Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9283
ISSN on-line: 1807-863X
Doi: 10.4025/actascibiolsci.v35i4.18663

Structure of the periphytic algae associated with a floating macrophyte in an open lake on the upper Paraná river floodplain, Brazil

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ABSTRACT. We aimed to access the knowledge of the structure of the periphytic algae community on a floating substrate, the macrophyte *Ricciocarpus natans* (L.) Corda, during two hydrological periods in a connected environment at the Paraná river floodplain. Attached algal was removed from the substrate with the aid of a soft-bristled brush and distilled water jets and was fixed immediately for qualitative and quantitative analysis. The total richness of the periphytic algae was 188 taxa. February showed the highest species richness (154 taxa), while total species density exhibited an inverse pattern, with the highest values occurring in June (273.4 10^3 ind. cm^{-2}). Bacillariophyceae comprised the largest fraction of density, which was reflected by the abundance of *Achnanthidium minutissimum* (Kütz.) Czarn. Community structure of periphytic algae in *R. natans* followed the same pattern of other substrates, as previously determined. This suggests that main factor acting on the structure of periphyton at the Paraná river floodplain is primarily the floodpulses regime. The hydrochoric dispersion of *R. natans* across the various environments comprising the floodplain favors its communities associated, as the periphytic algae, subject to passive transport via water movement. Floating rhizoids of *R. natans* also may act as a mesh retainer, promoting the colonization of many metaphytic and planktonic species. However, in order to better understand and delineate patterns of ecosystem functioning, it is recommended that natural substrates be used which have greater stability in the environment, such as rooted or submerged macrophyte species.

Keywords: periphyton, community structure, natural substrate, *Ricciocarpus natans*.

Estrutura das algas perifíticas associadas a uma macrófita flutuante em uma lagoa aberta da planície de inundação do alto rio Paraná, Brasil

RESUMO. Objetivou-se conhecer a estrutura da comunidade de algas perifíticas em um substrato flutuante, a macrófita *Ricciocarpus natans* (L.) Corda, em dois períodos hidrológicos em um ambiente conectado na planície do alto rio Paraná. O material perifítico foi removido do substrato com ajuda de pincel de cerdas macias e jatos de água destilada e imediatamente fixado para a análise qualitativa e quantitativa. A riqueza total das algas perifíticas foi de 188 táxons. Fevereiro apresentou a maior riqueza (154 táxons), enquanto que a densidade total apresentou um padrão inverso, no qual os maiores valores ocorreram em junho (273,4 10^3 ind. cm^{-2}). Bacillariophyceae compôs a maior fração da densidade, refletida pela abundância de *Achnanthidium minutissimum* Czarn (Kütz.). A estrutura da comunidade de algas perifíticas em *R. natans* seguiu o mesmo padrão de outros substratos, conforme estudos anteriores. Isto sugere que o principal fator atuante sobre a estruturação do perifíton na planície do rio Paraná seja primariamente o regime de pulsos. A dispersão hidrocórica de *R. natans* ao longo dos vários ambientes que compõem a planície favorece suas comunidades associadas, como as algas perifíticas, sujeito ao transporte passivo através do movimento da água. Os rizóides flutuantes de *R. natans* também podem atuar como uma malha retentora, promovendo a colonização de muitas espécies metafíticas e planctônicas. No entanto, a fim de melhor compreender e delinear padrões de funcionamento dos ecossistemas recomenda-se o uso de substratos naturais que possuam maior estabilidade no ambiente, tais como espécies de macrófitas aquáticas enraizadas ou submersas.

Palavras-chave: perifíton, estrutura da comunidade, substrato natural, *Ricciocarpus natans*.

Introduction

Research investigating the structure and functioning of biological communities on the Paraná river floodplain all point to the river's hydrological regime and tributaries as the main factors influencing the region's ecological processes (THOMAZ et al., 2007). Hydrometric level variation and its effect on aquatic communities has been examined on several occasions with regard to the Paraná river floodplain, including work focusing on the local periphyton community (ALGARTE et al., 2006, 2009; ALGARTE; RODRIGUES, 2013;

LEANDRINI et al., 2008; RODRIGUES; BICUDO, 2001; ZANON et al., 2013; and others). Most of these studies involved analysis of periphytic algae in their ecological context on natural substrate: the aquatic macrophyte *Eichhornia azurea* Kunth, which covers extensive areas on the littoral margins of different environments on the floodplain.

However, recent work has been carried out investigating the periphytic community when associated with other natural substrates (BIOLO; RODRIGUES, 2010, 2013; FERREIRA et al., 2011a; MORMUL et al., 2010), and specifically with *Ricciocarpus natans* (L.) Corda, a small floating macrophyte present in various environments on the Paraná river floodplain, according to surveys previously realized conducted by S.M. Thomaz and colaborators (SANTOS; THOMAZ, 2007). This particular macrophyte was not reported for the current study environment until 2008 (FERREIRA et al., 2011b). Studies involving this substrate include an examination of the taxonomy of periphytic algae belonging to the classes Xanthophyceae and Euglenophyceae carried out by Biolo and Rodrigues (2010), as well as the elucidation of the structure and dynamics of the periphyton; however, these latter works have been restricted to Argentina (POZZOBON; TELL, 1995; RODRÍGUEZ et al., 2011; TELL, 1977; TESOLÍN; TELL, 1996).

The present study was therefore devised with the primary aim of revealing the structure of the periphytic algae community associated with the floating macrophyte *R. natans*, during two hydrological periods in a connected environment on the Paraná river floodplain. We also try to verify if there was some importance of the diversity of natural substrates for the structure of the periphytic community in a floating substrate.

Material and methods

Study area

Of the wide variety of aquatic environments present on the Paraná river floodplain, backwaters have particularly unique characteristics. Consisting of shallow areas between lotic and lentic in nature, backwaters on the floodplain are permanently connected to the Paraná river and thus receive the latter's direct influence. The 'Pau Véio' backwater, site of the present study, is located near the municipality of Porto Rico on Mutum Island, Paraná State (22°44'50.76"S - 53°15'11.16"W), on the border between the states of Paraná and Mato Grosso do Sul.

Methodology

The natural substrate selected for algal sampling consisted of rhizoids of the floating aquatic macrophyte *Ricciocarpus natans* (Ricciaceae). This liverwort is a free floating macrophyte, with lobed thallus forming branches and delicate rhizoids, and often can be found trapped to other macrophytes due to the reduced size and water movement (POTT; POTT, 2000). Plants were collected in three replicates (n = 3) during two different hydrological periods: high water (February 2008) and low water (June 2008), from multi-specific banks of aquatic macrophytes along the backwater. Plants were immediately conditioned in Wheaton (150 mL) previously sprayed with distilled water and kept in a polystyrene box on ice.

Flasks designated for quantitative analysis were wrapped in aluminum foil (dark bottles). In the laboratory, attached algal material was removed from the substrate with the aid of a soft-bristled brush (number 00) and distilled water jets; material assigned for qualitative analysis was fixed immediately in Transeau solution 1:1, while that destined for quantitative analysis was placed in 5% acetic lugol solution, as recommended by Bicudo and Menezes (2006).

Quantitative analysis was performed using a sedimentation chamber and inverted microscope following the Utermöhl method (UTERMÖHL, 1958), and using random fields as recommended by Bicudo (1990). The equation applied in order to calculate density followed that of Ros (1979) adapted to the area of substrate, with the results expressed per unit area (ind. cm^{-2}). Substrate area was determined by averaging areas of rhizoid, based on the area of an ellipse multiplied by two (both sides).

Community structure was evaluated in terms of the following attributes: species richness (number of taxa), algal density, species abundance and dominance (LOBO; LEIGHTON, 1986), diversity and evenness, using the software program PC-ORD version 4.0.

Physical and chemical properties of water were determined simultaneously with biological data collection. Values for each of these variables were obtained and transferred to the Laboratory of Limnology at Nupélia (Limnology, Ichthyology and Aquaculture Research Group), State University of Maringá, Paraná State, Brazil.

Results

The hydrometric level of the Paraná river exhibited certain irregularities during 2008, with low values, an absence of typical flooding and the occurrence of short pulses or small daily fluctuations

(Figure 1) (BIOLO; RODRIGUES, 2013; ROBERTO et al., 2009). Others abiotic data of the 'Pau Véio' backwater is shown in the Table 1.

Accordingly, February was characterized by higher values of water temperature, conductivity, turbidity, total nitrogen and ammonia, phosphorus and orthophosphate, while the highest values of dissolved oxygen, alkalinity, transparency and nitrate were observed in June. Water pH, total dissolved solids, and organic and inorganic fractions showed stable values across the two collection periods. Fractions of total phosphorus and phosphate were higher in February, as was that of nitrogen. During this part of the year, the backwater's supply of allochthonous nutrients is derived from the influence of flood pulses that increase the hydrometric level of the Paraná river (RODRIGUES; BICUDO, 2001). More detailed discussion about the abiotic data in 2008 are shown by Roberto et al. (2009).

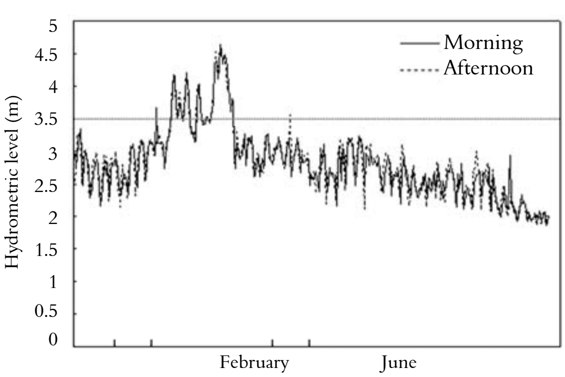

Figure 1. Hydrometric level of the Paraná river in 2008. Dashed line indicates the overflow level.

Table 1. Abiotic data recorded alongside sampling of biological material in the 'Pau Véio' backwater on the Paraná river floodplain in the study period (February and June 2008).

Abiotic data/Month of 2008	February	June
Temperature (ºC)	27.0	19.4
Turbidity (NTU)	5.46	3.33
Conductivity (uS cm^{-1})	67.2	56.7
Transparency (m)	2.25	3.1
pH	6.71	6.83
Dissolved oxygen (mg L^{-1})	3.36	6.15
Alkalinity (μEq L^{-1})	370.7	468
Total solids (μg L^{-1})	2.2	2.1
Inorganic dissolved solids (mg L^{-1})	1.15	1.30
Organic material (mg L^{-1})	1.05	0.80
Total nitrogen (μg L^{-1})	351	227.5
NO_3^- (μg L^{-1})	74.1	135.8
NH_4^+ (μg L^{-1})	41.0	4.9
Total phosphorus (μg L^{-1})	21.3	13.2
PO_4^{++} (μg L^{-1})	8.8	4.9

This unusual year in the river's hydrological regime was probably a result of the operation of dams located above the study area, mainly at Porto Primavera (ROBERTO et al., 2009; THOMAZ et al., 1997). Despite the hydrological periods not presenting themselves as sharply delimited, as in previous years, daily fluctuations probably were reflected by changes in the river's biotic and abiotic characteristics, as well as in the typical periods of high and low water.

The total richness of the periphytic algal community and other associated algae on *R. natans* consisted of 188 taxa, regardless of hydrological period. Of these 188, 61 taxa belonged to the class Bacillariophyceae, 24 Chlorophyceae, 7 Chrysophyceae, 4 Cryptophyceae, 34 Cyanophyceae, 9 Euglenophyceae, 6 Oedogoniophyceae, 1 Rhodophyceae, 6 Xanthophyceae and 36 Zygnemaphyceae. In terms of the richness of these algal classes, Bacillariophyceae were predominant (32.5%), followed by Zygnemaphyceae (19.2%), Cyanophyceae (18.1%) and Chlorophyceae (12.8%). Classes characterized by lower values of richness during both sampling periods were Euglenophyceae, Chrysophyceae, Oedogoniophyceae, Xanthophyceae, Cryptophyceae and Rhodophyceae, which together represented 17.6% of total taxa. In terms of sample period, February showed the highest species richness, 154 total taxa, in contrast to 103 total taxa found in June (Figure 2).

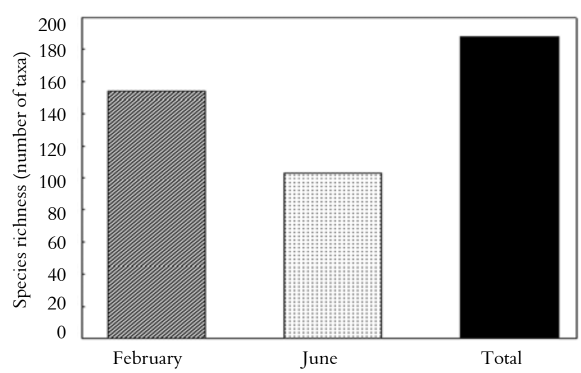

Figure 2. Species richness of algal classes of periphyton on *Ricciocarpus natans* in the 'Pau Véio' backwater during the study period (February and June 2008).

Total species density exhibited an inverse pattern in relation to species richness for the periods sampled, with the highest values occurring in June (273.4 10^3 ind. cm^{-2}) and lower values in February (31.8 10^3 ind. cm^{-2}). Bacillariophyceae comprised the largest fraction of total density in both sampling periods: 21.7 10^3 ind. cm^{-2} in February and 246.7 10^3 ind. cm^{-2} in June (Figures 3 and 4). These values largely reflect the predominant abundance of *Achnanthidium minutissimum* (Kütz.) Czarn. (117.8 10^3 ind. cm^{-2}). Other diatoms taxa, like *Fragilaria capucina* (22.8 10^3 ind. cm^{-2}) and *Gomphonema gracile*

(30.5 10^3 ind. cm^{-2}) were well represented (in both periods and in June, respectively).

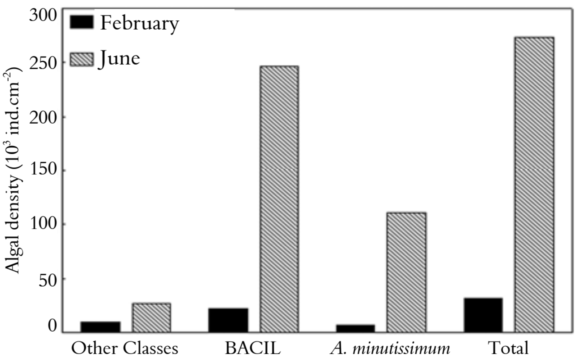

Figure 3. Total density of class Bacillariophyceae (BACIL), with an emphasis of the density of the diatom *Achnanthidium minutissimum,* and all the classes, of periphyton on *Ricciocarpus natans* in the Pau Véio backwater during the study period (February and June 2008).

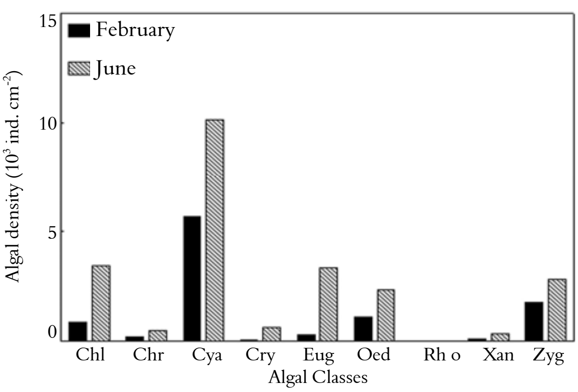

Figure 4. Total density of classes (except class Bacillariophyceae) of periphytic algae on *Ricciocarpus natans* in the 'Pau Véio' backwater during the study period (February and June 2008) (Chl = Chlorophyceae; Chr = Chrysophyceae; Cya = Cyanophyceae; Eug = Euglenophyceae; Oed = Oedogoniophyceae; Rho = Rhodophyceae; Xan = Xanthophyceae; Zyg = Zygnemaphyceae).

Abundant species were: *A. minutissimum*, *Cymbella affinis* Kützing, *Encyonema mesianum* (Cholnoky) D.G.Mann, *E. silesiacum* (Bleisch) D.G.Mann, *Fragilaria capucina* Desmazières, *Gomphonema brasiliense* Grunow, *G. clevei* Fricke, *G. gracile* Ehrenberg, *G. parvulum* (Kützing) Kützing, *Navicula* cf. *cryptocephala* Kützing, *Nitzschia amphibia* Grunow, *N. palea* (Kützing) W. Smith, *Ulnaria ulna* (Nitzsch) Compère (Bacillariophyceae) and *Leptolyngbya perelegans* (Lemmermann) Anagnostidis & Komárek (Cyanophyceae). No dominant species in the community were observed, although the percentage of *A. minutissimum* reached close to dominance in 2008 (40.6%). The diversity and evenness of species were 3.53 bits $ind.^{-1}$ and 0.7 bits $ind.^{-1}$ respectively, in February, and 2.67 bits $ind.^{-1}$ and 0.57 bits $ind.^{-1}$ respectively, in June.

Discussion

Despite the differences in behavior of the many aquatic environments that characterize the floodplain, the permanent connectivity of semi-lotic environments - including the 'Pau Véio' backwater - results in the latter being directly affected by changes in the river's hydrometric level (THOMAZ et al., 1997). In this way, the irregularity of the hydrometric levels of the Paraná river observed during 2008 was also reflected in the recorded variation of biotic and abiotic variables. On February 2008, when limnological conditions were more favorable for the development of algae (higher temperature and phosphoric fractions concentrations), specific richness was higher than on June 2008. However, the dominance of some groups in terms of abundance, such Bacillariophyceae, in unfavorable limnological conditions as presented in June 2008 (lower temperatures and phosphoric fractions concentrations) was recorded.

These facts mean that species richness and density of periphytic algae in what would be the typical periods of high (February 2008) and low water (June 2008) followed the same pattern as that observed in periphytic communities associated with other substrates in previous studies investigating the Paraná river floodplain (ALGARTE et al., 2006, 2009; LEANDRINI et al., 2008; MURAKAMI et al., 2009; RODRIGUES; BICUDO, 2001). This indicates that floodpulses - even those of low intensity and amplitude, as reflected by the influence of daily fluctuations in hydrometric level - act as the preponderant macrofactor determining the structure and dynamics of periphyton in this ecosystem. Regard to class Bacillariophyceae, this group are well documented at the Paraná river floodplain and may to dominate the periphytic community under certain environmental conditions (LEANDRINI; RODRIGUES, 2008; RODRIGUES; BICUDO, 2001, 2004; RODRÍGUEZ et al., 2011). It suggests that the type of substrate did not influenced primarily structure of the periphytic community, since the periphytic algae on the floating macrophyte R. natans presented the same pattern as on other substrates at this floodplain (wich is mainly governed by floodpulses).

The present study focused on a particular macrophyte substrate: *R. natans*. This species was first reported by Thomaz et al. (1997) only in unconnected environments on the Paraná river floodplain, suggesting that it could act as a bioindicator species. However, later research carried out by Santos and Thomaz (2007) and Ferreira et al. (2011b) reported it in both connected and unconnected systems. The hydrochoric dispersion of *R. natans* (FERREIRA et al., 2011b; SANTOS; THOMAS, 2007) across the various environments comprising the floodplain is extremely important, not only for the dynamics of the macrophyte itself, but also for that entire biological communities, including periphytic algae. Periphytic algae can be also affected by the diversity of macrophytes in lowland environments (BIOLO; RODRIGUES, 2013; ALGARTE et al., 2006; MURAKAMI et al., 2009;) due to the availability of additional substrate to be colonized, as well as the influence of algal entrainment in multiple ecosystems due to macrophyte dispersion – as suggested by the present study.

In this context, the periphytic algal community of a floating macrophyte is particularly interesting, because contrary to that occurring in other periphytic habitats, communities associated with this type of substrate are subject to passive transport via water movement (POZZOBON; TELL, 1995; RODRÍGUEZ et al., 2011). In addition, the floating rhizoids of *R. natans* may act as a mesh retainer, promoting the colonization of many metaphytic and planktonic species (RODRÍGUEZ et al., 2011; TESOLÍN; TELL, 1996), as observed occurring in the ‘Pau Véio’ backwater.

In general, a high diversity of species was recorded on *R. natans*, including a number of taxa found in studies investigating other natural substrates such as *E. azurea* (RODRIGUES; BICUDO, 2001; RODRIGUES et al., 2004; FONSECA; RODRIGUES, 2005; BIOLO; RODRIGUES, 2013). This highlights the importance of exchange between different algal habitats: metaphytic, planktonic and periphytic.

The results of the present study are also in agreement with earlier work (AGOSTINHO et al., 2000) revealing the Upper Paraná river floodplain to support a high diversity of species, as reflected in both the periphytic community and other algae associated with *R. natans*. The numbers recorded here are significantly higher than those of Pozzobon and Tell (1995), whose study of the periphytic algal community on the same substrate in an Argentine lake found a total of only 26 taxa, compared to the 188 observed in the ‘Pau Véio’ backwater - and even higher than the findings by Rodríguez et al. (2011), consisting in 105 taxa. Although, these authors have not reported values for diversity in their study, in the present work were high (between 2.67 and 3.53 bits ind.$^{-1}$).

However, in order to better understand and delineate patterns of ecosystem functioning, it is recommended that natural substrates be used which have greater stability in the environment, such as rooted or submerged macrophyte species. The methodology of the present study contained inherent difficulties as a result of its use of the floating substrate *R. natans*. The latter plants are small and structurally delicate, and can be easily transported via water currents both within the same environment and to others, as well as potentially be trapped amongst other macrophytes (POTT; POTT, 2000). Moreover, *R. natans* is not an abundant species nor recurrent in a given place and time (THOMAZ et al., 2007), thus restricting its use. Studies that require larger spatial and temporal scales, standardized and appropriate for the study of the periphytic community in question, should therefore consider other substrate species.

Conclusion

Despite the peculiarities of the substrate, periphyton associated with *R. natans* are affected by variation in hydrometric level in a similar way to those found on other natural substrates in the upper Paraná river floodplain. However, we recommend the use of more stable substrates in ecological studies of the periphytic community, due to the methodological standardization required for the investigation of such large-scale space-time dynamics.

The present study also suggests the importance of substrate diversity for the community structure of periphytic algae in the upper Paraná river floodplain, jointly influence of typically metaphytic and planktonic algae observed.

Acknowledgements

The authors would like to acknowledge the CNPq / CAPES scholarships granted to the authors, as well as the scientific professionals at Nupélia (Research Nucleus in Limnology, Ichthyology and Aquaculture) for their assistance during the development of this work. This research was conducted as part of the PELD – Pesquisas Ecológicas de Longa Duração/CNPq - The Upper Paraná river floodplain - Site 6 Project.

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Received on September 19, 2012.
Accepted on April 4, 2013.