Periphytic algae of two bioforms of macrophytes in a subtropical shallow lake of Argentina

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ABSTRACT – The aim of this study was to analyse the structure and temporal variations in density and diversity of periphytic algae from *Potamogeton illinoensis* Morong (submerged and perennial macrophyte) and *Nymphoides indica* (Linné) Kuntze (rooted floating leaves and seasonal growth). The study was conducted in a shallow lake in northeastern Argentina (27° 29' S; 58° 45' W), between March 2007 and February 2010. Sixty-one taxa were exclusive to *P. illinoensis*, 12 were exclusive to *N. indica,* and 54 were common to both. Density, number of species and diversity were comparatively higher in *P. illinoensis* than in *N. indica*. *Cyanobacteria* (mainly *Stigonema hormoides* Bornet & Flahault) were dominant in *P. illinoensis*, whereas *Chlorophyta* (*Oedogonium* spp.) were dominant in *N. indica*. *Potamogeton illinoensis* developed a stable, mature epiphytic community over time. In *N. indica,* the density and diversity of periphytic algae were related to the plant seasonality and water level fluctuations.

Key words: community structure, temporal variations

RESUMO – **Algas perifíticas de duas bioformas de macrófitas em um lago raso subtropical da Argentina.** O objetivo deste estudo foi analisar a estrutura e as variações temporais de densidade e diversidade de algas perifíticas de *Potamogeton illinoensis* Morong (macrófita submersa e perene) e *Nymphoides indica* (Linné) Kuntze (enraizada com folhas flutuantes e crescimento sazonal). O estudo foi realizado em um lago raso do nordeste da Argentina (27° 29' S; 58° 45' W), entre março de 2007 e fevereiro de 2010. Sessenta e um táxons foram exclusivos para *P. illinoensis*, 12 exclusivos para *N. indica* e 54 foram comuns a ambas as formas de macrófitas. A abundância, número de espécies e diversidade foram comparativamente maior em *P. illinoensis* que em *N. indica*. *Cyanobacteria* (principalmente *Stigonema hormoides* Bornet & Flahault) dominaram em *P. illinoensis*, enquanto *Chlorophyta* (*Oedogonium* spp.) fez em *N. indica*. *Potamogeton illinoensis* desenvolveu uma comunidade epífita estável, madura ao longo do tempo. Em *N. indica* a densidade e diversidade de algas perifíticas foram relacionados pela sazonalidade da planta e as flutuações do nível de água.

Palavras-chave: estrutura da comunidade, variações temporais

INTRODUCTION

Among the communities adhered to and/or associated with vegetation, periphyton stands out due to its ecological importance as a producer of organic matter, and its role in the metabolism of aquatic ecosystems (Wetzel 1983). Ecological research and methodological aspects of this community were included in several books (Wetzel 1983, Stevenson *et al.* 1996, Pompêo & Moschini-Carlos 2003, Azim *et al.* 2005, Schwarzbold *et al.* 2013).

Despite the importance of this community in aquatic ecosystems, studies related to periphyton are scarce (Lowe 1996, Fernandes & Esteves 2011).

In some South American countries (e.g. Brazil), a steady increase in research over the past 30 years was noted (Schneck 2013).

In Argentina, most investigations of periphyton on macrophytes (epiphyton) were carried out in the central region (Buenos Aires province, and Paraná River floodplain). These include taxonomy, biomass, structure and dynamics, and its use as an indicator of water quality, aspects that were summarised by Rodriguez (2008). Recent studies included the temporal variation of the periphyton biomass (dry weight, organic weight, and chlorophyll-*a*) of *Egeria densa* Planchon in a Pampean stream (Giorgi & Feijoó 2010). The composition and diversity of periphyton on *Ricciocarpus natans* Corda and *Schoenoplectus californicus* (C.A. Meyer) Soják in five shallow humic lakes in the wetland (Otamendi Natural Reserve) of the Lower Paraná floodplain were studied by Rodríguez *et al.* (2011).

The few data available for the northeastern region of Argentina include the taxonomic study of algae associated with roots of *Azolla caroliniana* Willdenow (Tell & Pizarro 1984) and various plant substrates (Pizarro 1991, 1995) in lenitic environments of the Corrientes province. Planas & Neiff (1998) quantified the epiphyte biomass in roots, stipules and stolons of *Eichhornia crassipes* (Martius) Solms, and stressed the importance of light as a potential limiting factor for the growth of periphyton in environments located at the beginning of the floodplain of the Paraná River in its Argentine section.

Here, we studied the microalgae that integrate the periphyton of *Potamogeton illinoensis* Morong and *Nymphoides indica* (Linné) Kuntze by its abundance, species diversity, and seasonal variations related to environmental variables. Taking into account the factors that affect the development of periphyton, we inferred that this community presents temporal variations and quali-quantitative differences between both macrophytes in relation to their bioform, position in the water body, and environmental variables.

MATERIAL AND METHODS

Study site

The research was carried out in a small subtropical shallow lake called Laguna Aeroclub, Corrientes province, Argentina (27° 29' S; 58° 45' W). It is located in the basin of the Riachuelo River (a tributary of the Paraná River), it has an area of 26 ha, a rounded shape, an average depth of 4.2 meters, and no inlets or outlets. Its water regimen depends on rainfall and the climate is transitional subtropical (Bruniard 1981).

The study was conducted between March 2007 and February 2010. During this study period, the depth of Laguna Aeroclub varied between 3.5 and 4.5 m (4.2 ± 0.3 m) and remained at 4.5 m from March 2007 until December 2008 (normal climate cycle: alternating between wet and dry seasons). Then, up to February 2010, the depth gradually decreased to 3.5 m and the shore moved approximately 10 m with respect to its initial level. A dynamic ecotone, which moved in parallel with the decrease in the water level, developed during this prolonged drought.

Substrate studied

Potamogeton illinoensis is a submerged, generally perennial, rhizomatous, and bottom-rooted plant, with mainly vegetative propagation. It grows in permanent water bodies and it was the dominant macrophyte in Laguna Aeroclub throughout the study (36 samples).

Nymphoides indica is an herbaceous plant, rooted to the bottom with floating leaves. It grows in permanent or temporary water bodies (Martínez & Gómez Sánchez 2006). In the northeastern region it has a long reproductive period, 7-10 months, from spring to autumn (Arbo & Tressens 2002). The growth and development of this species is generally affected by water level fluctuations (Neiff 1986). The plants die during drought. The seeds are germinated under water, creating new plants. Usually, several generations are produced per year. In this study, generation (G) was considered when there was a new plant development, after the disappearance of its vegetative part in the previous month. In Laguna Aeroclub, eight generations of this plant (20 samples) were recorded.

Sampling design

Three plants of *P. illinoensis* and three of *N. indica* were manually and randomly collected every month, between March 2007 and February 2010. Apices (70 cm long) were collected from *P. illinoensis*, whereas the most developed leaves, after being separated from the petiole, were taken from *N. indica*. The material was immediately transported to the laboratory in glass containers with filtered lake water.

To determine the minimum sampling area for quantitative analysis, different area sizes were tested to achieve stabilization of the species-area curve

(Aloi 1990, Bicudo 1990), and three subsamples were obtained from the middle part of each leaf. In *P. illinoensis,* leaves number 7 to 10, counted from the apex of growth, were selected. Assuming that both sides of the leaf were able to be colonised, the size of each subsample was 1.56 cm^2. In contrast, in *N. indica*, which has only one colonisable surface (abaxial side of the leaf), the size of each subsample was 7.06 cm^2.

The periphyton was obtained by scraping and washing the subsamples with a brush and distilled water under a stereoscopic microscope. The material obtained was transferred to glass flasks, fixed and preserved in Lugol's solution, with known volume (Schwarzbold 1990). The total of each subsample was quantified in an inverted microscope, using tubular chambers of 2, 5 or 10 cm^3 according to the concentration of algae and particulate organic matter, and/or inorganic matter present. The abundance was expressed as ind.cm^{-2} of colonised surface (Robinson 1983). The filaments and/or colonies were quantified as an individual. For taxonomic determinations, living material and/or material fixed with 4% formaldehyde was used.

Species diversity (H') was estimated by applying the Shannon-Wiener index (Shannon & Weaver 1963) from density data, and expressed as bits ind.$^{-1}$. Species richness (SR) referred to the number of taxa observed in each quantitative sample.

The sampling site where the *P. illinoensis* samples were collected corresponded to a water body distance between three and five meters from where the *N. indica* plants were located. At each site, temperature, conductivity (YSI 33 SCT conductometer) and dissolved oxygen (YSI 54 A oxygen meter) in the entire water column were measured *in situ*. pH was measured with Metrohm A G Herisau digital pH meter on the surface layer. Transparency was estimated with a Secchi disk 25 cm in diameter. Nutrients (Nitrites+Nitrates, Ammonium and Orthophosphates) from the surface layer, between 0 and 50 cm, were analysed by the staff of the Chemical Laboratory of the Centro de Ecología Aplicada del Litoral (CONICET), following APHA methods (1995).

Biotic and abiotic variables were correlated using Spearman's rank-order correlation coefficient. To compare the environmental variables with periphyton results between *P. illinoensis* and *N. indica*, the Mann-Whitney (M-W) *U* test (Steel & Torrie 1997) was used. For the cluster analysis, we selected the species of algae whose density was ≥ 10 % of the total periphyton of each sample and/or represented more than 60 % of the samples. The Pearson correlation coefficient was calculated, and cluster analysis was carried out by the unweighted average linkage procedure for the 29 taxa of algae selected (Infostat Program, Di Rienzo *et al.* 2006).

RESULTS

Environmental variables

The depth of Laguna Aeroclub varied between 3.5 and 4.5 m (4.2 ± 0.3 m). Water transparency was high (Secchi disk 137 ± 32 cm). The temperature showed a pattern of seasonal variation with maximal values in the surface layer (between 18.7 ± 2.3 and 31.2 ± 1.8 ºC) and minimal values near the bottom (between 16.5 ± 1.4 and 28 ± 0.5 ºC).

Electrical conductivity was low in the first 2 or 3 meters of depth (between 56 ± 5 and 85 ± 12 µS cm^{-1}) and higher towards the bottom (142.5 ± 102 µS cm^{-1}). Dissolved oxygen was high in the surface layer (8.0 ± 2.7 mg L^{-1}) and decreased towards the bottom (6.2 ± 2.6 mg L^{-1}), generating conditions of hypoxia in the samplings of spring 2007 and 2008. pH oscillated around the neutral point, between 6.4 and 8.5 (7.6 ± 0.5). Nutrient concentration was low. The forms of N presented values between undetectable and maximum concentrations of 80 and 145 µg L^{-1} of ammonium and nitrites + nitrates, respectively. Phosphorus (orthophosphates) did not exceed 5 µg L^{-1}.

The main environmental variables showed no statistically significant spatial differences between sampling sites of each macrophyte. However, temporal variations were observed during the sampling period between normal climate cycle and prolonged drought (see Table 1).

Table 1. Variation Range and Mean Values (± SD) of some environmental variables measured during normal climate cycle and prolonged drought in Laguna Aeroclub (*n* = number of observations). Values of the Mann Whitney *U* test for variables with statistically significant differences between the two climatic cycles are included.

Climatic cycles	Normal ($n = 22$)		Prolonged Drought ($n = 14$)		Mann-Whitney *U* test	
Variables	Range	Mean (± SD)	Range	Mean (± SD)	*U*	*p*
Depth (m)	4.0-4.5	4.41 (0.20)	3.5-4.0	3.90 (0.33)	68	0.001
Temperature (ºC)	14-31	22.7 (5.3)	16-31	24.5 (5.5)	-	-
Secchi disk (cm)	80-220	141 (39)	90-150	131 (19)	-	-
pH (u)	7.4-8.5	7.9 (0.5)	6.4-8.3	7.4 (0.4)	74	0.009
Dissolved oxigen (mg L^{-1})	4.5-19.2	8.6 (2.9)	4.4-9.0	6.5 (1.3)	64	0.003
Conductivity (µS cm^{-1})	50-75	62 (7.9)	65-99	77 (8.2)	23	0.000
Ammonium (µg L^{-1})	0.1-80	14.2 (25)	0.1-80	16.5 (29.9)	-	-
Nitrites+Nitrates (µg L^{-1})	0.1-10	5.0 (2.2)	5.0-145	30.3 (42.1)	77	0.01
Ortophosphates (µg L^{-1})	0.1-5.0	4.5 (1.4)	0.1-5.0	4.3 (1.3)	-	-
Precipitations (mm)	0.0-114	99 (26)	0.0-6.5	2.2 (1.9)	53	0.000

Abundance and diversity of the periphyton

Regarding *Potamogeton illinoensis*, a total of 115 taxa of algae distributed in seven taxonomic groups: *Cyanobacteria* (42), *Chlorophyta* (51), *Bacillariophyta* (16), *Xanthophyta* (3), *Glaucophyta* (1), *Euglenophyta* (1) and *Dinophyta* (1) were recorded (Table 2). The density of the periphyton ranged between 72 and 507 ind.cm^{-2} (227 ± 106) (Fig. 1). Three groups stood out for their frequency and density in the following order of importance: *Cyanobacteria* (118 ± 63 ind.cm^{-2}), *Chlorophyta* (69 ± 39 ind.cm^{-2}), and *Bacillariophyta* (35 ± 29 ind.cm^{-2}).

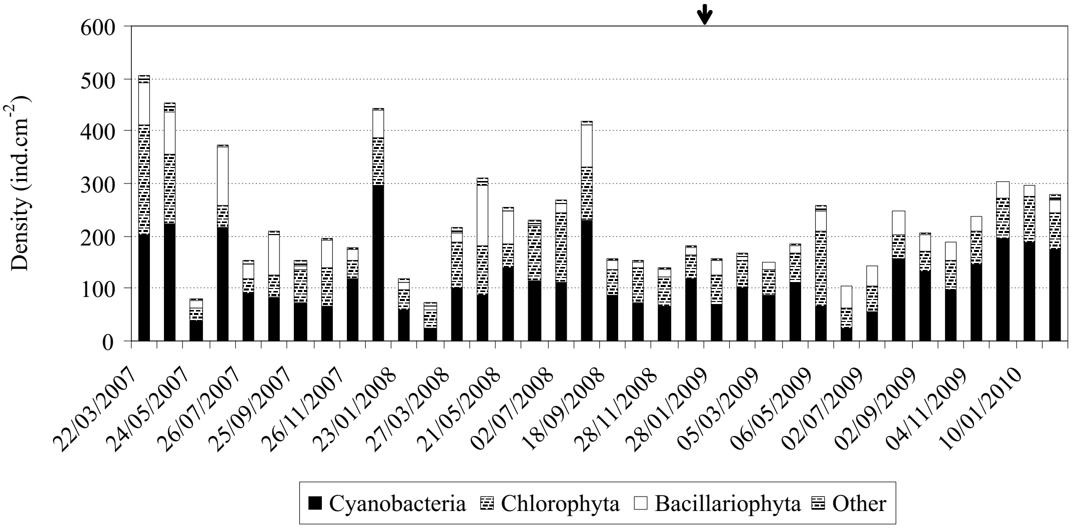

Fig. 1. Variations in density (ind.cm^{-2}) of the main taxonomic groups of the periphytic algae of *Potamogeton illinoensis*. Other: *Xanthophyta*, *Glaucophyta*, *Euglenophyta* and *Dinophyta*. The arrow indicates the start of a prolonged drought.

Cyanobacteria were mainly composed of epiphytic filamentous forms (61 %) with dominance of *Stigonema hormoides* Bornet & Flahault for the most part of the study, except for the samplings of winter and spring 2008, and winter 2009, in which *Leibleinia epiphytica* (Hieronymus) Compère with *Heteroleibleinia mesotricha* (Skuja) Anagnostidis & Komárek, *Aphanocapsa delicatissima* West & G.S. West and *Pseudanabaena catenata* Lauterborn were respectively dominant. The colonial forms of this group were characterised mainly by *A. delicatissima* and *Microcystis aeruginosa* (Kützing) Kützing. *Chlorophyta* were represented by *Zygnematales*, *Chlorococcales* and *Chaetophorales* (Table 2). *Bacillariophyta* were characterised by the predominance of pennate diatoms, without dominant taxa. Species richness ranged between 23 and 61 (43 ± 12) taxa, with more than 30 in most of the samples (81 %), whereas H' ranged between 2.2 and 3.8 (3.1 ± 0.4) bits, with values higher than 3.0 bits in 58 % of the samples. In this substrate, the main attributes of the periphyton showed no relation with the environmental variables measured between the surface and 3.5 m, the area where the apical part of the plants was located. At the taxonomic level, *Cyanobacteria* presented a good relationship with water transparency, although not statistically significant ($r_s = 0.318$; $p = 0.058$).

Regarding *Nymphoides indica*, a total of 66 taxa distributed in six taxonomic groups: *Cyanobacteria* (15), *Chlorophyta* (36), *Bacillariophyta* (10), *Xanthophyta* (2), *Glaucophyta* (1) and *Euglenophyta* (2) were recorded in this bioform (Table 2).

The density of the periphyton ranged between 10 and 453 (168 ± 139) ind.cm^{-2} (Fig. 2), and showed variations closely related to changes in the hydrometric level of Laguna Aeroclub. Density was higher during the first four generations, G1 to G4, (during normal climate cycle) with respect to the last generations, G5 to G8, (during prolonged drought ($p < 0.02$)). During the development of G1 to G4, the water level remained fairly stable (4.5 m in the samplings of 2007-2008, and 4.3 m at the beginning of 2009). Subsequently, and until the end of the study, the periphytic algae community failed to stabilise (G5 to G8). During this period, the water level decreased to 3.5 m and the population of *N. indica* was reduced by 50 %.

Filamentous *Chlorophyta* (*Oedogonium* spp.) were dominant in all samples. The second group in order of importance was *Cyanobacteria* (*Coelosphaerium kuetzingianum* Nägeli and *Aphanocapsa elachista* West & G.S. West). *Bacillariophyta* showed low density, like *Xanthophyta*, *Glaucophyta* and *Euglenophyta*, which were sporadically observed (Fig. 2). The density of *Chlorophyta* ($p < 0.01$) and *Cyanobacteria* ($p < 0.05$) was higher during the first 22 months of sampling (during normal climate cycle) with respect to the last 14 months (during prolonged drought).

Species richness ranged between 11 and 41 (22 ± 8) taxa, with more than 20 in 60 % of the samples, whereas H' ranged between 1.1 and 3 (2.2 ± 0.5) bits, with values lower than 3.0 bits in 90 % of the samples. Periphyton abundance presented no statistically significant correlation with the environmental variables measured in the surface layer, where the leaves of this macrophyte were located.

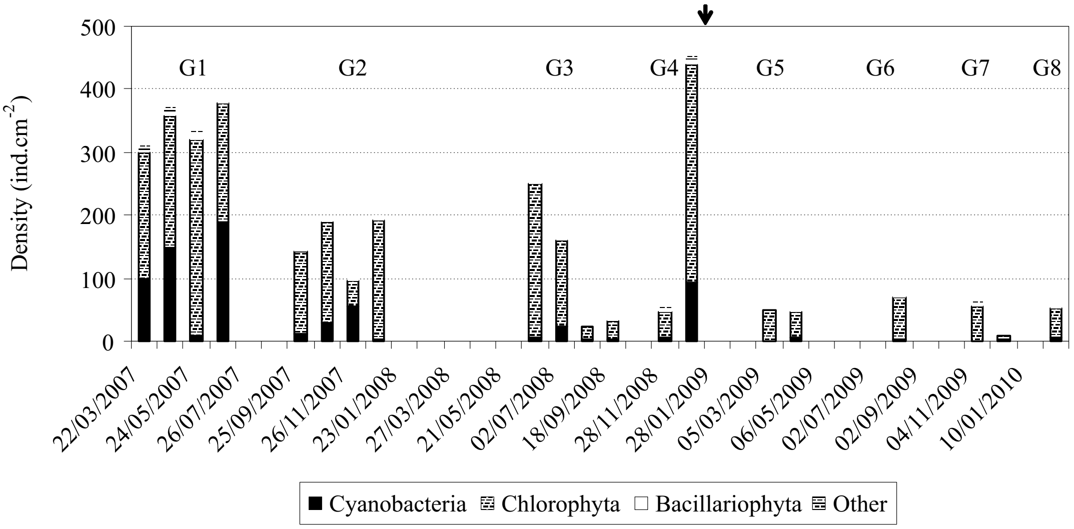

Fig. 2. Variations in density (ind.cm^{-2}) of the main taxonomic groups of the periphytic algae of *Nymphoides indica*. Other: *Xanthophyta*, *Glaucophyta* and *Euglenophyta*. G: generation. The arrow indicates the start of a prolonged drought.

Comparison of the periphytic community among both macrophytes

Periphyton density was higher in *P. illinoensis* than in *N. indica* ($p < 0.05$). The differences were primarily given by *Cyanobacteria* ($p < 0.001$), *Bacillariophyta* ($p < 0.001$) and *Glaucophyta* ($p < 0.001$). The same taxonomic groups, except for *Dinophyta*, with a planktonic representative (*Peridinium* sp.) in *P. illinoensis*, were recorded in the periphyton of both macrophytes. A total of 61 taxa identified (48 %) were exclusive to *P. illinoensis*, 12 (9 %) were exclusive to *N. indica,* and 54 (43 %) were common to both.

The number of species per sample (SR) was higher in *P. illinoensis* (R = 28-58 taxa) with respect to *N. indica* (R = 15-31) with significant differences between them ($p < 0.001$). Species diversity was also higher in *P. illinoensis* (M = 3.0 ± 0.4 bits ind.$^{-1}$) than in *N. indica* (M = 2.2 ± 0.5 bits ind.$^{-1}$) ($p < 0.001$).

Figure 3 shows the 29 taxa selected. Cluster analysis determined the formation of two separate groups with a level of correlation of 0.009 ($p < 0.05$). The first group - A includes an association of dominant and/or exclusive species to *P. illinoensis* with species common to *N. indica,* but with a higher density or frequency in *P. illinoensis*. The second group - B comprises the dominant and/or subdominant taxa in *N. indica*, and the species common to both bioforms, but better represented in *N. indica*.

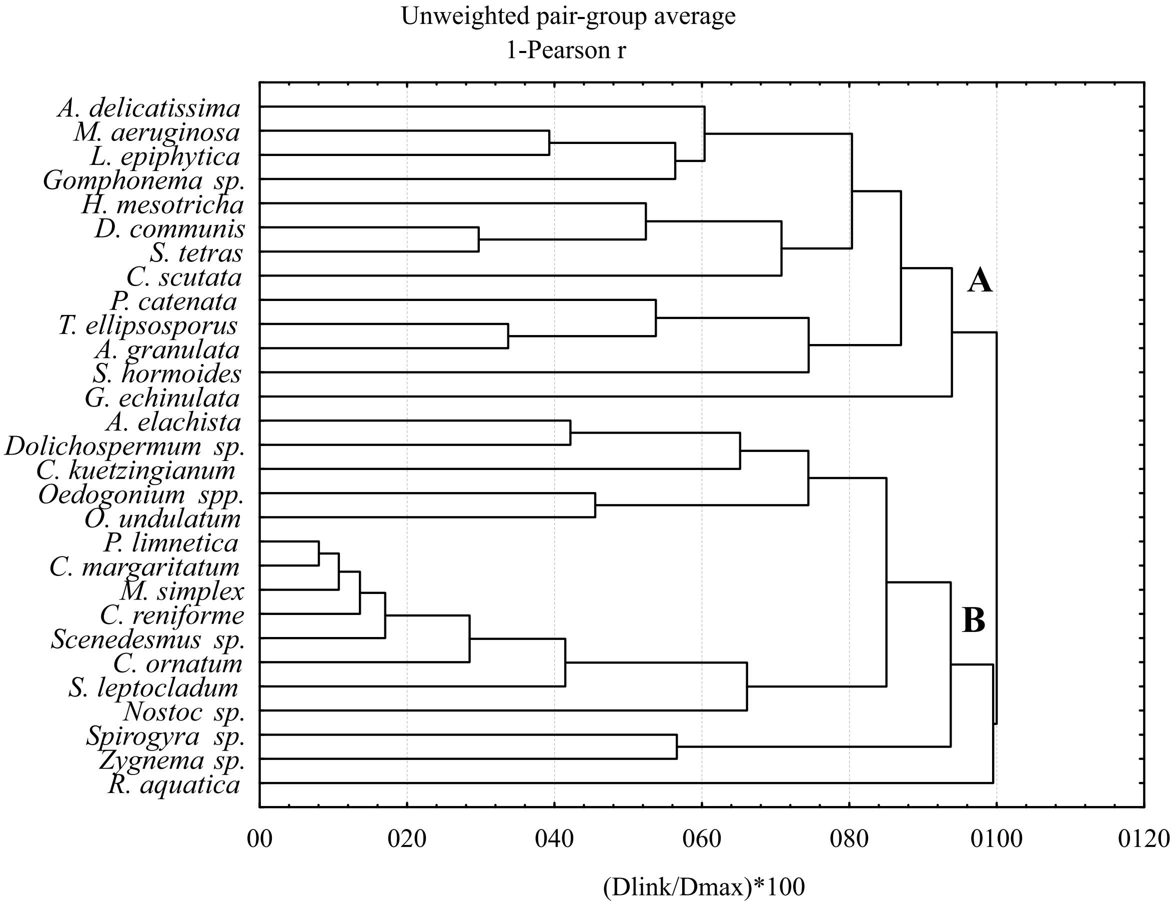

Fig. 3. Dendrogram of the algal associations resulting from the cluster analysis.

DISCUSSION

Laguna Aeroclub, with little human disturbance, preserves much of its natural characteristics. Rainfall regulates its hydrometric level, a factor influencing the biotic and abiotic characteristics of this ecosystem (Matveev *et al.* 1992). In the present study, there was a distinction between a normal climate cycle and a long dry period.

The structure and dynamics of periphyton was related to habitat and the presence of each macrophyte. *Potamogeton illinoensis,* with a mature periphytic community since the beginning of the study, showed temporal changes in density, maintaining its specific composition for most of the study period. These issues are probably related to the habitat of this macrophyte (submerged and perennial). In *N. indica* (rooted floating leaves and seasonal growth), the periphyton showed good development during the normal climate cycle, when the water level remained more stable. When the drought affected the littoral area of Laguna Aeroclub, the populations of each generation of *N. indica* were reduced. These aspects are reflected in the periphytic algae, which failed to stabilise and were maintained with low density and composition of taxa. However, the taxonomic groups and dominant taxa in each macrophyte were the same over time, and the community experienced temporal changes in density. These aspects differ from what occurs in lentic environments of the floodplains of large rivers, where steep and rapid fluctuations of the water level undoubtedly affect the substrate availability and the potential development of periphytic algae (Goldsborough *et al.* 2005, Taniguchi *et al*. 2005, Algarte *et al*. 2006).

In both macrophyte-dominated epiphytic filamentous forms belonging to different taxonomic groups, the physiognomy of the dominant microalgae (strictly epiphytes) seems to be adapted to the architecture of each macrophyte, and possibly to the availability of light (although there was no good relationship between the latter and periphyton).

In *P. illinoensis*, the filamentous and heterotrichous thallus of *S. hormoides* presented optimal development on the surface of leaves. Other filamentous *Cyanobacteria* (*Leibleinia epiphytica*, *Heteroleibleinia mesotricha*, *Oscillatoria limosa* Agardh ex Gomont, *Pseudanabaena catenata* Lauterborn), with epiphytic or benthic habitat, also occur (Komárek & Anagnostidis 2005). The low light requirements of *Cyanobacteria* (Dokulil 1984) may account for their dominance in the periphyton of *P. illinoensis*, 2 or 3 meters deep.

The genus *Oedogonium*, which is filamentous, uniseriate, with a basal cell fixed to the substrate, and dominant in *N. indica*, seemed to develop towards the optimal conditions of light of the surface layer, due to its high light requirement (Dokulil 1984). The predominance of *Oedogoniales* in the littoral area, among the representatives of the epiphyton and/or metaphyton, commonly occurs in wetlands of the northeastern region of Argentina (Zalocar de Domitrovic 2003). This has also been pointed out for water bodies in floodplains of South American rivers during the low water periods (Schwarzbold 1992, Taniguchi *et al*. 2005). For shallow lakes of the Lower Paraná floodplain, Tesolín & Tell (1996) reported dominance of filamentous algae throughout the year, plus *Oedogonium* spp., also *Zygnemataceae* (*Zygnema* spp., *Spirogyra* spp. and *Mougeotia* spp.).

Desmidiaceae are often associated with aquatic macrophytes of the littoral zone (Brook 1981, Coesel 1982), which may explain their greater abundance and variety of taxa in *N. indica* (such as some species of the genera *Cosmarium* Corda ex Ralfs and *Staurastrum* Meyen ex Ralfs). The presence of this group was also noted for extensive wetlands of the Iberá System, Argentina (Zalocar de Domitrovic 2003) and Pantanal Matogrossense, Brasil (De-Lamonica-Freire 1985, 1992, Carvalho Camargo *et al.* 2009).

The coexistence of phytoplanktonic and metaphytic taxa in this community seems to be related to the variations in habitat experienced by microalgae during their life history (reproductive strategies, migration and/or adaptations for survival, sedimentation from plankton, etc). Several authors have reported imprecise limits between metaphyton and plankton, mainly for shallow and/or flooding environments due to the great interaction between the different compartments of the ecosystem (Margalef 1983, Goldsborough & Robinson 1996, Ferragut *et al.* 2005). Colonies of *Aphanocapsa delicatissima* and *Microcystis aeruginosa,* more abundant and/or exclusive to the periphyton of *P. illinoensis,* are attributable to the vicinity and/or sedimentation from the phytoplankton, since they adhere to the leaves of this substrate thanks to the mucilage surrounding the colonies. Something similar would occur with *A. elachista* in the surface layer, since it adheres to the abaxial side of *N. indica* leaves. Other planktonic taxa, such as *Scenedesmus* sp., *Monactinus simplex* (Meyen) Corda, *Stauridium tetras* (Ehrenberg) Hegewald among others, including those with special adaptation for buoyancy by aerotopes (*Cylindrospermopsis raciborskii* (Woloszynska) Seenayya & Subba Raju, *Dolichospermum* sp., *Radiocystis fernandoi* Komárek & Komárková-Legnerová, *Sphaerocavum brasiliense* Azevedo & Sant' Anna, *Microcystis wesenbergii* (Komárek) Komárek) also suggest sedimentation from the phytoplankton. The composition of epiphytic algae in both macrophytes (e.g. *Eunotia* spp., *Gomphonema* sp., *Cocconeis placentula* Ehrenberg, *Characiopsis* sp., *Oedogonium* spp. among others) shares similar characteristics with adaptations for adhesion to the substrate (Round 1981).

Studies of phytoplankton and epiphyton in similar shallow lakes of the northeastern region of Argentina documented the great importance of meroplankton in a wind-driven system (Asselborn *et al.* 1998, Forastier 2012, Vallejos 2014, Zalocar de Domitrovic 2003). The sporadic presence of meroplanktonic species (primarily *Aulacoseira granulata* (Ehrenberg) Simonsen) in the periphyton of both macrophytes could be attributed to wind resuspension of filaments from the bottom sediments.

Laguna Aeroclub is characterised by low nutrient concentrations where P is the main limiting factor for phytoplankton development (Matveev *et al.* 1992, Zalocar de Domitrovic *et al.* 1998) and also probably for the periphyton microalgae. The limitation of this element for the growth of periphytic algae was noted for some shallow systems of South America (Fermino *et al.* 2011, Ferragut & Bicudo 2009, Ferragut *et al.* 2010, Huszar *et al.* 2005).

In this study, the periphytic algae community was not related to the concentration of nutrients. This is probably due to the position of the microalgae in the periphyton matrix to obtain nutrients from the surrounding water (Burkholder *et al.* 1990), and/or to the complexity of processes that occur in the littoral zone. Vegetation and organic soils produced by decay of dead plant material have a crucial role in regulating water quality and the mass transfer of nutrients within the system (Neiff *et al.* 2011). The increase in the concentration of nutrients (particularly N: Ni+NA) recorded during the decrease in the water level of Laguna Aeroclub during the drought was probably due to the degradation of a part of the macrophytes of the littoral zone (Forastier 2012).

The taxonomic richness of periphyton algae varies according to the biological types colonised. In general, the more diverse the aquatic vegetation and/or the greater the number of divisions in the leaves, the greater microhabitat offer for algal development (Coesel 1982). In this regard, Rodrigues Capítulo *et al*. (2010) reported a greater number of species in *Ceratophyllum demersum* Linné than in *Potamogeton* and *Egeria*. In turn, the senescent leaves supported a more dense and diverse epiphyton than the younger leaves, which tend to be devoid of epiphytes (Rogers & Breen 1983). This may explain the abundant variations recorded in both macrophytes among leaves of the same plant and/or different plants on the same date, or on different sampling dates.

The climate-hydrological changes would adversely affect the vegetation diversity and the stability of the ecosystem (Neiff *et al.* 2011). Changes in the water level of Laguna Aeroclub were closely related to precipitations. The decrease in the water level (littoral area) caused a reduction of *N. indica* plants and some variations in the environmental variables (such as an increase of nutrients, conductivity and decrease of dissolved oxygen, pH). In *P. illinoensis* (submerged and perennial macrophyte), a stable, mature epiphytic community was developed over time without significant differences in density between the normal climate cycle and the prolonged drought. On the other hand, in *N. indica* (rooted floating leaves and seasonal growth), the periphytic community was strongly conditioned by the seasonality and availability of plants. Both bioforms of macrophytes presented algal species in common, however, the dominant taxa were different. Changes in environmental conditions did not affect the coexistence of periphytic algae, whose structure in each bioform was maintained over time, causing changes in its density, strongly marked in the case of *N. indica*.

Table 2. Comparative distribution of algal taxa found in both macrophyte bioforms. X: presence, -: unobserved. The taxa selected for the cluster analysis of Figure 3, are indicated with an asterisk.

Taxa	***Potamogeton illinoensis***	***Nymphoides indica***
Cyanobacteria		
Aphanizomenon sp.	X	-
Aphanocapsa delicatissima West & G.S. West *	X	X
A. elachista West & G.S. West *	X	X
A. planctonica (G. M. Smith) Komárek & Anagnostidis	X	-
Aphanothece stagnina (Sprengel) A. Braun	X	X
Calothrix geitonos Skuja	X	-
C. marchita Lemmermann	X	-
C. scytonemicola Tilden	X	-
Chroococcus minor (Kützing) Nägeli	X	-
C. varius A. Braun	X	X
Coelosphaerium kuetzingianum Nägeli *	X	X
Cyanosarcina spectabilis (Geitler) Kováčik	X	-
Cylindrospermopsis raciborskii (Woloszynska) Seenayya & Subba Raju	X	-
Dolichospermum sp. *	X	X
Fischerella sp.	X	-
Gloeotrichia echinulata (J.E. Smith & Sowerby) Richter *	X	-
G. longicauda Schmidle	X	-
Gomphosphaeria aponina Kützing	X	X
Hapalosiphon flexuosus Borzi	X	-
Heteroleibleinia mesotricha (Skuja) Anagnostidis & Komárek *	X	-
Leibleinia epiphytica (Hieronymus) Compère *	X	-
Leptolyngbya perelegans (Lemmermann) Anagnostidis & Komárek	X	-
Lyngbya maior Meneghini ex Gomont	X	-
Merismopedia tenuissima Lemmermann	X	X
Microcystis aeruginosa (Kützing) Kützing *	X	X
M. wesenbergii (Komárek) Komárek	X	-
Nostoc sp. *	X	X
Oscillatoria sp.	X	X
O. limosa Agardh ex Gomont	X	-
Phormidium sp.	X	-
Planktolyngbya contorta (Lemmermann) Anagnostidis & Komárek	X	-
P. limnetica (Lemmermann) Komárková-Legnerová & Cronberg *	X	X
Planktothrix clathrata (Skuja) Anagnostidis & Komárek	X	-
Pseudanabaena catenata Lauterborn *	X	-
P. galeata Böcher	X	-
Radiocystis fernandoi Komárek & Komárková-Legnerová	X	-
Rivularia aquatica De-Wildeman *	X	X
Scytonema bohneri Schmidle	X	X

S. tolypothrichoides Kützing	X	-
Sphaerocavum brasiliense Azevedo & Sant' Anna	X	-
Stigonema hormoides (Kützing) Bornet & Flahault *	X	X
Trichormus ellipsosporus (Fritsch) Komárek & Anagnostidis *	X	-
Chlorophyta		
Actinotaenium sp.	X	-
Acutodesmus acuminatus (Lagerheim) Tsarenko	X	-
Ankistrodesmus falcatus (Corda) Ralfs	X	X
A. gelifactum (Chodat) Bourrelly	X	-
Botryococcus braunii Kützing	X	-
Bulbochaete sp.	X	X
Chaetophora elegans (Roth) C.A. Agardh	X	-
Chaetosphaeridium globosum (Nordstedt) Klebahn	X	-
Closterium sp.	X	X
Coelastrum pulchrum Schmidle	X	-
Coleochaete scutata Brébisson *	X	X
Cosmarium binum Nordstedt	-	X
C. connatum Brébisson	-	X
C. granatum Brébisson ex Ralfs	X	-
C. margaritatum (Lund) Roy & Bissett *	X	X
C. moniliforme (Turpin) Ralfs	X	X
C. ornatum Ralfs *	X	X
C.reniforme (Ralfs) Archer *	X	X
C. tenue Archer	X	X
Crucigenia quadrata Morren	X	-
Desmidium sp.	-	X
Desmodesmus communis (Hegewald) Hegewald *	X	-
D. intermedius (Chodat) Hegewald	X	-
Dictyosphaerium ehrenbergianum Nägeli	X	-
Elakatothrix gelatinosa Wille	X	-
Euastrum dubium Nägeli	-	X
E. gemmatum (Brébisson) Ralfs	X	X
E. turgidum Wallich	X	-
Eudorina elegans Ehrenberg	X	-
kirchneriella lunaris (Kirchner) Moebius	X	X
Micrasterias alata Wallich	X	X
M. radiata Hassall	-	X
Microspora sp.	-	X
Monactinus simplex (Meyen) Corda *	X	X
Monoraphidium contortum (Thuret) Komárková-Legnerová	X	-
Mougeotia sp.	X	X
Nephrocytium agardhianum Nägeli	X	-
Oocystis lacustris Chodat	X	-

Oedogonium spp.*	X	X
O. undulatum (Brébisson) A. Braun *	X	X
Pediastrum duplex Meyen	X	-
Pleurotaenium ehrenbergii (Brébisson) De Bary	X	-
Pseudopediastrum boryanum (Turpin) Hegewald	X	-
Scenedesmus sp. *	X	X
Selenastrum bibraianum Reinsch	X	X
Sphaerocystis schroeteri Chodat	X	X
Sphaerozosma laeve (Nordstedt) Thomasson	X	X
Spondylosium pulchrum (Bailey) W. Archer	X	-
Staurastrum arctiscon (Ehrenberg) Lund.	-	X
S. gracile Ralfs	-	X
S. leptocladum Nordstedt *	X	X
S. orbiculare Ralfs	X	X
S. sebaldi Reinsch	-	X
Stauridium tetras (Ehrenberg) Hegewald *	X	X
Staurodesmus cuspidatus (Brébisson) Teiling	X	X
S. triangularis (Lagerheim) Teiling	X	-
Stigeoclonium sp.	X	-
Spirogyra sp. *	X	X
Ulothrix sp.	X	-
Xanthidium sp.	-	X
Zygnema sp. *	X	X
Bacillariophyta		
Aulacoseira granulata (Ehrenberg) Simonsen *	X	X
Cocconeis placentula Ehrenberg	X	X
Cymbella sp.	X	X
Diatomea pennada 1	X	X
Diatomea pennada 2	X	X
Diatomea pennada 3	-	X
Eunotia sp.	X	X
E. bilunaris (Ehrenberg) Mills	X	X
E. formica Ehrenberg	X	X
Gomphonema sp. *	X	X
G. gracile Ehrenberg	X	-
G. parvulum (Kützing) Kützing	X	-
Navicula sp.	X	-
Nitzschia sp.	X	-
Pinnularia sp.	X	-
Stauroneis sp.	X	-
Synedra sp.	X	-
Xanthophyta		
Characiopsis sp.	X	X

Tetraedriella jovetii (Bourrelly) Bourrelly	X	X
Tetraplektron sp.	X	-
Glaucophyta		
Glaucocystis nostochinearum Itzigsohn	X	X
Euglenophyta		
Euglena sp.	X	X
Phacus sp.	-	X
Dinophyta		
Peridinium sp.	X	-

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