the influence of allochthonous material contribution (Dantas, 2008). Based on the comparison of different lagoons from eight floodplains in South America, Carvalho et al. (2001) mentioned that diel mixing, greater light penetration and fertilization due to sediment re-suspension during low water phase, are the main causes of increments in phytoplankton biomass. The influence of hydrodynamic conditions on the seasonal variation of periphyton biomass was related in Paranapanema River floodplain (Leandrini and Rodrigues, 2008) and Jurumirim reservoir (Moschini et al., 2000).

In short, periphyton biomass and content of N and P increased during the course of the colonization process, but the potential limitation also increased. Although biomass, N and P content increased with colonization time, the nutrient partition was not good. Periphyton N and P content uncoupled the availability of TN and TP of the water, but the ratio N:P of the water and periphyton indicated high P-limitation. The variation of status nutrients and biomass accumulation were influenced by colonization time (autogenic process) and scale seasonal. Finally, the present study contributes to a better understanding of the periphyton community dynamics in Amazonian freshwater system.

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