Aquatic macrophytes as indicators of water quality in subtropical shallow lakes, Southern Brazil

Macrófitas aquáticas como indicadores da qualidade da água em pequenos lagos rasos subtropicais, Sul do Brasil

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Abstract: Aims: We evaluated the potential of aquatic macrophyte communities as bioindicators in six small shallow lakes. **Methods:** The sampling was conducted monthly for one year, during which all macrophytes were surveyed, and the water temperature, dissolved oxygen, pH, conductivity, total alkalinity, chlorophyll-*a*, suspended matter, total nitrogen (Nt) and total phosphorus (Pt) were measured. **Results:** In total, forty-three species were recorded, and there were significant differences in the species richness and limnological conditions among the lakes studied. A canonical correspondence analysis showed that the concentration of nutrients (Nt and Pt), chlorophyll-*a*, suspended matter, dissolved oxygen and pH were the most important predictors of the distribution of macrophytes. Some emergents were related to the high concentration of nutrients, chlorophyll-*a*, and suspended matter. Moreover, the most submersed species were associated with environments with low nutrient concentrations and the lowest values chlorophyll-*a* and suspended matter. In addition, some species submerged and floating were related to low values pH, alkalinity and dissolved oxygen. Limnological differences between lakes may be cited as the main causes of the observed heterogeneous distribution of macrophytes. **Conclusions:** These results indicate the importance of limnological characteristics of the different environments in the macrophyte community composition and the potential role of this community as a bioindicator in shallow lakes in southern Brazil.

Keywords: bioindicators, aquatic vegetation, shallow lakes, eutrophication.

Resumo: Objetivo: Foi avaliado o potencial bioindicador da comunidade de macrófitas aquáticas em seis pequenos lagos rasos. **Métodos:** O acompanhamento foi mensal durante um ano, sendo que em cada coleta, além do registro de todas as espécies de macrófitas foram determinadas a temperatura da água, oxigênio dissolvido, pH, condutividade elétrica, alcalinidade total, clorofila-*a*, material em suspensão, nitrogênio total (Nt) e fósforo total (Pt). **Resultados:** No total, quarenta e três espécies foram registradas, e ocorreram diferenças significativas na riqueza de espécies e nas condições limnológicas entre os lagos estudados. A análise de correspondência canônica mostrou que a concentração de nutrientes (Nt e Pt), clorofila-*a*, material em suspensão, oxigênio dissolvido e pH foram os mais importantes preditores da distribuição das macrófitas aquáticas. Algumas espécies emergentes estiveram relacionadas à alta concentração de nutrientes, de clorofila-*a,* e de material em suspensão. Por outro lado, a maioria das espécies submersas foram associadas a ambientes com baixa concentração de nutrientes e os menores valores de clorofila-*a,* e de material em suspensão. Além disso, algumas espécies submersas e flutuantes foram relacionadas a baixos valores de pH, alcalinidade e oxigênio dissolvido. As diferenças limnológicas entre os lagos podem ser apontadas como as principais causas da distribuição heterogênea observada das macrófitas. **Conclusões:** Estes resultados indicam a importância das características limnológicas dos diferentes ambientes na composição da comunidade de macrófitas aquáticas e o potencial papel bioindicador dessa comunidade em lagos rasos do sul do Brasil.

Palavras-chave: bioindicadores, vegetação aquática, lagos rasos, eutrofização.

1. Introduction

Aquatic macrophytes compose an important community in limnic ecosystems because, in most cases, they are the main primary producers, they produce high biomass, and they contribute to biodiversity (Wetzel, 1993; Esteves, 1998). Macrophytes in shallow lakes are involved in various feedback mechanisms that tend to maintain a clear water state (Scheffer, 1998).

This community has a large ecological amplitude (Esteves, 1998; Thomaz, 2002) and therefore may colonize environments with different ecological characteristics (Thomaz and Bini, 1998) and withstand sudden environmental changes (Menezes et al., 1993; Esteves, 1998).

Macrophytes are organisms with low mobility and cannot avoid any combination of flow, nutrient availability and other physical and chemical characteristics that influence their survival in aquatic systems. Thus, an assembly of such organisms in a river or lake can be an effective indicator of the integrated combination of the pressure and stress disorders that affect their habitat (Murphy, 2000).

Several studies have analyzed environmental factors associated with the richness and species composition of macrophytes (Bini et al., 1999; Virola et al., 2001; Maltchik et al., 2002; Thomaz et al., 2003; Heegaard, 2004; Rolon et al., 2004). It is clear that macrophytes are limited to a set of characteristics of a specific habitat (Murphy, 2002) and that they respond differently to environmental conditions (e.g., trophic status) (Barko et al., 1986; Van Geest, 2005). When all habitat conditions are known, the distribution of plant species can be satisfactorily provided (Guisan and Zimmermann, 2000). Recently, many efforts have been made in developing a biotic index based on macrophytes and predictive models that can be used as management tools in monitoring the quality of water bodies (Camargo et al., 2003; Ciecierska, 2006; Clayton and Edwards, 2006; Joye et al., 2006; Beck et al., 2010; Kocic et al., 2008; Penning et al., 2008a, b; Søndergaard, 2010).

In the coastal plain of Rio Grande do Sul, there are common and diverse dense macrophyte stands in their aquatic environments (Albertoni et al., 2005). The present study investigated six lakes of the coastal plain of Rio Grande do Sul with different limnological characteristics, aiming i) to identify the community of aquatic macrophytes and ii) to verify the importance of species composition as a predictor of limnological characteristics. Our hypothesis is that this community is different according to the limnological characteristics of the ecosystems studied, so that ecological groups indicate such environmental variations.

2. Material and Methods

2.1. Study area

The study was conducted in six shallow lakes on the *campus* of the Federal University of Rio Grande - FURG (32° 04' 43" S and 52° 10' 03" W), municipality of Rio Grande, Rio Grande do Sul, Brazil (Figure 1). The city of Rio Grande is located in southern Brazil on the Rio Grande do Sul Coastal Plain. The coastal plain is characterized by low relief and by the absence of rivers. Streams and ponds constitute the hydrographic network (Vieira and Rangel, 1988). The climate is humid subtropical (Cfa according to the Köppen classification), with average annual temperature varies between 13 °C (winter) and 24 °C (summer). The winter and spring are characterized by intense humidity, and the summer is dry, with total annual rainfall is between 1200 and 1500 mm (Klein, 1998). NE winds dominate for most of the year. In the autumn, and particularly in winter, S (mainly SE) winds become very important (Krusche et al., 2002).

The *campus* has about 250 ha of land, a great number of small natural and artificial water bodies, which due to the geomorphological characteristics of the region, have a gentle slope at the edge of the coastal region where providing a large area where, during periods of high rainfall, the soil remains saturated. These environments have different limnological and trophic levels, which enable the development of unique biological communities (Albertoni et al., 2005; Marinho et al., 2009; Trindade et al., 2009).

Dunas Lake (4) is a shallow body of water situated along a strip of dunes, and the area and depth are greatly influenced by the seasonal rainfall pattern in the region, ranging from a 1.5 m to a few centimeters deep (Trindade, 2008). During periods of high rainfall, the littoral zone remains submerged, forming an extensive lake. In dry periods, the water flow is reduced, creating small ponds connected by wetlands; the littoral zone is then an area that can be characterized by habitat heterogeneity.

Polegar Lake (5) is an artificial lake, built about 14 years ago, that has an area of about 1 ha and a maximum depth of 1.6 m. The Negro Lake (1) has a rounded shape with an area of 0.5 ha, a maximum depth of 3.10 m and dystrophic features (Albertoni et al., 2005). Present in its surroundings

is *Eucalyptus* sp., which shades the lake and protects it from the wind and contributes continuously to the input of organic matter, the decomposition of which releases humic substances that lead to the darkening water.
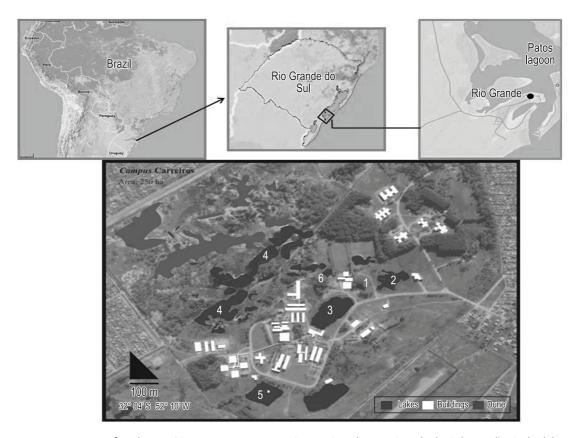
The Reitoria Lake (2) is a wetland, and its depth varies with rainfall, not exceeding 2 m deep. Tree species along the lake edges supply organic matter to the lake. The Biguás Lake (3) has a surface area of about 1.5 ha and a maximum depth of 2 m. In this lake, there are two small islands, which often serve as shelters and resting places for cormorants, herons, ducks and geese. These birds contribute inputs of organic matter and are the lake's main source of enrichment, accelerating the process of eutrophication (Trindade et al., 2009). Lake Centro Esportivo (6) has a round shape, with depth of approximately 2 meters, and high water transparency. Its environment is composed of shrubs and grasses that protect it from erosion.

2.2. Methodology

The sampling was conducted monthly during 2008 and consisted of surveying the species present in each lake and the limnological characteristics of the environment. The species survey was conducted by walking through the environments until there was no further increase in the number of species (Filgueiras et al., 1994). The sampling effort was proportional to the size of the environment sampled to get a better picture of the total number of species in each environment. The identification followed the taxonomic literature (Forno, 1983; Cordazzo and Seelinger, 1988, Cook, 1990; Irgang and Gastal Junior, 1996; Pott and Cervi, 1999; Gil and Bove, 2007; Barros, 1960). The angiosperms species were arranged by family according to APG II - Angiosperm Phylogeny Group (2003), the pteridophytas according Tryon and Tryon (1982) and algae Van-de-Hoeck et al. (1995). The ecological groups were classified according to Irgang and Gastal Junior (1996).

The limnological characteristics that were analyzed *in situ* were the water temperature (°C), dissolved oxygen (mg.L^{-1}), pH and conductivity (µS.cm^{-1}). A subsurface water sample was brought to the laboratory to determine total alkalinity (mEq.L^{-1}) (Carmouze, 1994), total nitrogen (mg.L^{-1}) (Mackereth and Talling, 1978), total

Figure 1. Location of study area (Carreiros *campus*, FURG, Rio Grande, Rio Grande do Sul, Brazil). Codes lakes: 1 - Negro; 2 - Reitoria; 3 - Biguás; 4 - Dunas; 5 - Polegar; 6 - Centro Esportivo.

phosphorus (µg.L^{-1}) (Valderrama, 1981), suspended matter (mg.L^{-1}) (Paranhos, 1996) and chlorophyll-*a* (mg.L^{-1}) (Chorus and Bartram, 1999). Sampling of variables were performed at the same time (between 10 h and 12 h) and in triplicate. The classification of trophic state of studies lakes followed previous studies (Albertoni et al., 2005, 2007; Marinho et al., 2009; Trindade et al., 2008, 2009), and the lakes Dunas, Reitoria and Centro Esportivo are classified as mesotrophic, Polegar as oligotrophic, Negro as dystrophic and Biguás as eutrophic.

Macrophyte richness were determined for total number and average annual number of species recorded in each environment and frequency for proportion of lakes where the species occurred and the number de occurrences during the year in each lake. The differences in mean species richness and abiotic variables throughout the year (for season) and among the lakes studied were tested using a repeated measures ANOVA, with an a posteriori Tukey test.

The influence of environmental variables on species composition was analyzed with a Canonical Correspondence Analysis (CCA) (Ter Braak, 1986). For environmental variables were done "a priori" test (ANOVA repeated) that showed significant differences between lakes, but not differences among year seasons in each lake (p > 0.05). Then, the CCA was based on the frequency of species recorded over the study period in each environment and average annual data for abiotic variables (all variables were log-transformed). The frequency values ranged from zero (absent in the environment) to 12 (present during the 12 months of collection).

3. Results

Throughout the study, a total of 43 macrophyte species were recorded (Table 1). The distribution of species at each lake during the study is show in Figure 2. The species *Luziola peruviana* Juss. ex J. F. Gmel. was the only species found in all environments. *Alternanthera philoxeroides* (Mart.) Griseb., *Bacopa monnieri* (L.) Pennell, *Azolla filiculoides* Lam., *Centella asiatica* (L.) Urb., *Hydrocotyle bonariensis* Lam. and *Ludwigia peploides* (Kunth) P.H.Raven were found in more than 80% of the lakes studied. However, most species (70%) were found in less than 50% of the lakes. Considering all lakes, the species richness of macrophytes did not differ significantly throughout the seasons (F$_{3,68}$ = 0.10979, p = 0.954). However, richness was significantly different between lakes (F$_{5,66}$ = 407.06, p < 0. 001) (Figure 3). The Dunas

Lake had the highest richness (mean = 31.91, SD = 1.62), and Polegar Lake had the lowest richness (mean = 7.16, SD = 0.83). Only Lakes Centro Esportivo and the Reitoria did not differ in species richness (p = 0.378).

The classification of ecological groups showed that in all the lakes, there was a predominance of emergent or amphibious species, which comprised 90% of the species (Figure 2). We found all ecological groups only in lakes Dunas and Centro Esportivo. At Biguás lake, there were no submersed species (free and/or rooted), and at lakes Reitoria and Negro, the submerged rooted biotype was absent. In Lake Polegar there were not free-floating and submerged aquatic macrophytes.

Table 2 shows the average values of abiotic variables for each lake. The Negro Lake had the lowest pH, temperatures and dissolved oxygen concentration and can be considered an acid lake with dystrophic features as described by Albertoni et al. (2005). The Biguás Lake had significantly higher values for all of the abiotic variables analyzed, including a slightly basic pH and high concentrations of chlorophyll-*a*, dissolved oxygen and nutrients (nitrogen and total phosphorus), and may be characterized as a eutrophic environment, as described by Trindade et al. (2009). The lakes Dunas and Polegar had near-neutral pH. Polegar Lake showed oligotrophic characteristics, with lower values of chlorophyll-*a* and nutrient concentrations, while Dunas Lake, which has an oligo-mesotrophic environment, showed intermediate values for these variables. Lake Centro Esportivo and the Reitoria did not differ with respect to abiotic variables, both being characterized as mesotrophic.

The first two CCA axes together explained 65.87% of the variation in species composition (Figure 4). Nutrient concentrations (Nt and Pt), chlorophyll-*a*, suspended matter, dissolved oxygen and pH were the most important predictors of the distribution of macrophytes. The emergent/amphibious species, *Cyperus odoratus* L., *Polygonum ferrugineum* Wedd., *Polygonum hydropiperoides* Michx, *A. philoxeroides*, *Vigna luteola* (Jacq.) Benth., *L. peploides*, *Enydra anagallis* Gardner, were strongly associated with characteristics of eutrophic environments, that is directly related to higher concentrations and/or values of the predictors of the distribution. The submerged species, including *Cabomba caroliniana* A. Gray, *Nitella* sp. and *Chara* sp.,and floating *Wolffia brasiliensis* Wedd. were associated with the lowest concentration

Table 1. List of species and ecological groups of aquatic macrophytes found in six lakes of the *campus* Carreiros of Rio Grande, Rio Grande do Sul, Brazil. Frequency (%) represents the proportion of lakes where the species appeared throughout the study.

Family/Species	Species code	Morpho-ecology group	Frequency (%)
CHARACEAE - Chlorophyta			
Chara sp.	Cha	Submerged rooted	33
Nitella sp.	Nit	Submerged rooted	17
SALVINACEAE - Pteridophyta			
Azolla filiculoides Lam.	Azol	Free floating	83
Salvinia herzogii de la Sota	Savh	Free floating	17
Salvinia minima Baker	Savm	Free floating	17
ALISMATACEAE - Angiosperms			
Echinodorus tenellus (Mart.) Buchenau	Ech	Emergent/amphibious	33
Sagittaria montevidensis Cham. & Schltdl.	Sagm	Emergent/amphibious	17
AMARANTHACEAE			
Alternanthera philoxeroides (Mart.) Griseb.	Alt	Emergent/amphibious	83
APIACEAE			
Centella asiatica (L.) Urb.	Cen	Emergent/amphibious	83
ARACEAE			
Lemna valdiviana Phil.	Lva	Free floating	50
Pistia stratiotes L.	Pis	Free floating	17
Wolffia brasiliensis Wedd.	Wofb	Free floating	17
Wolffiella oblonga (Phil.) Hegelm.	Wof	Free floating	17
ARALIACEAE			
Hydrocotyle bonariensis Lam.	Hyb	Emergent/amphibious	83
Hydrocotyle ranunculoides L.f.	Hyr	Emergent/amphibious	50
ASTERACEAE			
Mikania periplocifolia Hook. & Arn.	Mik	Amphibious	17
Enydra anagallis Gardner	Eny	Emergent/amphibious	83
CABOMBACEAE			
Cabomba caroliniana A.Gray	Cab	Submerged rooted	17
CYPERACEAE			
Androtrichum trigynum (Spreng.) H.Pfeiff.	Andt	Emergent/amphibious	17
Ascolepis brasiliensis (Kunth) Benth. *ex* C.B.Clarke	Ascb	Emergent/amphibious	17
Cyperus haspan L.	Cyph	Emergent/amphibious	33
Cyperus odoratus L.	Cypo	Emergent/amphibious	50
Cyperus rigens C.Presl	Cypr	Emergent/amphibious	33
Pycreus polystachyos (Rottb.) P.Beauv.	Pycp	Emergent/amphibious	17
Schoenoplectus californicus (C.A.Mey.) Soják	Scl	Emergent/amphibious	50
Scirpus giganteus Kunth	Scg	Emergent/amphibious	50
FABACEAE			
Erythrina crista-galli L.	Ery	Emergent/amphibious	17
Vigna luteola (Jacq.) Benth.	Vig	Emergent/amphibious	33
LENTIBULARIACEAE			
Utricularia breviscapa C.Wright *ex* Griseb.	Utrb	Free submerged	67
Utricularia gibba L.	Utrg	Free submerged	67
MENYANTHACEAE			
Nymphoides indica (L.) Kuntze	Ny	Rooted with floating leaves	50
ONAGRACEAE			
Ludwigia multinervia (Hook. & Arn.) Ramamoorthy	Ludm	Emergent/amphibious	50
Ludwigia hexapetala (Hook. & Arn.) Zardini et al.	Ludh	Emergent/amphibious	83
Ludwigia peploides (Kunth) P.H.Raven	Ludp	Emergent/amphibious	83
PLANTAGINACEAE			
Bacopa monnieri (L.) Pennell	Bac	Emergent/amphibious	83

Table 1. Continued...

Family/Species	Species code	Morpho-ecology group	Frequency (%)
POACEAE			
Luziola peruviana Juss. *ex* J.F.Gmel.	Luz	Emergent/amphibious	100
POLYGONACEAE			
Polygonum ferrugineum Wedd.	Polf	Emergent/amphibious	50
Polygonum hydropiperoides Michx.	Polh	Emergent/amphibious	67
PONTEDERIACEAE			
Eichhornia crassipes (Mart.) Solms	Eic	Free floating	33
POTAMOGETONACEAE			
Potamogeton pectinatus L.	Potp	Submerged rooted	33
SALICACEAE			
Salix humboldtiana Willd.	Salx	Emergent/amphibious	17
TYPHACEAE			
Typha domingensis Pers.	Tyd	Emergent/amphibious	17
XYRIDACEAE			
Xyris jupicai Rich.	Xyj	Emergent/amphibious	67

Table 2. Annual mean and standard deviation of abiotic variables in the water column of the six lakes studied. T °C: Water temperature (°C); DO: Dissolved Oxygen (mg.L^{-1}), C: Conductivity (µS.cm^{-1}), TA: Total Alkalinity (mEq.L^{-1}); Chla: Chlorophyll-*a* (µg.L^{-1}), SM: suspended matter (mg.L^{-1}) TN: Total Nitrogen (mg.L^{-1}), TP: Total Phosphorus (µg.L^{-1}). Codes of trophic states of lakes: O - Oligotrophic; M - Mesotrophic and E - Eutrophic.

	Dunas (M)	Polegar (O)	Negro (D)	CE (M)	Reitoria (M)	Biguás (E)	p-value
T °C	20.72 ± 3.71	20.08 ± 4.06	18.22 ± 3.52	19.7 ± 4.16	21.09 ± 4.14	19.88 ± 4.58	n.s.
pH	6.53 ± 0.40	6.51 ± 0.50	4.66 ± 0.28	5.92 ± 0.26	5.56 ± 0.24	8.11 ± 1.05	**
OD	4.88 ± 1.06	6.79 ± 0.87	1.54 ± 0.59	4.10 ± 0.71	3.81 ± 1.10	8.58 ± 1.41	**
CE	154.57 ± 17.39	72.9 ± 12.73	99.62 ± 10.50	111.06 ± 21.24	77.7 ± 5.29	191.19 ± 28.60	**
AT	1.20 ± 0.30	0.44 ± 0.14	0.14 ± 0.28	0.83 ± 0.25	0.37 ± 0.06	1.54 ± 0.13	**
Chla	20.27 ± 21.54	18.56 ± 11.28	37.28 ± 25.50	20.80 ± 7.50	40.35 ± 31.95	152.38 ± 85.83	*
MS	5.47 ± 5.03	7.08 ± 3.37	8.7 ± 5.06	4.32 ± 2.48	6.02 ± 8.31	52.36 ± 27.82	*
Nt	0.67 ± 0.11	0.47 ± 0.13	1.12 ± 0.08	0.88 ± 0.31	0.88 ± 0.10	3.75 ± 1.29	**
Pt	41.64 ± 36.48	28.60 ± 16.58	60.94 ± 11.89	34.64 ± 12.89	29.87 ± 5.59	256.96 ± 64.76	**

Nomenclature - n.s. (not significant), * $p < 0.01$ and ** $p < 0.001$.

of chlorophyll-*a*, low suspended matter and concentrations of nutrients, while free-floating species *Salvinia herzogii* de la Sota, *Pistia stratiotes* L. and *Salvinia minima* Baker were associated with intermediate conditions.
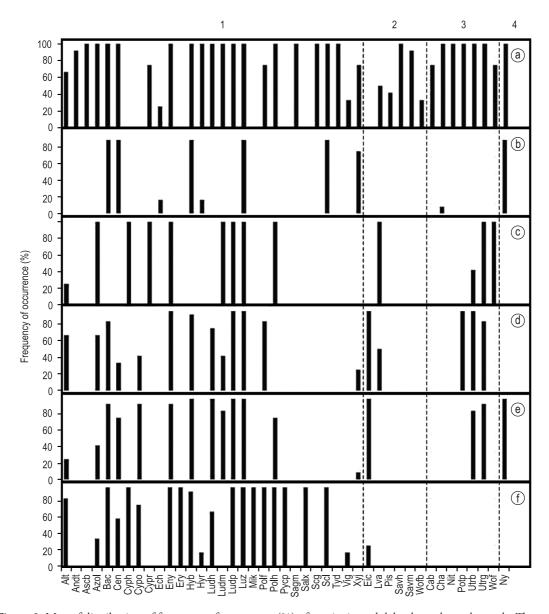
The other two submerged species, *Utricularia breviscapa* C.Wright *ex* Griseb. and *Utricularia gibba* L., and floating species *Lemna valdiviana* Phil., *Wolffiella oblonga* (Phil.) Hegelm., and *A. filiculoides* were more related to low values of pH, alkalinity, dissolved oxygen, probably reflecting their high frequency of occurrence in the lakes Negro and Centro Esportivo.

It may be noted that *L. peruviana* was located near the center of the chart, suggesting that the different characteristics of the study sites do not seem to markedly affect this species.

4. Discussion

Studies have shown a similar pattern of colonization and diversity of macrophytes in wetlands of Rio Grande do Sul, with a predominance of emergent and amphibious species. These species, normaly, have frequency of occurrence rare in different environments, (Rolon et al., 2004, 2008, 2010; Maltchik et al., 2007). The environments in the present study also followed this pattern, with only seven widely distributed species, and in all lakes, the most common species were emergent or amphibious. Shallow water environments with frequent fluctuations in their levels of flooding favor the development of these biotypes (Esteves, 1998; Albertoni et al., 2005; Sponchiado and Schwarzbold, 2008).

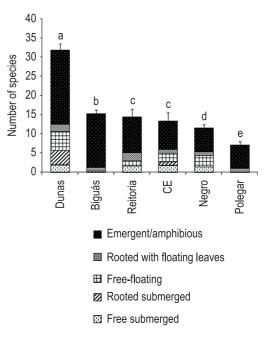The distribution of macrophytes in lakes has been related by many authors with the

Figure 2. Map of distribution of frequency of occurrence (%) of species in each lake throughout the study. The species are separated for ecological groups: 1 - emergent/amphibious; 2 - floating; 3 - submerged and 4 - rooted with floating leaves. Codes lakes: a - Dunas; b - Polegar; c - Negro; d - Centro Esportivo; e - Reitoria e f - Biguás. Codes species: See Table 1.

limnological characteristics of the environments, such pH (Vestergaard and Sand-Jensen, 2000; Catling et al., 1986; Jackson and Charles, 1988), and concentrations of chlorophyll and nutrients (Rørslett, 1991: Murphy, 2002; Bini, 1999). Our results showed that the different limnological characteristics of each environment seem to influence the success of the species.
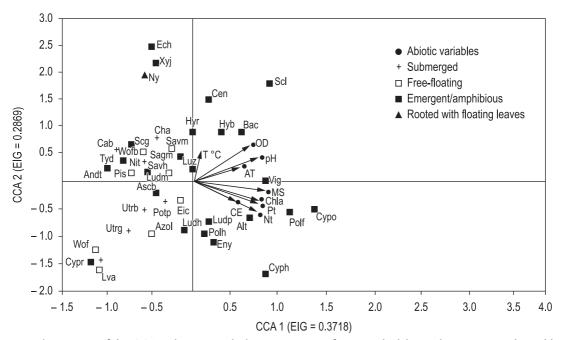
The values of the abiotic variables are similar to those found in other studies of shallow water environments (Albertoni et al., 2005, 2007; Marinho, 2009; Trindade et al., 2008, 2009).

The small seasonal variation found in these values may be the result of morphometric features of the environments and climate in the region because, according to Trindade et al. (2009), the low depth associated with the constant wind action causes the homogenization of the water column in the lakes, and daily variations become more pronounced than seasonal ones. However, the heterogeneity of the limnological characteristics of lakes studied appears to have been determinant in structuring the aquatic macrophyte community.

Several studies have documented that the trophic state and light conditions in the environment can influence the development and colonization of aquatic macrophytes (Mitchell, 1974; Wetzel, 1990; Esteves, 1998; Scheffer, 1998; Thomaz and Bini, 1998; Thomaz, 2002; Nurminen, 2003; Kocic et al., 2008; Penning et al., 2008a). In this study, the concentrations of nutrients (Nt and Pt) and the abiotic variables related to the radiation attenuation (chlorophyll-*a* and suspended matter) were the main predictors for the variation of macrophytes. These results indicate that the trophic characteristics of the different environments influence the composition of macrophyte communities in shallow lakes.

However, other studies have shown that several water chemistry variables such as pH (Catlinge et al., 1986) and alkalinity (Jackson and Charles, 1988) also exert strong influence on the distribution of macrophytes, especially submerged ones (Vestergaard and Sand-Jensen, 2000). In this study it was shown that these variables were also important in the occurrence of some species.

Different forms of life require different nutrient sources and have variable tolerances of exposure to environmental characteristics (Toivonen and Huttunen, 1995). In the lakes studied, some emergent and amphibious species were tolerant of high trophic conditions and poor lighting conditions. Studies have shown that emergent macrophytes may occur in areas with turbid

water that is nutrient rich; for example, at a large lake in the southwest coast of Finland, the diversity and richness of emergent species increased with the trophic status of the lake (Nurminen,

Figure 3. Average annual richness and ecological groups of aquatic macrophytes found in six shallow lakes of the Carreiros *campus*. Values represent the mean and standard deviation of species richness throughout the study. Different letters represent significant differences in species richness among lakes (p < 0.001).

Figure 4. Diagram of the CCA ordination with the composition of species, the lakes and environmental variables in the vectors studied. (EIG = eigenvalues of axes). For the definitions of the environmental variables, see Table 2 codes. For species codes, see Table 1.

2003). Camargo et al. (2003) report that highly productive environments have a marked growth of phytoplankton, which limits the growth of submerged and floating species but not the rooted macrophytes, which use the sediment as their main source of nutrients.

Our results showed that free-floating species were also related to intermediate nutrient concentrations. This ecological group gets its nutritional requirements from the water column (Bini et al., 1999; Thomaz, 2002), then its association with the nutrients may be a direct result of these nutrients facilitating its growth. Moreover, some of these species, such as *E. crassipes*, have vegetative growth, which confers a competitive advantage for obtaining nutrients in the environment. Many studies have demonstrated great potential for the proliferation of some floating species (Reddy and DeBusk, 1985; Bini et al., 1999; Thomaz, 2002; Camargo et al., 2003), which can cause serious damage not only to the multiple uses of water but also to other communities in the environment.

In this study, the environment with oligotrophic characteristics and low concentrations of nutrients (Polegar Lake) did not provide a favorable environment for the growth of floating macrophytes. However, the Biguás Lake, which had nutrient-rich water, had no species in this ecological group. According to Heegaard et al. (2001), an increase in the concentration of nutrients can promote biological diversity; however, the continuity of this process can lead to a decrease in biodiversity, the disappearance of some plant species and the appearance of others. Thus, the accelerated process of eutrophication in this lake mainly allows the development of some emerging or amphibious species, which dominate the environment.

Most of the submerged species are limited by the attenuation of radiation and are indicative of environments with low nutrient concentrations (Scheffer, 1998; Thomaz, 2002; Camargo et al., 2003). Similarly, the species *C. caroliniana, Nitella* sp. and *Chara* sp. were related to characteristics of environments with this characteristics , as found in the Lake Polegar and Dunas. At the two lakes with values greater concentrations of nutrients and suspended material (Negro and Biguás), species of this biotype were not found. Their absence is possibly related to the high marked hypertrophy and growth of phytoplankton in the lake Biguás and dystrophic features (high decomposition of humic substances) in the Negro Lake, which cause poor lighting conditions. These results indicate

that increased eutrophication and turbidity can result in a reduction or elimination of submerged macrophytes, and their presence in the environment can be a strong indicator of good water quality. Moreover, according to Palma-Silva et al. (2002), submerged species such as Charophyta have an important role in bottom-up control of phytoplankton by maintaining a clear water state.

However, studies have documented that some species may be strongly influenced by pH and alkalinity, as these variables are closely related to the concentrations of bicarbonate an important source of inorganic carbon for photosynthesis and growth of submerged species (Catling et al., 1986; Jackson and Charles, 1988; Spence and Maberly, 1985; Madsen and Sand-Jensen, 1991). Vestergaard and Sand-Jensen (2000) in Danish lakes have documented that acidic lakes with low alkalinity are generally poor in submerged species. In the present study the submerged species *U. breviscapa* C.Wright *ex* Griseb. and *U. gibba* L., and floating *L. valdiviana* Phil., *W. oblonga* (Phil.) Hegelm and *A. filiculoides* were related to low values of pH, alkalinity and dissolved oxygen, as found in Negro lake. According to some studies (Spence and Maberly,1985; Vestergaard and Sand-Jensen, 2000) the modes of carbon use, and therefore the concentration of bicarbonate (alkalinity and pH), differ among taxonomic groups and also between species with same growth form. These results indicate these species appear to have been favored by such conditions.

The species *L. peruviana* was widely distributed in the studied environment and was not directly influenced by the different environmental characteristics. According to Sponchiado and Schwarzbold (2008), this species is dominant in shallow ponds. This dominance is possibly derived from its growth from plugs and its good resprouting ability throughout the year (Neiff, 2000; Boldrini et al., 2005).

The different ecological groups of aquatic macrophyte communities in the lakes were effective indicators of environmental characteristics, mainly trophic status and luminosity. Emergent or amphibious species were related to high concentrations of nutrients and poor lighting conditions (high chlorophyll-*a* and suspended matter), while free-floating were related to intermediate concentrations. In contrast, the submerged species were good indicators of environments with characteristics of low concentration of nutrients. However, we point

out the importance of other water chemistry variables such pH, alkalinity and dissolved oxygen in the distribution of some species of macrophytes, especially submerged.

Our hypothesis was supported because differences in limnological characteristics of the lakes were reflected in the aquatic vegetation and can be identified as a major cause of macrophyte heterogeneity. These results indicate the importance of limnological characteristics of different environments (especially the trophic status and luminosity) in the macrophyte community composition and the potential role for this community as a bioindicator in shallow lakes in southern Brazil.

Acknowledgements

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