Macrophyte Occurrence in Response to Anthropogenic Pressure in Reservoir

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Abstract

The objective of this study was to evaluate the effect of anthropogenic land use on the community of aquatic plants in the vicinity of a consolidated artificial reservoir. Two landscape units (LU) were outlined adjacent to a more than 50-year-old artificial reservoir, of which one (LU1) had a low and the second (LU2) a high human impact. In total, we found 20 plant species. Only two species were common to UP1 and UP2. The species diversity in LU1 (n=18) was greater than in LU2 (n=4), and plant distribution more even. Phosphorus, potassium, organic matter, calcium, and magnesium contents were lower in LU2. It can be concluded that the embankment induced the occurrence of more macrophyte species and plants, due to the soil conservation in the reservoir surroundings. The low human impact in this area allowed a greater diversity of native macrophytes. The intensification of land use around the reservoir impoverishes the soil, preventing the development of a diversified community of macrophyte.

Keywords: Aquatic Plants; Wetland; Conservation.

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In Brazil, 87.1% of the power generation capacity is hydroelectric (OECD, 2015). The embankment of rivers leads to the flooding of vast areas on plains with small slopes or even on plateaus, and is of fundamental to sustain the production of this type of electricity (Kelman et al. 2006).

Due to the flooding, damming leads to a series of environmental changes in the surrounding areas, resulting in the replacement of the original plant community by species adapted to a changing water level (amphibious), or those of aquatic environments (floating and submerged species) (Mukhopadhyay & Dewanji 2005, Peintinger et al. 2007). The chemical and physical water quality is changed with the increase of nitrogen and phosphate compounds and with turbidity (Wetzel 2001, Aitkenhead-Peterson et al. 2003). Also, the sediments introduced from adjacent areas represents another factor of reduction of the wetland quality and lifetime of the proper reservoir for energy generation. Aside from hampering the organoleptic quality of drinking water, these processes affect power generation. The water quality of the reservoir is also a consequence of the water quality in the neighboring areas, which were modified by the construction of the reservoir, with deforestation and the removal of natural soil horizons, affecting the soil functionality (Zhao et al. 2014; Navarro-Ortega et al. 2015). This functionality of the soil is understood as the barrier effect of the areas surrounding the reservoir, which can reduce or prevent the arrival of nutrients, pollutants and sediments from terrestrial systems. Thus, the environmental quality in the flooded area, which defines the quality of soil and biota in these ecosystems, depends on the level of anthropogenic pressure in the surroundings of the reservoir (Banach et al. 2009, Sass et al. 2010, Maëmets et al. 2010).

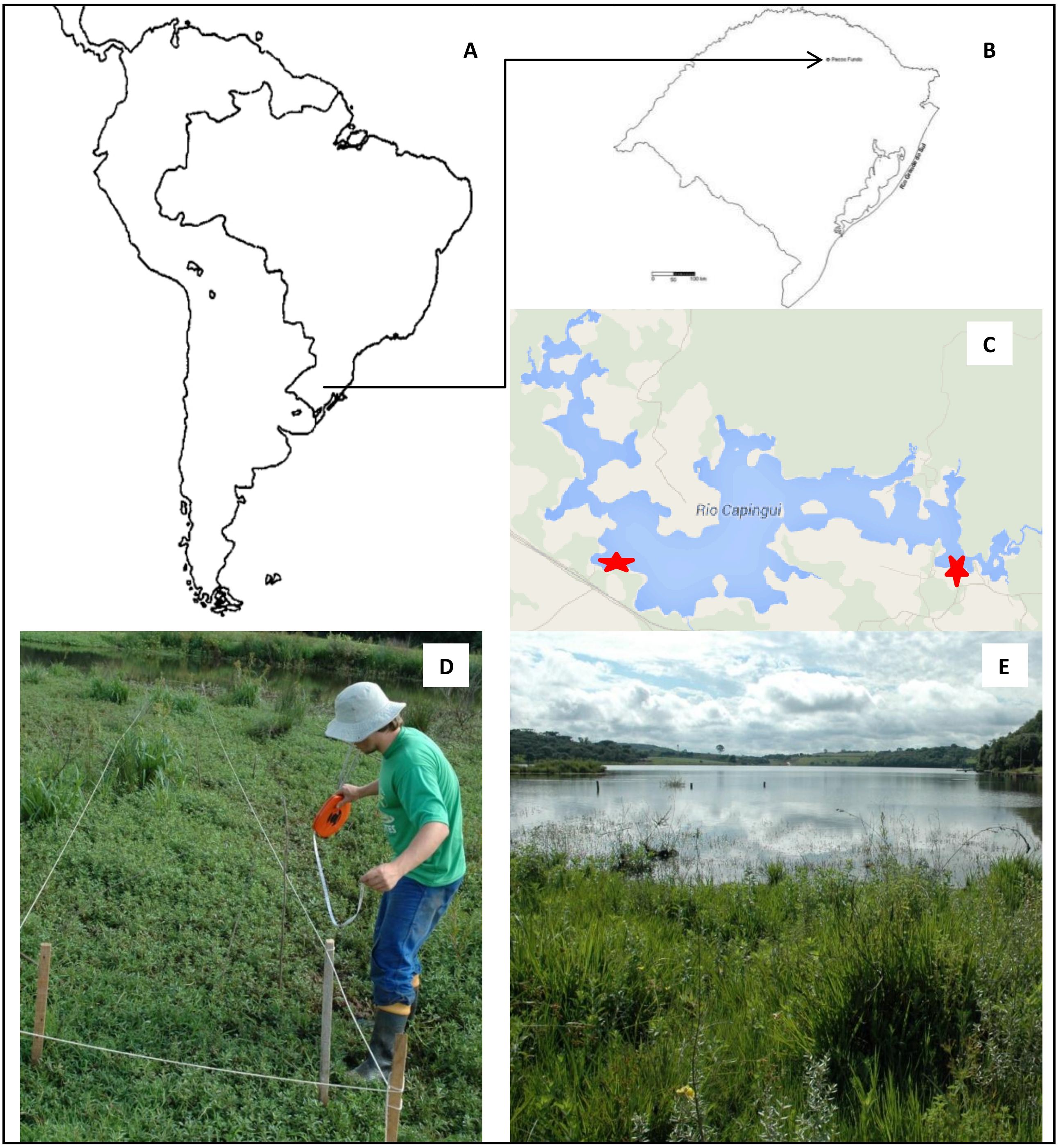
Brazil is home to about 980 macrophyte species (Chambers et al. 2008) in naturally flooded areas. The Pantanal of Mato Grosso comprises 280 species (Pott et al. 2011) and the upper Rio Paraná floodplain over 150 species (Ferreira et al. 2011). In southern Brazil, lagoons and coastal wetlands have varying species richness. In studies in this region, Pereira et al. (2012) recorded 43 species; Maltchik et al. (2011) 59 species; Spellmeier et al. (2009) 145 species; and Rolon et al. (2011) 176 species. Due to the richness of species and life forms of macrophytes, they play a key role in post-flooded environments and can serve as an indicator parameter of their quality.

We tested the hypothesis that flooding provides conditions for the development of new macrophyte communities, but that the species occurrence and frequency will depend on the subsequent land use in the areas surrounding the artificial reservoir. In this sense, the purpose of the study was the comparison of macrophyte communities in two landscape units, adjacent to an artificial reservoir, with different anthropogenic pressure. To this end, the occurrence of macrophyte species was investigated to relate their characteristics and distribution in the landscape units, as well as soil and water aspects.

Material and Methods

The reservoir of Capiguí, located in southern Brazil (Figure 1), was flooded in 1956 (CEEE, 2011). The soils are classified as Nitisols and Ferralsols (at higher altitudes) and poorly drained Gleysols (IUSS 2014).

Figure 1. A: Latin America, southern Brazil. B: State of Rio Grande do Sul and Passo Fundo, municipality where the reservoir is located; C: Reservoir of Capiguí; D: Transect perpendicular to the margin of Landscape Unit 2; E: Overview of Landscape Unit 1



Fonte: Os Autores.

The climate is humid subtropical (Cfa according to Köppen), with no dry season, temperature of the warmest month above, mean annual temperature 17.5 °C, and mean annual rainfall 1787.8 mm. The relative air humidity is on average 72% (Cunha 1997).

The reservoir covers an area of 6.27 Km^2 and has a perimeter of 43.43 km. Prior to flooding, the region was covered with native grasslands, forest fragments and family farming. The current land use in the 100 m around the reservoir consists of field/pasture or agriculture (52%); forest cover with varying degrees of conservation (40%); residential areas (6%) and forestry (2%) (CEEE 2011).

Choice of Adjacent Areas (Landscape Units)

Fifty-two years after the reservoir had been constructed, two landscape units were selected on farms with the presence of aquatic plants during visits to the reservoir (Figure 1). The units were chosen at random for the presence of macrophytes, visual characterization of the wetlands and the land use history, based on ethnographic information from local residents. The landscape units are temporarily flooded, mainly due to the reservoir management for energy demand. So, the two landscape units were described as follows:

- Landscape Unit 1 (LU1- 28º 20' 30.00" S and 52º 10' 18.5" W, 634 m asl, 3.6% slope), is located on a farm and represents the control: low anthropogenic pressure, with no agricultural cultivation of annual or perennial crops nor cattle grazing within a distance of 1,000 m from the reservoir. Residences are built at a distance of at least 200 m.
- Landscape unit 2 (LU2 - 28º 19' 46.2" S and 52º 13' 56.0" W, 634 m asl and slope of 3.52%): high anthropogenic pressure, characterized by land use with frequent presence of grazing cattle. Agricultural inputs (fertilizer or lime) are not used directly nor agricultural machinery for any kind of management. Landscape unit LU2 is part of a small farm, where, in addition to dairy farming, annual corn and wheat crops are grown, and 15,000 birds are fattened in a poultry-house at a distance of more than 200 m from the flooded area.

Sampling

In the two units (LU1 and LU2) a transect (width 1 m, length 19 m - in both unit) was delimited, perpendicular to the reservoir shores (Figure 1, letters D and E), adjacent to the flooded area, with the presence of macrophytes. Wetlands presented very homogeneous as your face, so it was considered only a transect.

The following variables were recorded in field charts for each transect, divided into one m^2 units, totaling 19 sample units (quadrats): presence of vascular species (macroalgae were excluded), biological form (Irgang & Gastal 1996), plant cover degree (Braun-Blanquet et al. 1979), type of plant distribution, plant appearance, and sun exposure level. Thus, the relationship of number of species per quadrat between the more and less humid environments in LU1 and LU2 can be established. The macrophytes were collected from 04 to 10 January 2009. Voucher specimens of each macrophyte species were collected for herborization, and deposited in the Herbarium Rio Grande do Sul, Passo Fundo (RSPF), of the Institute of Biological Sciences, University of Passo Fundo (ICB/UPF).

Soil and water samples were collected from each LU. Composite soil samples were collected with a cutting shovel from the 0-20 cm layer, consisting of a blend of four sub-samples of about 500 g each. Water samples were collected in a clean, sterile container from the flooded part of the two landscape units. All analytical determinations of soil chemical properties were performed in the Laboratory Soil Analysis, Faculty of Agronomy and Veterinary Medicine, University of Passo Fundo, according to the methodology described by Tedesco et al. (1995). The results of soil analysis were interpreted as proposed by the Brazilian Society of Soil Science (CQFS 2016).

Treatment of Results

After species identification, the frequency of occurrence was recorded (FAI = (ni/N) x 100) in each LU, where FAI = frequency of species i; ni = number of sample units where the species was recorded; N = total number of sample units.

The macrophytes, recorded on the Braun-Blanquet scale were converted to the ordinal scale of van der Maarel (1979) to assess the diversity index. The Shannon-Wiener diversity index was calculated using the program Divers (version 2011), to compare the landscape units. The sampling effort was evaluated using a species accumulation curve with 1000 simulations, to evaluate the sampling efficiency (Colwell & Coddington 1994), through the EstimateS 9.1.0 software (Colwell 2013). Each area one quadrat corresponded to a sample unit. Accumulation curves were obtained using non-parametric Bootstrap estimators to confirm the validation of the sampling.The soil analyses data were discussed qualitatively and related with soil and water parameters.

Results

The species found in the reservoir of Capiguí in the units LU1 and LU2 are listed in Table 1. Fifteen families and 20 macrophyte species were recorded in both areas. The *Onagraceae* family (3 species), *Cyperaceae*, *Poaceae* and *Polygonaceae* (2 species each), were represented best. The four families accounted for 45% of all observed macrophyte species (Table 1).

In LU1 more than half of the species (n = 10) were considered rare (frequency of occurrence less than 12%), five species were considered common (frequency between 20 and 49%) and three constants (frequency greater than 50%). The so-called amphibious species accounted for 85% of the total and this portion consisted of procumbent herbs, with irregular distribution on predominantly clay soil, exposed to full sun, with biological forms of plants rooted in the substrate and tolerate to water stress (Table 1). Also, according to the List of flora species of Brazil (2016), 18 species were classified as native to Brazil and/or South America. *Alternanthera philoxeroides* (LU2) stood out for being present in all quadrats of LU2 and *Paspalum cf notatum* only in 21,05 % (Table 1). The difference between the diversity indices (Table 1) reinforces the disparity of the LU2 community (low richness and dominance of one species) compared to LU1 (richer in and more balanced relative abundance of species).

In both LUs, the number of species was higher farther away from the flooded environment all species found were classified as amphibious (Table 1).

Tables 2 and 3 show the results of water and soil analysis. Calcium levels in the soil were fairly different between the two landscape units. In surface waters, Ca is found at concentrations up to 15 mg L^{-1}, mostly in the minerals calcite, dolomite and gypsum (Paron et al. 2011). Magnesium occurs most often in the minerals magnesite and dolomite, at a mean concentration of 4 mg L^{-1} in natural waters (Clesceri et al. 1999). The Al levels were clearly below the maximum value allowed for Class I water classification in Brazil, i.e., 0.1 mg L^{-1} (Brasil 2005). The pH values were within the range considered normal (6.0 to 9.0) for all water classes. The conductivity was similar in the two LUs and indicated a low degree of water mineralization, i.e., the concentration of dissolved minerals was low (Clesceri et al. 1999).

These results indicate that the different landscape units fall into the same texture (proportion of clay), indicating a similar chemical reactivity with the environment. Similarly, soil pH values are interpreted as very low at the studied locations. The data of other properties were interpreted differently, indicating that the presence of animals in LU2 may have contributed reduce soil fertility. In LU1, higher phosphorus, potassium, organic matter, calcium and magnesium contents were observed than in LU2. The lower soil fertility may show the most intense anthropogenic effect on LU2.

Discussion

The embankment of the river Capiguí in the 1950's changed the landscape, allowing the installation and development of macrophyte communities in the originally well-drained soils. The response in species occurrence and frequency of macrophyte communities in relation to land use was contrasting between the two landscape units. In short, the increased human pressure reduced species richness and increased the abundance of the species *Alternanthera philoxeriodes*.

Table 1. Family and botanical species, Number of species, Shannon diversity index frequency of occurrence (%) and description of two macrophyte communities in the surroundings of the reservoir of Capiguí in two landscape units: LU1 (low anthropogenic pressure) and LU2 (high anthropogenic pressure).

FAMILY/BOTANICAL SPECIES	FREQUENCY %		SPECIES DESCRIPTION						
	LU1	LU2	BF	DSU	PA	WP	ST	SE	O
AMARANTHACEAE									
***Alternanthera philoxeroides* (Mart.) Griseb**	5.26	100.00	amp	i, r	h,p	d,a	c	sop fs	n
APIACEAE									
Eryngium sp	36.84		amp	i	h,p	ws	c	fs	ni
BORAGINACEAE									
***Echium plantagineum* L.**	10.53		amp	i	h,p	ws	c	fs	ni
CLUSIACEAE									
***Hypericum brasiliense* Choisy**	26.32		amp	i	h,p	ws	c	fs	n
COMMELINACEAE									
***Commelina erecta* L.**	5.26		amp	i	h,p	ws	c	fs	n
CYPERACEAE									
***Rhynchospora aurea* Vahl**	57.89	5.26	amp	i	h,p	ws	c	fs	n
***Eleocharis sellowiana* Kunth**	21.05		amp	i	h,p	ws	c	fs	n
HALORACEAE									
***Myriophyllum aquaticum* (Vell.) Verdcourt**	42.11		evp	i	h,p	d,a	c	sop	n
JUNCACEAE									
***Juncus effusus* L.**	10.53		amp	i	h,p	ws	c	fs	n
LYTHRACEAE									
***Cuphea calophylla* Cham. et Schldt**	10.53		amp	i	h,p	ws	c	fs	n
MAYACACEAE									
***Mayaca sellowiana* Kunth**	5.26		evp	i	h,p	d,a	c	sop	n
MENYANTHACEAE									
***Nymphoides humboldtiana* (Kunh) Kuntze**	10.53		fl	i	h.p	d,a	c	fs	n
ONAGRACEAE									
***Ludwigia multinervia* Hook. & Arn.**		5.26	amp	i	h,p	ws	c	fs	n
***Ludwigia peploides* (Kunth) Raven**	5.26		amp	i	h,p	ws	c	fs	n
***Ludwigia sericea* (Cambess.) H. Hara**	57.89		amp	i	h,p	ws	c	fs	n
POACEAE									
Paspalum cf notatum		21.05	amp	i	h,p	ws	c	fs	n
***Panicum schwackeanum* Mez**	31.57		amp	i	h,p	ws	c	fs	n
POLYGONACEAE									
***Polygonum acuminatum* Kunth**	5.26		amp	i	h,p	ws	c	fs	n
***Polygonum meisnerianum* Cham.**	52.63		amp	i	h,p	ws	c	fs	n
XYRIDACEAE									
Xyris jupicai Rich	5.26		amp	i	h,p	ws	c	fs	n
Number of species	**18.00**	**4.00**							
Shannon-Wiener diversity index	**1.03**	**0.13**							

BF: Biological form: fl = floating leaves, evp = emergent vegetative part, amp = amphibious (drought-tolerant, all forms rooted in the substrate). DSU: Distribution in sample unit i = irregular, r = regular. PA: Plant Appearance: h = herb, p = procumbent. WP: presence of water: ws = waterlogged soil (saturated with water); d = water depth; a = flooded area (water deeper than 3 cm). ST: Predominant Soil texture: c= clay. SE: Sun exposure: fs = exposed to full sun, sop = shaded by other plants. O: Origin, n = native to South America, ni = no information. Characteristics recorded at the moment of sampling and the origin from consultations of literature sources and herbarium.

Fonte: Os Autores.

BOTANICAL ANALYSIS OF SPECIES OCCURRENCE

The most common organic form (amphibious) (Table 1), may be associated with the fluctuation of the water level of the reservoir, which is designed to accumulate water for the downstream system.. The analysis of species occurrence in the transects (LU1 and 2) shows an predominance in amphibious species (Figure 1). To survive in flooded areas, plants have to undergo a series of physiological and morphoanatomical adaptations (Evans 2003, Jackson & Colmer. 2005, Bailey-Serres & Voesenek. 2008, Colmer & Voesenek 2009, Jackson et al. 2009) to survive hypoxic or anoxic environments, or anaerobic conditions of the soil (Sairam et al. 2008). This indicates that amphibious plants are highly tolerant to variations in the water level, but are affected by waterlogged soils, that possibly occur very close to the flooded area.

The variations in richness, biological forms and type of sun exposure (Table 1) were largest in LU1. The distribution of all plants in LU1 was irregular, suggesting that intraspecific competition processes regulate the species distribution. Soil fertility was higher in this area. The lowest species richness in the area with greater human disturbance was also reported by Meyer & Francheschinelli (2010) and Galvão et al. (2011). Sass et al. (2010) pointed out that different disturbance gradients in the vicinity of ponds affect species differently by increasing or decreasing their abundance.

The Shannon diversity index was lowest for LU2 (Table 1). The difference was a result of the dominance of *A. philoxeroides* and the small number of species in this LU. Importantly, these wetlands are recent, since the embankment was constructed in the 50s, so this community is assumedly still in the succession process. In the state of Rio Grande do Sul and other Brazilian regions, the Shannon diversity index is usually above 2.0 (Boldrini et al. 2008, Alves et al. 2011, Evangelista et al. 2012).

Table 2. Chemical properties of water collected in the landscape units LU1 and LU2.

LANDSCAPE UNIT	ANTHROPOGENIC LEVEL	PROPERTIES				
		Ca **mg L^{-1}**	**Mg** mg L^{-1}	**Al** mg L^{-1}	**pH** Um	**CE** µS cm^{-1}
LU1	Low	4.87	2.5	0.01	6.9	31.5
LU2	High	6.59	2.95	0.01	6.1	30.3

Fonte: Os Autores.

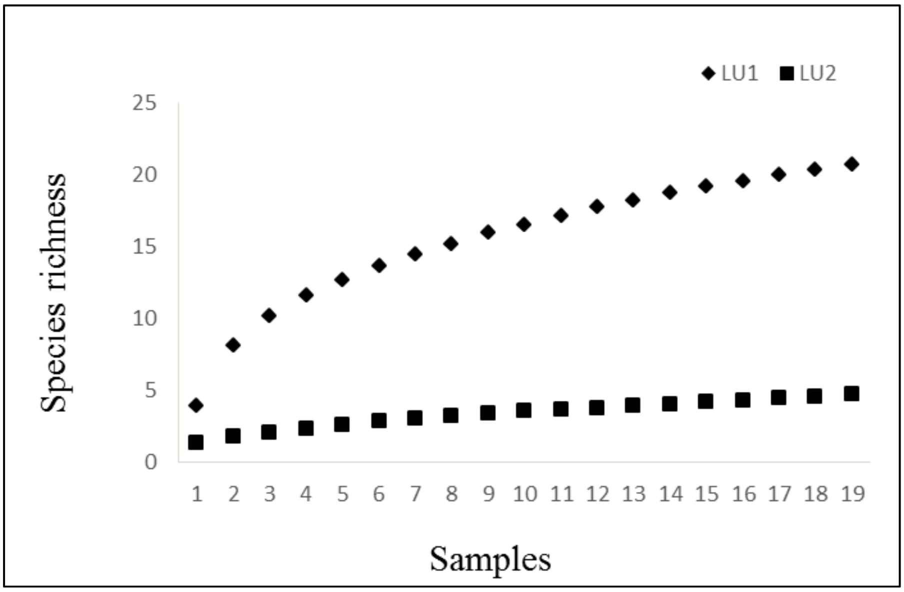
Table 3. Soil analysis results in two areas: LU1, LU2 and low anthropogenic pressure, high anthropogenic pressure.

AREA	Cy (%)	pH	SMP Ind.	P (mg dm^{-3})	K (mg dm^{-3})	O.M. (%)	Al (cmolc dm^{-3})	Ca (cmolc dm^{-3})	Mg (cmolc dm^{-3})	H +Al (cmolc dm^{-3})	CEC (cmolc dm^{-3})	V (Sat. (%))	Al (Sat. (%))	K (Sat. (%))	S (mg dm^{-3})	B (mg dm^{-3})	Mn (mg dm^{-3})	Zn (mg dm^{-3})	Cu (mg dm^{-3})
LU1	40	4.7	4.9	12	102	6.4	1.4	3.1	1.1	15.4	19.6	22	24	1.3	32	0.5	76	9.1	7.3
LU2	38	4.8	4.9	6	65	2.8	2.7	1.8	0.5	15.4	17.7	14	52	0.9	22	0.4	83	9.6	6.8

Cy Clay content; SPM=buffer solution; .OM = soil organic matter; CEC= Cation exchange capacity; V =base saturation Ca+Mg+K/S+Al); S = Ca+Mg+K, in cmolc kg^{-1}

Fonte: Os Autores.

Figure 2. Species accumulation curves using the Bootstrap estimator. LU1: Landscape Unit 1 (low anthropogenic pressure); LU2: Landscape Unit 2 (high anthropogenic pressure)..



Fonte: Os Autores.

Influence of Human Action on Occurrence of Macrophyte Species

The plant richness in LU2 was restricted to occurrence of four species, with highest occurrence frequency of *A. philoxeroides*, indicating that the phytosociological conditions were favorable for its development. This dominance of *A. philoxeroides* can be justified by conditions such as: high adaptation of the species to low soil fertility and exclusion of other species by selective grazing pressure, since the biomass of the species is little affected by fragmentation (Dong et al. 2012). *Alternanthera philoxeroides* was found from the flooded to the driest environment, with wide distribution and high degree of soil cover, with value 8 in 47% and 9 in 53% of the quadrats assessed on the van der Maarel scale. In LU2, the colonization and competition potential of this species, native to South America, was confirmed, for being herbaceous perennial, stoloniferous, with pronounced clonal propagation (Kissmann & Groth 2000, Gunasekera & Bonila 2001). The clonal habit is a common propagation strategy among the macrophytes, which together with the high phenotypic plasticity, make this species invasive in other environments (Ward et al. 2008, Geng et al. 2007).

The adaptation of *A. philoxeroides* in LU2 influenced the occurrence of other species negatively, e.g., those found in the LU1. The species *Paspalum notatum* cf was recorded exclusively in LU2 with the second highest occurrence frequency (Table 1), but had a low soil cover degree in the quadrats. The genus *Paspalum* is well-adapted to wetlands, has forage value and almost all species are perennial (Penteado & Macedo 2000, Rocha & Lins 2009, Maciel et al. 2010). The fact iof being associated with nutrient-poor soils can explain its occurrence in LU2 (Table 3). In LU2, the rudimentary agriculture and extensive grazing may have contributed to the selection of this species by selective grazing of animals, resulting in reduced species richness in LU2 (Table1). It was not possible to evaluate the total number of species in LU1 (Figure 2). In this landscape occurred greater wealth of species and also of life forms related to different habitats (floating leaves, emergent vegetative part and amphibious – Table 1). The evaluation in LU2 shows tendency of stabilization of the accumulation curve, indicating that probably all the species were evaluated. Carvalho et al. 2011 support the hypothesis of a positive relationship between community resilience and richness. Even with potential species to collect, this study supports this hypothesis.

In tropical regions, the low human impact stimulates a greater diversity of macrophytes which is desirable in flooded environments, which are responsible for the receipt, retention and export of sediments and nutrients. Such areas also mitigate climate changes, represent a biodiversity reserve and can be used for tourism, recreation and appreciation of the natural and cultural heritage.

Conclusion

The damming over 50 years ago allowed an investigation of two areas surrounding the reservoir, where it was found that that most procumbent amphibious native macrophytes species are located in areas that are less affected by humans. A greater protection of the areas surrounding the reservoir, in other words, a reduced human impact, allows a greater diversity of macrophytes. This response is desirable in this environment type, for functioning as a buffer zone and avoiding pollutants entry. The intensification of land use in the reservoir surroundings restricted macrophyte diversity.

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Ocorrência de Macrófitas como Resposta da Pressão Antropogênica em Reservatório

RESUMO

O objetivo deste estudo foi o de avaliar o efeito do uso antrópico do solo sobre a comunidade de plantas aquáticas no entorno de um reservatório artificial consolidado. Foram delimitadas duas unidades paisagísticas (UP) no entorno de um reservatório artificial de mais de 50 anos: a UP1 apresenta baixo impacto antrópico e a UP2 apresenta alto impacto antrópico. No total, foram encontradas 20 espécies de plantas. Apenas duas espécies foram comuns em UP1 e UP2. A UP1 apresentou maior diversidade de espécies (n=18). Os teores de fósforo, potássio, matériaorgânica, cálcio e magnésio foram menores na UP2 (n=4). Pode-se concluir que o processo de barramento permite a ocorrência de maior número de espécies e de plantas de macrófitas, pela conservação do solo adjacente ao reservatório. O baixo impacto antrópico nessa área permite maior diversidade de macrófitas nativas. A intensificação do uso do solo no entorno do reservatório não permite o desenvolvimento de comunidade diversificada de macrófitas, pois empobrece o solo.

Palavras-chave: Plantas Aquáticas; Conservação; Áreas Úmidas.

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