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Application of Catchment- and Local-Scale Variables for Aquatic Habitat Characterization and Assessment in the Brazilian Semi-Arid Region

Aplicação de variáveis em nivel local e de bacia de drenagem na caracterização e avaliação de ambientes aquáticos no semi-árido brasileiro

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Abstract

The state of the physical habitat is influenced by factors operating at several spatial and temporal scales, such as geomorphology, climate, hydrology, land use and water quality. This work measures diversity and availability of the physical habitat in natural and artificial aquatic systems in the northeast of Brazil. It aims to survey local- and catchment-scale physical variables and evaluate their importance as a basic framework for characterization and assessment of aquatic habitats in the Brazilian semi-arid region. This study was performed in two areas of the Brazilian semi-arid (Seridó/Borborema and Buíque/Vale do Ipojuca), classified as being of extreme biological importance and identified as priority areas for biodiversity conservation in the Caatinga. The present study showed that the aquatic habitat in semi-arid Brazil is diverse and dynamic, with a range of habitat elements available for colonization by the aquatic biota. Stream sites showed a similar to greater array of marginal habitat elements and substrate composition when compared to reservoirs, and the composition of the habitat varied with habitat type (river/reservoir) and seasons (dry/wet). Results presented have implications for the conservation and management of Brazilian semi-arid systems. Given that the habitat is the basic framework for colonization of aquatic organisms, the potential mechanisms that maintain biotic diversity lie at all levels of the river watershed. It is fundamental therefore, to identify the parts of the riverine ecosystems that are vital to maintaining its health.

Key words: intermittent streams, reservoirs, conservation, substrate composition.

Resumo

O estado do habitat físico é influenciado por fatores que atuam em diversas escalas, como a geomorfologia, o clima, o regime hidrológico, o uso da terra e a qualidade da água. Este trabalho quantifica a diversidade e a disponibilidade do habitat físico em sistemas aquáticos naturais e artificiais no semi-árido do Brasil, com o objetivo de levantar variáveis físi-

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cas em escala local e de bacia de drenagem, e analisar sua importancia na composição de uma estrutura básica para a caracterização e avaliação desses ambientes. Este estudo foi desenvolvido nas regiões de Seridó/Borborema e Buíque/Vale do Ipojuca. Estas áreas são consideradas de extrema importância biológica e são identificadas como prioritárias para a conservação da Caatinga. Os resultados mostram que o hábitat aquático no semi-árido brasileiro é diverso e dinâmico, compreendendo um conjunto amplo de elementos disponíveis para a colonização pelos organismos. Os rios mostraram uma gama de elementos do hábitat marginal e da composição do substrato igual ou superior àquela dos reservatórios. Além disso, a composição do hábitat variou entre os dois tipos de ambiente estudados (rios/reservatórios) e com as estações do ano (seca/chuvosa). Os resultados apresentados têm implicações importantes para a conservação dos ambientes aquáticos do semi-árido. Tendo em vista que o hábitat físico é a estrutura basica para a colonização por parte dos organismos aquáticos, os mecanísmos potenciais que mantêm a biodiversidade aquática ocorrem nos varios níveis da bacia de drenagem. Portanto, é fundamental identificar os componentes, ao longo dos sistemas ripários, que são vitais na manutenção da sua integridade biológica.

Palavras-chave: rios intermitentes, reservatórios, conservação, composição do substrato.

Introduction

Intermittent streams in semi-arid Brazil are distinctive landscape features, existing as dry watercourses for most of the year. Maltchik and Medeiros (2006) recognized that the extremes of flooding and drying are drivers of important processes maintaining diversity within these systems. Therefore, conservation measures in the semi-arid region of Brazil should include the maintenance of the natural flow regime of aquatic systems, to ensure long-term survival of species (Maltchik and Medeiros, 2006). Nevertheless, conservation measures should also take into account the composition and diversity of the aquatic habitat available, as the physical habitat is the framework for colonization by the aquatic fauna (e.g. Martin-Smith, 1998). Also, the state of this living space will influence biotic structure and organization within aquatic systems (Mugodo *et al.*, 2006). The state of the physical habitat, namely composition and diversity, is influenced by factors operating at several spatial and temporal scales (Boys and Thoms, 2006). At the catchment level, geomorphology and climate will influence habitat at the reach scale, by affecting hydrology, sedimentation, nutrient inputs and channel morphology (Davies *et al.*, 2000; Mugodo *et al.*, 2006). At the local level, land use and land management will also influence stream reach scale habitat (Richards *et al.*, 1996).

Methods for assessment of the physical habitat available to aquatic organisms provide important tools for several aspects of river management and conservation, and therefore, procedures used to assess habitat ought to be ecologically and geomorphologically meaningful (Thomson *et al.*, 2001). Despite that, habitat assessment methods need to be developed and tested in semi-arid aquatic systems of Brazil, as they are not as well developed as methods used to evaluate other aspects of river condition, such as water quality. Habitat assessment is of great use for predicting the potential distribution of key species, such as fish (Boys and Thoms, 2006) and invertebrates (Richards *et al.*, 1997), based on their habitat requirements. Also, the observed and potential (or predicted) habitat may be compared with the habitat requirements of a species in order to evaluate the need for habitat management and the overall health of the ecosystem based on the needs of the aquatic biota (Maddock, 1999).

This work measures diversity and availability of the physical habitat in natural and artificial aquatic systems in the northeast of Brazil. This paper aims to survey local- and catchment-scale physical variables and evaluate their importance as a basic framework for characterization and assessment of aquatic habitats in two areas of the Brazilian semi-arid region.

Material and methods

Study area

This study was performed in two different areas of the Brazilian semi-arid region: Seridó/Borborema and Buíque/Vale do Ipojuca (as per Tabarelli and Silva, 2003) (Table 1; Figure 1). These areas are classified as being of extreme biological importance and were identified as priority areas for biodiversity conservation in the Caatinga by Silva *et al.* (2003), because they present high diversity of species and are rich in endemisms. The Seridó area is located in southern Rio Grande do Norte (RN) and northern Paraíba (PB) between Patos and Caicó (Figure 1). Average annual temperature is 30.7°C, with the maximum monthly average in October (31.0°C) and the minimum average in February (29.3°C). Precipitation is concentrated between January and April, with 350 to 800 mm per annum and an annual average of 600 mm (Amorim *et al.*, 2005). Altitude in Seridó ranges between 100 and 800 m (Governo do Estado da Paraíba, 1985). The Buíque area is located around the town of Buíque in central Pernambuco (PE) (Figure 1). Average annual temperature and precipitation are 25°C and 1095.9 mm, respectively. Rainfall is concentrated between April and June.

Altitude ranges between 800 and 1000 m (Rodal *et al.*, 1998).

Study design and sampling

Within each study area, three sites were selected to represent typical artificial and natural temporary and semi-permanent environments (Table 1). Sites consisted of stream reaches, usually 100 to 500 m long, and artificial reservoirs created from stream impoundment. Sampling was conducted during one year on four occasions during the wet (April and June 2006) and dry seasons (September and December 2006). Catchment- and stream reach-scale variables were selected based on local characteristics and on Pusey *et al.* (2004) (among others, Richards *et al.*, 1996; Davies *et al.*, 2000; Thomson *et al.*, 2001; Mugodo *et al.*, 2006). Catchment-scale variables were quantified based on general topographic features of the study area and river basin characteristics using 1:500.000 topographic maps, satellite imagery and GPS receiver. Reach-scale site variables represented morphometrical and water quality (physico-chemical) characteristics. The habitat structure comprised (i) marginal underwater and littoral elements (representing the abundance of marginal microhabitat elements) and (ii) the substrate composition.

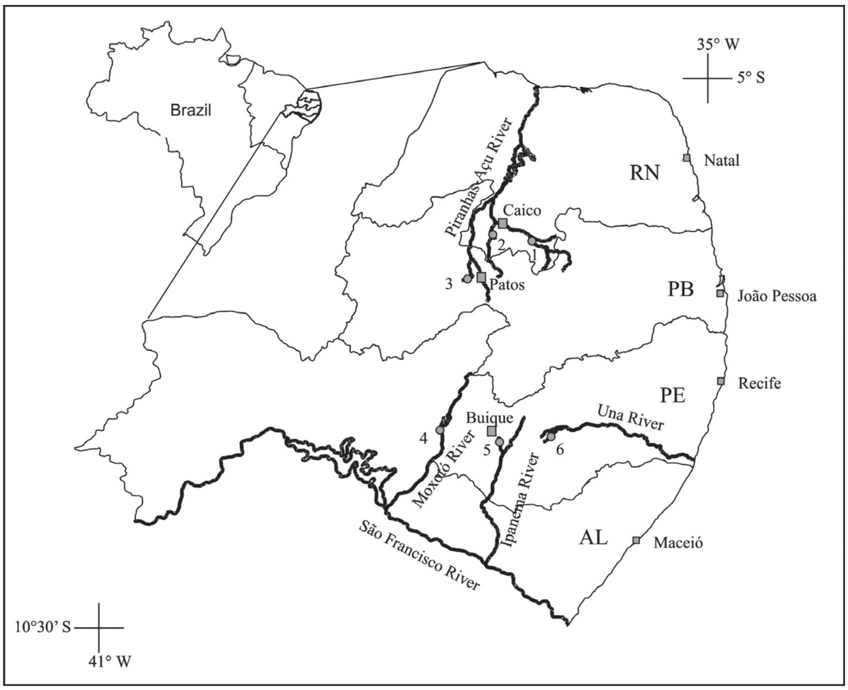

Figure 1. Study area showing the states of Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE) and Alagoas (AL), major river systems and sampling sites (1-6 as per Table 1) in the semi-arid region of Brazil.

Reach-scale water quality, habitat structure and some of the morphometrical features were estimated in survey points of one square meter and allocated into categories. Usually 3 to 12 random survey points were evaluated within each river reach or reservoir. Substrate composition and habitat elements were estimated as their proportional contribution to site wetted perimeter. For the evaluation of site morphology, width was measured using a measuring tape for distances of up to 100 m and GPS satellite receiver for greater distances. Depth was measured with a staff at approximately equivalent distances along a transect to represent habitat depth (average depth of the first 3 m from the banks) and maximum depth. Water velocity was measured using the float method (Maitland, 1990). Bank slope was estimated visually and allocated into slope categories (< 30°, 30-60° and 60-90°). Water temperature (°C) and dissolved oxygen (mg/l) were measured with an oxygen meter (Lutron DO-5510), and transparency (cm) was measured with a Secchi disk.

Data analysis

Variation in habitat composition between sites and sampling occasions was

Table 1. General characteristics of the study sites. *A-priori* criteria for grouping habitat structure in the DCA are indicated with a (*).

Sample sites	Area *	Catchment Basin	River	Stream site location	Habitat type *	Position
1	Seridó/Borborema	Piranhas-Açu	Seridó	Seridó River	Stream	06° 36' 30.24" S 36° 46' 57.18" W
2	Seridó/Borborema	Piranhas-Açu	Sabugi	Cipó Stream	Stream	06° 38' 39.42" S 37° 10' 30.84" W
3	Seridó/Borborema	Piranhas-Açu	Espinharas	Recanto Stream	Reservoir	07° 00' 18.06" S 37° 23' 28.20" W
4	Buíque/Vale do Ipojuca	São Francisco	Moxotó	Escama Peixe Stream	Stream	08° 30' 55.74" S 37° 42' 58.44" W
5	Buíque/Vale do Ipojuca	São Francisco	Ipanema	Mulungu Stream	Reservoir	08° 37' 35.94" S 37° 07' 44.40" W
6	Buíque/Vale do Ipojuca	Una	Una	Salobro Stream	Reservoir	08° 39' 04.26" S 36° 34' 57.24" W

investigated using Detrended Correspondence Analysis (DCA) of the standardized arcsine-squareroot-transformed data. The Multi-Response Permutation Procedure (MRPP) (Biondini *et al.*, 1985; McCune and Grace, 2002) was used to test for differences in habitat composition between the two study areas (Seridó and Buíque), habitat types (stream and reservoir) and seasons (wet and dry). For all MRPP analyses, the chance-corrected within-group agreement (A) is presented as a measure of the degree of within group homogeneity, compared to random expectation. Where MRPP detected significant differences further analysis was performed to reveal which particular habitat elements contributed significantly as the source of difference in habitat composition, using McCune and Mefford's (1999) Indicator Species Analysis. Indicator Values (IV) were calculated using the method of Dufrene and Legendre (1997). These were tested for statistical significance ($p<0.05$) using a Monte Carlo technique with 1000 runs. The influence of reach- and catchment-scale variables on habitat structure was evaluated using Canonical Correspondence Analysis (CCA) following McCune and Grace (2002). Data were centered and normalized and tested with Monte Carlo randomization (100 runs). All statistics were performed on PC-ORD 4.27 (McCune and Mefford, 1999).

Results

The structure of the habitat for all study sites consisted generally of C4 plants growing in the littoral margins (namely grass), aquatic macrophytes, including floating plants (commonly *Salvinia* sp., *Pistia* sp. and *Azolla* sp.), emergent plants (*Nymphaea* spp.) and submerged plants (*Ceratophyllum* sp. and *Egeria* sp.) and algae (attached to the substrate and filamentous) (Table 2). Overhanging riparian vegetation, woody debris, leaf litter and root masses were also present in the sites studied. Substrate composition was composed mostly of mud and sand, with fewer contributions of cobbles, rocks and gravel (Table 2). Diversity of habitat structures was generally greater on river sites, in the Seridó area and during the wet season, despite a higher richness of habitat elements in the reservoir sites (Table 3). The substrate composition was also more diverse and richer in the river sites and in the Seridó area, whereas substrate was richer and more diverse during the dry season (Table 3). Detrended correspondence analysis (Figure 2) showed that differences in habitat structure were significant only between stream and reservoir sites (MRPP, A = 0.06, p = 0.03) and seasons (MRPP, A = 0.06, p = 0.03). Di-

Table 2. Percentages (± standard deviation) of the habitat elements of both marginal elements and substrate composition occupying the marginal wetted perimeter of the study sites and average water quality parameters.

Habitat elements	Average(SD)	Minimum-maximum
Marginal habitat		
Littoral grass	10.3 (±15.8)	0-54.0
Macrophytes	8.8 (±17.7)	0-54.8
Attached algae	6.5 (±14.2)	0-50.0
Filamentous algae	5.6 (±10.5)	0-33.3
Overhanging vegetation	4.9 (±10.7)	0-33.3
Submerged vegetation	4.5 (±9.6)	0-36.6
Small debris (<2 cm diameter)	3.5 (±3.3)	0-10.0
Large debris (>2 cm diameter)	2.0 (±4.5)	0-20.0
Leaf litter	1.8 (±4.9)	0-23.7
Root masses	0.4 (±1.2)	0-5.0
Substrate composition		
Mud	53.9 (±31.9)	0.7-98.0
Sand	38.2 (±29.5)	1.8-95.0
Cobbles	3.1 (±6.5)	0-25.0
Small gravel (<2 cm)	1.8 (±2.6)	0-10.0
Rocks	1.2 (±2.8)	0-10.0
Large gravel (>2 cm)	1.2 (±2.6)	0-10.0
Bedrock	0.5 (±1.8)	0-8.3
Water quality		
Temperature (°C)	29.5 (±2.9)	24.0-35.2
Dissolved oxygen (mg/l)	5.8 (±2.0)	1.8-9.4
Transparency (cm)	47.2 (±19.5)	16.0-90.0

Table 3. Diversity and richness of habitat elements in study sites across habitat types, study area and seasons.

Habitat elements	*A-priori* groups	Richness (R)	Shannon´s Diversity (H)
Marginal habitat			
Habitat type	River	4.4 (±2.3)	0.942 (±0.501)
	Reservoir	4.7 (±1.6)	0.937 (±0.397)
Area	Seridó	5.2 (±2.2)	1.040 (±0.539)
	Buíque	3.8 (±1.4)	0.829 (±0.283)
Season	Wet	5.3 (±2.1)	1.083 (±0.463)
	Dry	3.8 (±1.6)	0.808 (±0.389)
Substrate composition			
Habitat type	River	4.3 (±0.8)	0.857 (±0.289)
	Reservoir	3.0 (±0.9)	0.497 (±0.300)
Area	Seridó	3.9 (±0.9)	0.801 (±0.348)
	Buíque	3.3 (±1.1)	0.525 (±0.283)
Season	Wet	3.5 (±1.2)	0.607 (±0.333)
	Dry	3.8 (±0.9)	0.727 (±0.354)

Table 4. Axis summary statistics of Canonical Correspondence Analysis for habitat structure and catchment- and reach-scale variables.

	Axis 1	**Axis 2**	**Axis 3**
Eigenvalue	0.220	0.179	0.153
Variance in species data			
% of variance explained	18.4	15.0	12.8
Cumulative % explained	18.4	33.4	46.2
Pearson Correlation, Spp-Envt	0.990	0.935	0.948
Kendall (Rank) Corr., Spp-Envt	0.905	0.771	0.771
Total variance ("inertia")	1.19		

Table 5. Correlations for catchment- and reach-scale variables with the ordination axes after Canonical Correspondence Analysis.

		Correlations		
	Variable	Axis 1	Axis 2	Axis 3
Catchment scale morphology	River length	**-0.792**	-0.177	0.142
	Length of stream of site location	**-0.416**	-0.120	-0.051
	Distance of site from source	**-0.465**	0.085	-0.082
	Distance of site from mouth	-0.266	0.021	-0.010
	Elevation	**-0.553**	-0.300	0.251
Reach scale morphology	Margin slope	**0.595**	0.159	-0.317
	Site width	-0.295	**-0.520**	0.329
	Habitat depth	0.024	0.346	0.035
	Maximum depth	-0.154	-0.070	0.355
Reach scale water quality	Velocity	0.132	0.047	**0.423**
	Dissolved Oxygen	-0.026	-0.238	**-0.595**
	Temperature	0.324	-0.080	0.320
	Transparency	0.098	-0.281	0.091

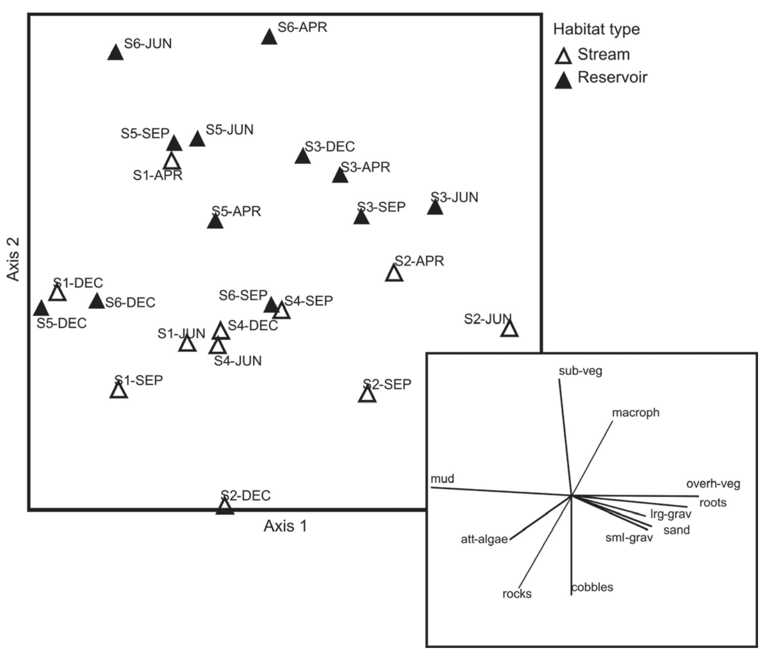

Figure 2. DCA results for habitat composition across the study sites. Insert box shows habitat elements correlated (r^2>0.2) with sampling sites/occasions in ordination space (denoted by vectors). The direction and length of vectors indicate strength of correlation. See Table 2 for full names of habitat elements. Sites (S1-S6) are coded as per Table 1 and sampling occasion. Abbreviations: APR, April; JUN, June; SEP, September; DEC, December.

fferences in habitat structure between the two study areas were not significant (MRPP, A = 0.01, p = 0.26). Indicator value analysis showed that important elements separating these groups were macrophytes for reservoirs (IV = 53.2, p = 0.01) and sand and cobbles for river sites (IV = 61.8, p = 0.02 and IV = 82.6, p = 0.002, respectively). Important habitat features separating seasons were submerged vegetation (IV = 48.4, 0.01) and overhanging vegetation (IV = 48.9, p = 0.02) for the wet season. No substrate elements were significantly important in separating sites according to seasons.

Canonical Correspondence Analysis showed that the reach- and catchment-scale variables were not strongly correlated, except for the distance of site to river source and length of stream of site location (Pearson´s correlation = 0.965), elevation and main river length (Pearson´s correlation = 0.853) and elevation and site width (Pearson´s correlation = 0.906). The total variance in the data ("inertia") was 1.19. The total variance explained by CCA was 46.2%, and most of this variation was explained by the first axis (18.4%) (Table 4). Nevertheless, axis 2 and 3 may not be disregarded as they also explained substantial portion of the variation in the data set. Results of the analysis show a significant relationship between habitat structure data and the reach- and catchment-scale variables, with the eigenvalue of the first axis too high to be expected by chance (Table 4, p values for eigenvalue and correlation for the first axis = 0.01). The first axis was strongly correlated with catchment-scale morphological variables, namely main river length, elevation and the highly correlated distance of site to river source and length of stream of site location. The first axis was also correlated with margin slope, a reach-scale morphological variable. Axes 2 and 3 were correlated with reach-scale variables of morphology (site width, axis 2) and water quality (water velocity and dissolved oxygen, axis 3). Figure 3 indicates that axis 1 represents a gradient of sites with habitat structure influenced by catchment-scale variables and the axis 2 represents sites influenced by reach-scale variables.

Discussion

The present study showed that the aquatic habitat in semi-arid Brazil is diverse and dynamic, with a range of habitat elements available for colonization by the aquatic biota. Stream sites showed a similar to greater array of marginal habitat elements and substrate composition when compared to reservoirs, and the composition of the habitat varied with habitat type (river/reservoir) and seasons (dry/wet).

Seasonal changes in the physical characteristics of variable environments have been reported for dry regions elsewhere (Mackey, 1991; Davis *et al.*, 2002). These changes are usually associated with fluctuating water levels and morphology of the habitat (Osborne *et al.*, 1987; Medeiros, 2005). In the present study, seasonal variations in water level and hydrological regime were found to influence morphometry and the habitat structure of the study sites. Given the lotic characteristics of stream sites, sand and cobbles were the most important habitat features in this habitat type as fine substrate like mud would be expected to be carried out during flooding. Figure 2 also gives indication that rocks, gravel and attached algae were important habitat elements in stream sites. Reservoirs, on the other hand, were characterized mostly by the presence of macrophytes, submerged vegetation and, to a lower degree, mud. The fact that aquatic macrophytes were not important elements defining habitat in the intermittent streams studied is related to the extremes of flooding during the wet period. Maltchik and Pedro (2001) and Pedro *et al.* (2006) found that flooding limited the occurrence of aquatic macrophytes in stream sites in semi-arid Brazil where communities of aquatic macrophytes subject to flooding showed a lower species richness than the communities with no floods.

The dry and wet cycles in semi-arid streams of northeastern Brazil are characterized by extremes of flooding and drought and regarded as the most important drivers of community structure in these systems (Maltchik and Medeiros, 2001; Maltchik and Florin, 2002). Results of the present study show that the dry and wet cycles also play an important role in the structure of the habitat, as composition of the marginal habitat and substrate were different between seasons. Interestingly, the marginal habitat was more diverse during the wet season than during the dry season. This result disagrees with other studies on habitat structure in temporary or semi-permanent systems (e.g. Kennard, 1995; Medeiros, 2005), which found that richness and diversity of habitat structures were greater during the dry season, when receding water levels cause the exposure of previously submerged physical structures, such as branches and logs. Data presented in this study indicate an opposite effect, as submerged vegetation and overhanging vegetation were characteristic habitat elements during the wet season. Given the increase in area of the aquatic systems during the wet period, the vegetation that once occupied the dry littoral margins of rivers and reservoirs is flooded, adding further complexity to the habitat. Also, as streams in flood reach their banks, the contact with the riparian vegetation reaches its maximum, further enhancing habitat complexity (e.g. Pusey and Arthington, 2003). As indicated by the high importance of overhanging vegetation during the wet season, proximity to the riparian vege-

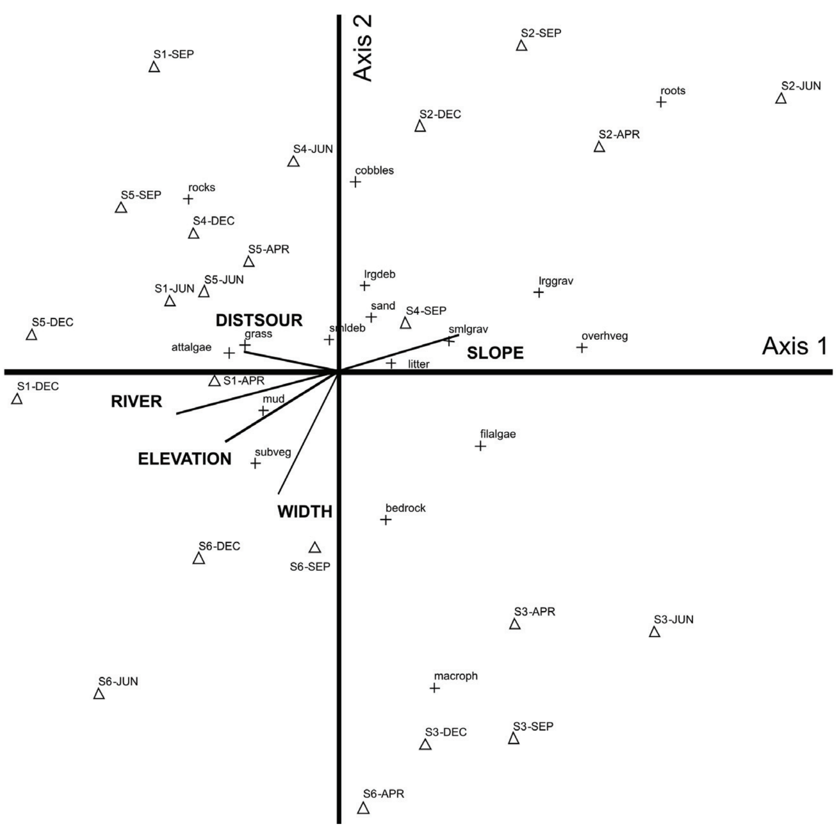

Figure 3. Biplot of ordination sites (Δ) (based on habitat structure) in the catchment- and reach-scale variables space, as defined by CCA. Vectors represent river length (RIVER), distance of site from source (DISTSOUR), elevation, margin slope (SLOPE) and site width (WIDTH). (+) indicates position of habitat elements in the ordination space.

tation generates shadow, limiting the growth of macrophytes, but adds elements to the littoral habitat such as root masses, leaf litter and debris. Substrate composition on the other hand, is more likely to be uncovered during the dry season, more importantly so in the intermittent streams, where features like cobbles and gravel will tend to be more frequent in the deeper reaches.

Despite differences in diversity and richness of habitat elements between Seridó and Buíque, the habitat structure was not different between the two study areas. Because the sampling design is not balanced (two reservoirs in the Buíque area and only one in the Seridó area), diversity and richness of habitat elements tended to be greater in Seridó, because of the dominance of stream sites in this region.

Lotic systems are thought to be organized as a nested hierarchy, both temporally and spatially (Johnson *et al.*, 1995; Poff, 1997). In a nested hierarchy, large-scale processes, such as climate and geomorphology, define higher levels of organization of the physical and biological aspects (e.g. river morphology, flow regime, species pool) of the river ecosystem (Johnson *et al.*, 1995). These higher levels of organization influence physical and biological factors at a variety of lower spatial and temporal scales, which may be particularly relevant to semi-arid systems (Poff, 1997; Maltchik and Medeiros, 2006). Therefore, over relatively short temporal and spatial scales (i.e. over dry-wet seasons and across catchments or river reaches) several factors may be influencing variations in the physical habitat available for colonizers.

In the context of the present study, Canonical Correspondence Analysis identified various levels of catchment- and stream reach-variables correlated with the habitat structure. At the catchment level, variables that represent stream order such as river length, length of the stream of site location and distance of site from source were important determinants of habitat structure. At the stream reach-scale, habitat structure was related with margin slope and site width, whereas depth was not an important determinant of habitat structure. As all habitat variables were measured at the margins, overall site depth should not be expected to be an important element affecting habitat structure (average depth was 34.4 ±19.4 cm). However, slope and width can affect the physical habitat through their influence on the degree of connectivity between aquatic and terrestrial habitat. It is important to bear in mind that the slope was measured in the banks, comprising the terrestrial portion of the margins. Local-scale water quality parameters were also found to be important descriptors of habitat structure, mostly those associated with the content of oxygen dissolved in the water (namely, dissolved oxygen and water velocity). Although temperature and transparency may also be related to dissolved oxygen, the former was relatively constant throughout the study sites (average water temperature was 29.5 ±2.9 °C) and the latter (estimated from Secchi depths) was very high across study areas with averages per site varying from 16 to 90 cm.

The habitat template has been suggested as a framework where abiotic factors influence the biota (Southwood, 1977). In stream ecosystems, flooding and flow variability have been suggested as the major axes on habitat template (Minshall, 1988; Poff and Ward, 1989). Although the results presented in this study indicate that seasonal variations associated with flooding and flow regime are important elements affecting the structure of the habitat, there are indications that the habitat template may be multidimensional. In semi-arid systems of Brazil, the habitat structure is being driven by many components at different levels, where the role of catchment characteristics and local morphology and water variables would increase in predominance at their respective scales. This highlights the importance of the link between habitat structure and the biotic diversity at local and regional levels.

The present study shows that the structure of the habitat in semi-arid systems in northeastern Brazil is composed of a range of elements that vary with habitat type and season, whereas habitat heterogeneity was stronger within local- and catchment-scale than between catchment areas. Therefore, several levels of the catchment hierarchy are important to the habitat structure, from catchment-scale variables like river size and elevation, to local characteristics such as width, slope and dissolved oxygen in the water. Such features should be evaluated and used as a basic framework for characterization and assessment of aquatic habitats in semiarid Brazil. Results presented have implications for the conservation and management of Brazilian semi-arid systems. Given that the habitat is the basic framework for colonization of aquatic organisms, the potential mechanisms that maintain biotic diversity lie at all levels of the river watershed. It is fundamental therefore, to identify the parts of the riverine ecosystems that are vital to maintaining its health.

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