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Structure and Dynamics of Benthic Macroalgae Communities in Lotic Ecosystems Under the Effect of Uneven Topography

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Research Article

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ABSTRACT

This study aimed to assess the effects of topographical gaps (waterfalls) of different proportions on the ecological characteristics and composition of benthic macro algae communities present in a lotic system. In this sense, the biotic (composition, richness, abundance, diversity, dominance and evenness) and abiotic (physical and chemical characteristics of water) characteristics were assessed in three topographical gaps of different proportions (2.80, 6.5 and 40 meters high). The analyses were made in a pre-established segment before and after each waterfall. Eight benthic macro algae taxa (50% belonging to the Cyanobacterial division, 37.5% to the division Chlorophyta and 12.5% to the division Heterokontophyta) were found. The floristic composition was similar both in different waterfalls and in different points of the same waterfall, which is due to the low occurrence of taxa, in addition to the wide distribution of some species (i.e., *Phormidium retzii*). Among the ecological parameters of communities, differences were found between the waterfalls (as to species richness and abundance, evenness and diversity index) and between different points of the same waterfall (abundance). The biotic variable most affected by micro-environmental variables (substrate size, depth and current speed) was the abundance of species. Thus, the presence of topographical gaps in the streambed or riverbed directly interfered, mainly, in the structure of benthic macro algae communities assessed, acting as a physical barrier and creating the specific conditions for the development of diverse communities in segments with similar lotic environments.

INTRODUCTION

The search for understanding the complex structure and function of communities in lotic ecosystems and its relation with environmental factors have been, for long, widely discussed in the literature. A classic example is the River Continuum Concept (RCC) proposed by Vannote et al. [1], which acknowledge that environmental physical characteristics (e.g., depth, water volume and anthropogenic use) may promote the structuring of aquatic communities (e.g., algae and macro-invertebrates). Additionally, Frissell et al. [2] propose the spatial hierarchy distinction of habitat as mean of understanding the functional variability of these ecosystems. In this sense, each spatial scale, which ranges from a regional scale (e.g., watershed) to a local scale (e.g., a rock in the streambed), has specific attributes to promote significant changes in aquatic communities, therefore, the understanding of biotic characteristics depends on the spatial scale observed.

Recent studies (e.g., Krupek et al. [3,4]) have sought to understand the real influence of the habitat on benthic macroalgae communities, focusing on the environmental heterogeneity at different spatial scales. According to Branco et al. [5] the structure of lotic macroalgae communities is influenced both by the local environmental variables and by the special characteristics of the habitat. However, considering the benthic macroalgae as an ecologically heterogeneous and distinct taxonomic group, several factors typical from the environment (e.g., waterfalls) may directly interfere in the structure and the dynamics of these organisms.

The habitat complexity in current water environments under natural conditions, characterized as highly heterogeneous and physically complex ecosystems, may determine the richness, abundance and diversity of aquatic organisms [6,7] and, finally, explain the common and typical mosaic distribution of benthic macroalgae [4,8]. It is therefore considered that the micro-environmental conditions (e.g., substrate type, current speed) resulted from the aquatic habitat diversity may lead to an extremely large variation in small areas within the same river segment. Such influences observed in short periods of time are equally if not more important than the macro-environmental variables (e.g., climate, geology and vegetation type) when considering the composition, structure and dynamics of macroalgae benthic communities at different spatial scales [9-12].

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Based on the above, this study aimed to assess the structure and the dynamics of macroalgal communities in a specific lotic environment under the effect of topographical gaps of different proportions. The initial assumption was that the macroalgae community was similar in different points of the same lotic environment, but presenting variation within the same point under the effect of the riverbed topography.

MATERIALS AND METHODS

Area of Study

Comprises the watershed of Rio da Prata (Silver River), a Rio Iguaçu (Iguazu River) tributary, located at the municipality of União da Vitória, southern Parana state, in the south of Brazil. Within this basin it was selected a river (Rio Papuã (Papuã River); 26°07’04.1"S; 51°09'58.5"W) that presents the particularity of three topographical gaps (waterfalls) 800 meter apart one from another, namely: a) cachoeira da Gruta (Cave falls), 2.80 m high and 3.0 m width; b) cachoeira da Piscina (Pool falls), 6.5 m high and 3.8 m width; c) cachoeira Campo Alto (Campo Alto falls), 40 m high and 8.3 m width. All segments were slightly shaded (<50% light incidence, according to De-Nicola et al. [13]), except for the point below falls 01 and above falls 02, which is characterized as opened (100% light incidence).

Sampling Procedures

The field works were performed during May 2015. Data collections were carried out in each of the waterfalls both at the preceding area (upstream) and the subsequent area (downstream) of the fall. In both areas were selected segments located between 10 and 20 meters away from the topographical gap, with a total of two segments assessed for each waterfall. Each segment consisted of a fragment 10 to 20 meters long where the biotic and abiotic variables analyses were performed.

For evaluating the biotic characteristics of macroalgae communities, a total of 20 rocks were randomly selected in each segment presenting visible algal mass macroscopic growth. The amounts of richness and abundance of present species were noted for each rock. For richness the absolute number of species was considered (in field defined as morphological types) and the abundance was visually estimated [14,15], thus obtaining the percentage coverage of each present species. Representatives of each specimen were collected and fixed in the field (4% formaldehyde) for later identification. For each rock it was further measured the following micro-environmental parameters: depth - obtained using a ruler and considered as the distance between the substrate and the surface of the water column; current speed - measured using a mechanical flowmeter General Oceanics R30, positioned immediately above the substrate; size of the substrate - obtained using a ruler, whereas this is considered to be the longest length of the rock. For segments Waterfall 2; point above and Waterfall 3; point below, a 25 cm diameter circle was used as default to determine the microhabitat and consequently the size of the substrate, once the segments’ bed is entirely formed by continuous rocks.

For the general characterization of each segment the following environmental parameters were measured: shadow and average width (using the classes proposed by De-Nicola et al. [13]. The water temperature was obtained using a thermometer, the pH and conductivity using an Extech EC500 meter and the dissolved oxygen using an OHI9146 Meter. All parameters were obtained in the field.

The species identification was made using a trinocular microscope Opton TNB-01B. Classification at division level followed the system proposed by Van den Hoek et al. [16]. All species collected were herborized in liquid medium (4% formaldehyde) and deposited in the Herbarium of Paraná State University, campus of União da Vitória.

Data Analysis

All data were submitted to descriptive statistics. Differences in species composition between the segments were obtained through the Jaccard similarity coefficient (Sj) and the **(Figure 1)** Detrended Correspondence Analysis (DCA) [17] that was applied to discriminate possible effects of topographical gaps on the microalgae spatial distribution patterns, based on the species presence/absence.

The community structure was described through the following variables: species richness, abundance (percentage coverage), Shannon Wiener Diversity Index (H´), Simpson dominance index (C) and Evenness (J). The variation in the structure of communities (richness, abundance, H’, C, J) in different segments was assessed though Factorial Analysis of Variance (ANOVA–type III). This analysis divides all variation in components representing variations at different spatial scales [18]. The independent hierarchic variables used were the waterfalls, the segments above and below the fall and the rocks assessed (micro-habitat). For each biotic variable, the differences in each hierarchical scale were assessed, as well as any possible interactions between them. For abundance (percentage coverage), the data were converted into logarithms, due to the large variation within the spatial scales assessed, in order to normalize its distribution and homogenize the variances.

The relationship between communities’ structure and composition and all micro-environmental variables at different spatial scales were examined through Multiple Linear Regression Analysis. Firstly, however, all variables were subject to correlation analysis through r Pearson coefficient in order to check whether they presented any co-variation or co-linearity. No significant correlations were obtained among the abiotic variables, and they were all (depth, current speed and substrate size) used in the Multiple Linear Regression Analysis.

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RESULTS

The sampled segments were very homogeneous as to the limnological characteristics **(Table 1)**. A total of 8 taxa were sampled **(Table 2)**, distributed in three divisions (Cyanobacteria–4 taxa, 50% of the total; Chlorophyta–3 taxa, 37.5% and Heterokontophyta=1 taxon, 12.5%). *Phormidium retzii* presented wide distribution, being present in all sampled segments, while *Phormidium* sp., *Tolypothrix distorta* and *Mougeotia* sp. were observed in only one segment **(Tables 2 and 3)**. The similarity index showed high values both considering the community composition among the waterfalls (01 and 02=0.78; 01 and 03=0.73; 02 and 03=0.66) and the different segments of each waterfall (point 01= 0.57; point 02=0.75; point 03=0.62). Similarly, DCA (77% explanation for Axis 1 and 2% for Axis 2) showed no difference between the sampling points, which were all very similar, basically due to the common presence of species *P. retzii*. Exception is made to point 03, which presented as special feature a large abundance of *E. pulvinata*.

Table 1. Water limnological characteristics of the sampled segments in the areas above and below each topographical gap assessed.

Variable	Waterfall					
	01		02		03	
	Below	Above	Below	Above	Below	Above
Temperature (°C)	15.4	16	16.4	17.5	17.5	16.8
pH	7.1	7.4	7.05	7.2	7.08	7.1
Dissolved oxygen (%)	89	94	84	92	91	85
Conductivity (µS/cm)	29	29	25	39	19	28
Total alkalinity (ppm)	90	90	98	91	92	90
Total hardness (mg/l $CaCO_3$)	31	31	21	31	24	23
Ammonia (N $mg.l^{-1}$)	0.11	0.13	0.14	0.09	0.12	0.08
Iron (Fe $mg.l^{-1}$)	0.25	0.23	0.24	0.26	0.25	0.22
Chlorides (Cl $mg.l^{-1}$)	0.17	0.19	0.18	0.19	0.20	0.21

Table 2. List of taxa found in each of the sampled segments in the areas above and below each topographical gap.

Taxon	Waterfall					
	01		02		03	
	Below	Above	Below	Above	Below	Above
Cyanobacteria						
Phormidium retzii	X	X	X	X	X	X
Phormidium sp.		X	-	-	-	-
Stigonema robusta	X			X	-	-
Tolypothrix distorta		X	-	-	-	-
Chlorophyta						
Ecbalocystis pulvinata	X		X	X	-	-
Mougeotia sp.	-	-	-	-	X	-
Spirogyra sp.	X			X	X	-
Heterokontophyta						
Vaucheria sp.		X	-	-	-	X

Table 3. Average figures and standard deviation of variables describing the community structure and the micro-environmental characteristics of each sampled segment in the areas above and below each topographical gap.

Variable	Waterfall					
	01		02		03	
	Below	Above	Below	Above	Below	Above
Community						
Richness	1.45 ± 0.5	1.15 ± 1.1	1.15 ± 0.3	1.45 ± 0.5	1.0 ± 0	1.05 ± 0.22
Abundance	62.1 ± 18.2	10.1 ± 18.2	10.1 ± 30.8	62.1 ± 28.0	62.1 ± 13.5	18.2 ± 24.6
Diversity index (H')	0.12 ± 0.22	0.12 ± 0.15	0.06 ± 0.17	0.12 ± 0.21	0.0 ± 0.0	0.02 ± 0.1
Dominance index (C)	0.92 ± 0.15	0.96 ± 0.11	0.95 ± 0.12	0.92 ± 0.15	1.0 ± 0.0	0.98 ± 0.06
Evenness (J)	0.18 ± 0.31	0.18 ± 0.26	0.08 ± 0.25	0.18 ± 0.31	0.0 ± 0.0	0.0 ± 0.14
Microhabitat						
Depth (cm)	2.6 ± 2.1	2.6 ± 2.1	4.2 ± 1.6	2.6 ± 2.1	3.8 ± 2.1	5.0 ± 2.3
Current speed (cm/s)	48.4 ± 41.6	48.4 ± 41.6	123.5 ± 55.2	48.4 ± 41.6	57.7 ± 51.7	116.2 ± 88.4
Substrate length (cm)	25.0 ± 0.0	40.6 ± 15.9	43.2 ± 15.9	25.0 ± 0.0	32.3 ± 13.8	27.7 ± 14.1

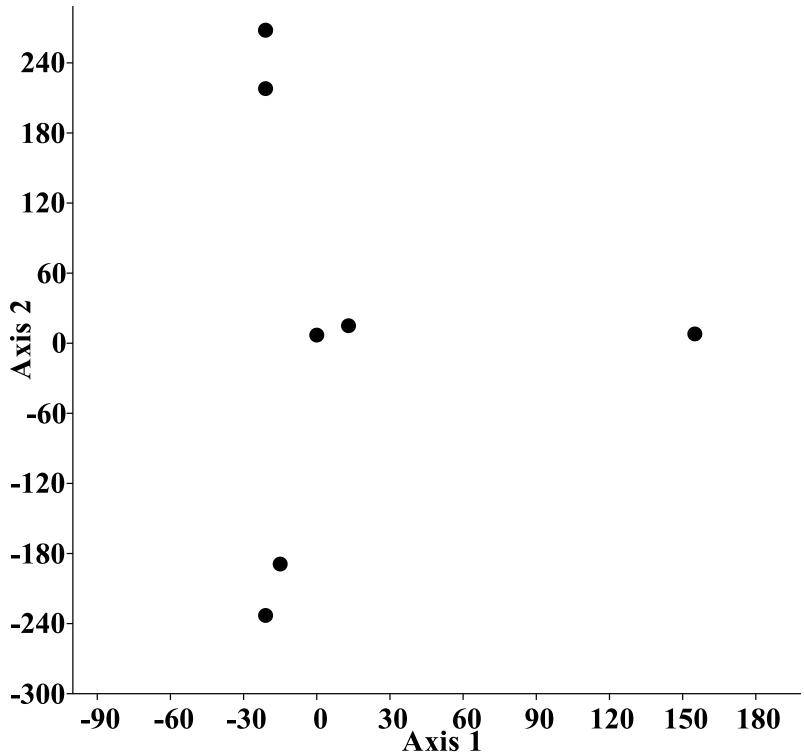

Figure 1. Detrended Correspondence Analysis (DCA) graphic showing the distribution of the sampling points based on the species composition. Pt. 01=waterfall 01, below; Pt. 02=waterfall 01, above; Pt. 03=waterfall 02, below; Pt. 04=waterfall 02, above; Pt. 05=waterfall 03, below; Pt. 06=waterfall 03, above.

DISCUSSION

The limnologic characteristics of all sampled segments were very similar, which evidences that spatial characteristics considered large-scale change very little within a lotic ecosystem (± 500 meters distance between the farthest points). Accordingly, these variables tend to cause little interference on macroalgae communities present in such environment, although these variables may express greater relevance over time. We thus consider that environmental conditions at a small spatial or local scale (micro-environmental variables) added by the geographic factor (topographical gap) are the factors that have greater interference on the composition, structure and dynamics of the sampled benthic macroalgae communities.

All taxa sampled present high occurrence in lotic environment, and these tend to develop under different environmental conditions. The predominance of Cyanobacteria and Chlorophyta has been reported in several studies [19-23] and the greater distribution of *P. retzzi* is consistent with the results obtained in other studies [19,21,23], demonstrating that it is a cosmopolitan species, although some authors [24-26] agree it actually is a set of species. The occurrence of some taxa in one or few sampling points.

The occurrence of some taxa in one or few sample points, as observed in this study, is also a typical characteristic of the group (benthic macroalgae), even in segments next to a lotic ecosystem. This characteristic has been credited to the specific micro-environmental characteristics of each place presenting macro algae in the streambed/riverbed [3], which may widely vary and, therefore, create areas with exclusive properties, which then determines the development of a mosaic of diverse populations in the lotic system bed.

Considering the characteristics of the group under study and the environment in which they occur, it is expected that specific conditions (e.g., riverbed disturbance and disposal of organic matter) present in the environment may be responsible for creating different conditions within a segment capable of generating different microenvironments for the development of an even more diversified community. This is the case of topographic unevenness generated by different proportions of waterfalls. Such condition may generate, especially below the topographic gap, an environment under constant physical disturbance, which may directly interfere in the regulation of the richness and diversity of macro algae community. According to some authors [27-29] environments that present disturbances at moderate levels tend to have higher species richness and diversity values. Given this assumption, the segments sampled before the topographic gap would tend to have a greater number and abundance of species when compared to the segments below the waterfalls. However, this result was not observed, with very similar ecological index values among the assessed environments. Regarding the species composition, however, 50% of total taxa occurred only in one segment above or below the uneven topography), 75% of which were observed in the segment above the waterfall. Specific conditions created by several factors, as well as different proportions of topographic unevenness may create a greater number of diverse micro-environmental conditions, leading to a higher chance of occupation by different taxa. Another important aspect to consider is that all species occurred in a single segment present extremely low abundance values (< 1% percentage coverage) when compared to taxa occurred in both segments (above and below the waterfall). This may be associated with the more general environmental condition in which occur the better-distributed taxa in this study (p. ex. *P. retzii e Spirogyra* sp.) and also previously reported in other studies [4].

Considering the initial assumption of the work, although very subtly observed, the composition of benthic macro algae communities was, as expected, more distinct in close points, but separated by the topographical gap, which may be a result of local changes produced by the effects of the falls. These effects may be observed both in the physical conditions of the habitat (e.g., substrate size, current speed) and in the chemical characteristics thereof (e.g., ions availability, pH) and can, therefore, generate particular conditions favoring the development of species with different characteristics - mainly morphological - and able to develop in each of these environments, regardless of the distance [3]. These effects seem to be less evidently perceived at a larger scale (between different points of the same river), which should be due to the macro-environmental conditions (e.g., water temperature, bed composition, altitude) occurring in the segment and that then impact on the entire ecosystem, allowing the presence and subsequent development of relatively similar benthic macro algae communities [4,24].

With regards to the ecological parameters obtained, although they have varied little along the different areas, it was observed a certain difference between the sampling points, mainly due to the specific micro-environmental conditions occurring throughout the segment. In this sense, the results seem, at first, contrary to those observed for the composition of species, which presented a greater variation between the different points of the same waterfall. The only ecological parameter that showed a significant variation at this scale was abundance (percentage coverage), which presented greater amounts in the above segment, probably due to the abrasive effect caused by the waterfall in the segment below the topographic gap. Except for waterfall 01 that presented greater values in the part below the gap, which is the smallest among the waterfalls assessed. In this segment the abundance values (below waterfall 01 and above waterfall 02) were the highest obtained, which is probably due to the greater light incidence in this area, with such being considered as the main factor in structuring the benthic macro algae communities [4,14,22,24,30].

Considering the sampled points between different waterfalls, significant differences were found among all parameters, except by dominance. This result proves that different parts of the same lotic segment present specific environmental conditions able to originate particular benthic communities, often even more different than different rivers/streams within an area or in different areas [4,5,8]. Although the topographical unevenness may generate environmental variation as to interfere in benthic macro algae communities, they may have a different effect on the composition and structure of these communities, being more effective in the first case, as observed in this study. Considering the common low number of species observed related to these organisms in lotic environments (references), the differences herein observed become even more remarkable, once such extreme topographical conditions select particular taxa, presenting structure variations (specially richness and abundance) due to the specific environmental conditions of each segment, such fact which may be evidenced by the wide range of micro-environmental abiotic parameters measured. The differences obtained for richness and abundance, considering the interaction between the waterfall and the points, reinforces this assumption regarding the characteristics described for these organisms.

CONCLUSION

Finally, considering that the micro-environmental conditions should be responsible for the spatial distribution in small scale, it was found, in this study, that among the biotic variables assessed only abundance proved to be significantly influenced by the abiotic variables. It was an expected effect, once abundance, in general, is the biotic variable with greater variation in this kind of environment and thus, is subject to a greater interference from environment conditions. Due to the low species richness of these organisms (common absence, or occurrence of a single species/sample point), these and all other ecological parameters tend to present lower variation, limited to a particular condition within a greater system (e.g., a rock in a river/stream).

Finally, this study demonstrated that the lotic system structure, herein represented by the different dimensions of topographical unevenness, may affect the composition, structure and, therefore, the dynamics of benthic macro algae communities, since differences were observed between the parameters assessed, and although the local spatial organization of each segment also impact on these organisms.

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