PANAMJAS
Pan-American Journal of Aquatic Sciences

Periphyton assemblages and their relationships with environmental variables in a eutrophic shallow lake from Pampa Plain, Argentina

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Abstract. The aim of this paper was to test the effect of changes in turbidity and chemical composition on periphyton community growing on *Schoenoplectus californicus*, a littoral macrophyte that is dominant in freshwater systems of Pampa Plain. Periphyton samples were collected and physico - chemical variables were monitored during a year at two sites in Los Padres Lake which differed in turbidity and some chemical variables scores. Our results showed that periphyton communities from both sampling sites were different in terms on biomass, density and dominant species. In general, periphyton from Station 1 (with higher turbidity) had a predominance of prostrate and erect diatoms (as *Rhoicosphenia abbreviata*, *Navicula cryptocephala* and *N. zanoni*) and was lesser developed than that from Station 2 (with lower scores of the mentioned environmental variable). Periphyton from Station 2 was more diverse, with a higher density of cyanobacteria, chlorophytes and euglenophytes beside diatoms like *Epithemia adnata*, *E. sorex*, *N. zanoni* and *Synedra acus*. Regression and multivariate analysis indicated that turbidity was the main variable affecting the amount of periphyton meanwhile this factor, together with CO_3^{2-} concentration were crucial for periphyton species composition.

Key words: periphytic algae; *Schoenoplectus californicus*; turbidity; chemical composition; Los Padres Lake

Resumen. Comunidad perifítica y su relación con variables ambientales en una laguna eutrófica pampeana (Argentina). El objetivo del presente trabajo fue evaluar el efecto de los cambios en los valores de turbidez y composición química del agua sobre el perifiton de *Schoenoplectus californicus*, macrófita litoral dominante en los ambientes pampeanos. Se establecieron dos sitios de muestreo en la Laguna de Los Padres (S_1 y S_2), los cuales difieren en sus valores de turbidez y de algunas variables químicas. Los resultados obtenidos indicaron que el perifiton desarrollado en ambos sitios difiere en cuanto a biomasa, densidad y especies algales dominantes. En términos generales, el perifiton de S_1, con mayores registros de turbidez, presentó un desarrollo menor que el de S_2 y predominancia de diatomeas postradas y erectas (como *Rhoicosphenia abbreviata*, *Navicula cryptocephala* y *N. zanoni*). En S_2, el perifiton fue más diverso, con una mayor densidad de cianobacterias, clorofitas y euglenofitas además de diatomeas como *Epithemia adnata*, *E. sorex*, *N. zanoni* y *Synedra acus*. Los análisis de regresión y multivariados realizados indicaron que la turbidez es la principal variable que afecta la acumulación del perifiton y que ésta, junto a la concentración de CO_3^{2-}, afectaron su composición específica.

Palabras claves: perifiton; *Schoenoplectus californicus*; turbidez; composición química; Laguna de Los Padres

Introduction

The development and structure of the periphyton community in freshwater systems are controlled by a number of hydrological and biological variables. Nutrient concentration (mainly P and N), water velocity, and light in the water column are the most important hydrological variables (Biggs *et al*. 1998, Pan *et al*. 2000, Irvine & Jackson 2006). Other factors, like the hydroperiod (Gottlieb *et al*. 2005), the mineral concentrations (Jüttner *et al*. 2003), the type of macrophyte (Claps 1991) and the herbivory (Jones *et al*. 1999) are

determinant, too, and together they influence the nature of periphyton assemblages (Goldsborough & Robinson 1996).

Components of community structure in periphyton include taxonomic and biochemical compositions, biomass and physiognomy (Steinman & McIntire 1986). The influence of interactions between these attributes and some environmental variables is, on certain occasions, controversial. According to some authors, nutrient concentration affects the periphyton biomass in a positive way (Cattaneo & Kalf 1980, Marcarelli & Wurstbaugh 2007), while for others, this relationship is negative or even non-existent (Bourassa & Cattaneo 2000, Bernhardt & Likens 2004, von Schiller *et al*. 2007). Nevertheless, in productive systems, high TDP (total dissolved phosphorus) concentrations lead to a decrease in the development of periphyton community, because of light attenuation caused by dense phytoplankton growth (Scheffer & Jeppensen 2007). This attenuation of light alters the availability of substrate for algal colonization, either by reduction of submerged macrophytes (Scheffer 1998) or by limitation of algal growth to the near-surface parts of littoral macrophytes (Esquius *et al.* 2010).

In addition to nutrient and light effects, several studies have demonstrated the potential importance of water chemical composition and catchment land use on periphyton algal assemblage, in lentic and lotic systems (Jüttner *et al.* 2003, Potapova & Charles 2003, Godwin *et al.* 2006, Bergey 2008). Changes in water conductivity and pH, and in the concentration of certain ions (as Cl^-, K^+ and SO_4^{2-}, among others) alter the structure of this community, modifying its taxa dominancy (Dela – Cruz *et al.* 2006, Passy 2006) and biomass accrual (Hill *et al.* 2003). Most of these modifications in hydrochemical and community composition are sometimes induced by alterations on catchment land use of freshwater ecosystems (Lowe & Pan 1996, Griffith *et al.* 2002, Gómez & Licursi 2003, Bahar *et al.* 2008).

Periphytic algae are closely associated with their substrates, which provide them more than an inert surface (Wetzel 2001). Physico-chemical characteristics of the substrate may influence algal assemblage composition and biomass, and together with environmental variables of freshwater ecosystems can determine the periphyton structure (Burkholder 1996). When the substrate is a living aquatic plant, an array of vegetal material is available to colonization, including leaves and stems, among others. Depending on the season, the condition of the plant acting as substrate, and the availability of water-column nutrients, the periphyton-substrate relationships could be positive, negative or neutral (Burkholder 1996, Burks *et al.* 2006).

Pampean shallow lakes from Buenos Aires Province (Argentina) are polimictic and highly productive waterbodies, with hydrodynamics strongly influenced by precipitations (Quirós 2005). Their catchments are highly exposed to human uses of land and water exploitation and are usually impacted by agricultural operations and food processing industries (Quirós & Drago 1999). Generally, these freshwater environments have an extensive and well-developed littoral zone (Quirós 2005) with marsh, submersed and free-floating macrophytes densely colonized by sessile microflora (Pizarro 1999). Despite the amount of information available on the structure of periphyton communities colonizing aquatic macrophytes in Argentina (Claps 1984, 1987, 1991, Pozzobon & Tell 1995, Tesolín & Tell 1996, Gómez *et al.* 2003, Dos Santos *et al.* 2008), only a few studies described the relationship between this community and its environment (Pizarro 1999, Pizarro & Alemanni 2005, Cano *et al.* 2008). More surveys are needed in order to understand the ecology of periphyton in eutrophic shallow lakes, which are widely represented in this region of South America.

The main objective of this research was to test the following hypothesis: (1) that periphyton biomass and density are affected by turbidity, and (2) that water chemical composition determines the periphyton species assemblage.

Material and Methods

Study area

Los Padres Basin has an area of 102 km^2 and is located in the Southeast of Buenos Aires Province, Pampean region, Argentina (Figure 1). The regional climate is mesothermic and subhumid, with little or no water deficiency and a mean annual precipitation of 809 mm $year^{-1}$. The mean temperature ranges from 8.1º C in June to 19.8º C in January, with an annual mean value of 13.7º C (Borrelli *et al*. 2011).

Los Padres Lake (37º 56' 30" S, 57º 44' 30" W) is placed at the eastern side of Sierra de Los Padres (Bocanegra & del Río 1991). This shallow permanent lake (maximum depth 2.4 m, average depth 1.2 m [Borrelli *et al.* 2011]) has a an area of 216 ha and can be considered a eutrophic lake, with total dissolved phosphorus and phytoplanktonic chlorophyll *a* values from 100 up to 400 µg L^{-1} and from 20 up to 90 µg L^{-1}, respectively (González

Sagrario & Balseiro 2003). This waterbody has only one inflow stream, Los Padres Stream, and one outflow, La Tapera Stream. The inflow stream drains through horticultural lands before flowing into the lake (Campana *et al*. 2001) where a big breeding colony of waterbirds is located (Josens *et al*. 2009). Opposite Los Padres Stream, the lake drains over a small dam into La Tapera Stream (Esquius *et al*. 2005).

In the littoral zone of the lake and in the input and output areas of Los Padres and La Tapera streams, respectively, *Schoenoplectus californicus* (C. A. Meyer) Soják is greatly developed. In addition to *S. californicus*, submersed (*Ceratophyllum demersum* L.) and free - floating macrophytes (e.g. *Ricciocarpus natans* L., *Azolla* sp. and Lemnaceae) are also frequently observed (González Sagrario *et al*. 1998). However, during our study Los Padres Lake was in the non - vegetated turbid phase (Esquius 2009).

From a hydrodynamic point of view Los Padres Lake, as many other Pampean shallow lakes, has an extreme dependency with the regime of precipitations, being this factor the main regulator of their water level at long and short terms (Quirós & Drago 1999; Quirós *et al*. 2002). Add to this, the construction of dams and their inappropriate management for regulation of the water level turns these shallow lakes into highly dynamic environments (Romanelli, unp. data).

Figure 1. Map of Los Padres Lake and its associated streams. (•) Study stations are indicated.

Sampling and water chemistry

Two sampling stations in Los Padres Lake were delimited: one located at the site of Los Padres Stream discharge area (Station 1) and the other, near the dam of La Tapera Stream (Station 2). These two sites differed in their turbidity (Esquius 2009, Esquius *et al*. 2010), also regarding to their soil composition (Miglioranza *et al*. 2004).

Each station was sampled every month, from July 2005 to July 2006, except in February 2006 due to the very low water level registered. Air and water temperature (with mercury in glass thermometer), transparency (with Secchi disk), and depth were measured among stands of *Schoenoplectus californicus*. Water was sampled and analyzed for dissolved oxygen concentration (DO), biochemical oxygen demand (BOD_5), pH, main ions (CO_3^{2-},

HCO_3^-, Cl^-, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+}), NO_3^{2-}, total dissolved phosphorus (TDP), conductivity, solid residue, hardness and turbidity according to APHA (1998).

For further analysis, DO was transformed to % of Oxygen Saturation, using water temperature measured at each sampling occasion and the theoretic solubility of oxygen in pure water at 760 mm atmospheric pressure (Wetzel 2001).

Periphyton collection and analysis

Twenty five stems of *Schoenoplectus californicus* (20 cm long, cut beginning at the water surface) were randomly removed up every month from each station, along a transect parallel to the shoreline. Ten samples were used to evaluate periphyton chlorophyll *a* concentration. The same number of stems was used to estimate dry weight (DW), ash (AS) and ash-free dry weight (AFDW) contents and five samples were used for periphyton taxonomy and count.

To extract chlorophyll *a* (Chl*a*), two pieces (5 cm^2 each) of each stem were randomly cut up and the biofilm was removed by brushing (Gómez *et al*. 2003). Then, these samples were filtered through 1 µm pore size glass fiber Sartorius prefilters and preserved at -20 ºC. The extraction of the pigment was completed using 90 % aqueous acetone solution and was estimated through spectrophotometry before and after acidification with HCl (0.1 N) to introduce a correction for phaeopigments (Cano *et al*. 2008). The final concentrations of chlorophyll *a* were calculated using equations given by Marker *et al*. (1980, in Cabrera Silva 1983).

For DW analysis, the whole stem was brushed and the material was pre - weighted and dried at 105 ºC until constant weight (Lakatos *et al*. 1982). For AS determination, dried samples with retained material were combusted at 505 ºC and re - weighted. AFDW content was calculated as the difference between DW and AS (Pizarro *et al*. 2004).

For periphyton community analysis, the biofilm of each stem was removed by brushing and preserved in a mixture of distilled water, alcohol and formol solution, in 6:3:1 proportion. The qualitative analysis was done using appropriate bibliography for algal identification (Guarrera *et al*. [1968, 1972], Hindák [1977, 1980, 1984, 1988, 1990], Germain [1981], Komárek & Anagnostidis [1985, 1989, 1999, 2005], Tell & Conforti [1986] and Cox [1996]). The quantitative analysis was performed in a 0.3 ml Sedgwick - Rafter chamber under an Olympus CH30 microscope. The estimated count error for each major algal species was ± 5 %. Species abundances were expressed as the number of individuals per cm^2, considering the bulrush area as the lateral area of a cylinder (Claps 1984). Periphytic algae physiognomy was established following the criteria proposed by Gómez *et al*. (2003).

Statistical analysis

Statistical differences in physical and chemical variables between both sampling stations were analyzed by means of Student Test (t) or Mann - Whitney Rank Sum Test (T). Species density, biomass and diversity (Shannon - Weaver Index) were used in order to characterize periphyton community. We evaluated the temporal differences in DW, AFDW, Chl*a* and total algal abundance (TAA) values between both stations using the non – parametric Kruskal – Wallis Test (H). Tukey Test was used for *post hoc* comparisons of the means (Zar 1984).

We explored the effect of turbidity upon periphyton DW, AFDW, Chl*a* and TAA using linear regression procedures. The independent variables mentioned above were appropriately transformed to comply with the methodological assumptions (Zar 1984).

We performed a multivariate analysis to investigate the relationships between periphytic species and the environment. These ordinations were executed using the Canoco 4.0 program for Windows (Lepš & Šmilauer 2003). Preliminary, Detrended Correspondence Analysis (DCA) was used on the environmental and species data. Environmental matrix was created using 17 log transformed environmental variables while for periphyton matrix, we used square – root transformed densities of 37 algal species. This transformation was used instead of a log transformation, as it was desirable to retain zero values (Urrea & Sabater 2009). Algal species used in periphyton matrix were selected from a total of 135 taxa, considering those found in more than 5 % of samples or with relative abundances greater than 1 %.

The DCA gradients of lengths were minor than 3 standard deviation units (2.589 and 1.610 for the first two axes) indicating a linear response, which justified the use of linear ordination techniques (Lepš & Šmilauer 2003). After that, a Redundancy Analysis (RDA) was used on the same above mentioned data matrixes. Weighted correlations and variance inflation factors (VIF > 10) were used to identify the intercorrelated variables (Brooks *et al*. 2001). On this basis, variables depth and solid residue were deleted from subsequent

analyses. RDA with step - wise forward selection was performed on all samples and a subset of 15 environmental variables to identify which of these variables explained a statistically significant amount of variation ($P< 0.05$) in periphyton data. The significance of each variable was tested using an unrestricted Monte Carlo permutation test (999 permutations) (Griffith *et al*. 2002). Finally and with the aim of exploring the relationships between significant environmental variables (resulting of RDA with step - wise forward selection) and periphyton species, we performed Spearman correlation procedures (Zar 1984).

Results

Environmental variables

Table I shows the mean and standard deviation values of the main physico – chemical variables registered in each sampling site. Turbidity was different between both sampling sites, reaching always higher values at Station 1 and ranging from 385 to 811 FTU ($T= 105$, $p < 0.0001$). Values estimated at Station 2 showed smaller fluctuations than those from Station 1, being 108 FTU the highest value registered there (Figure 2).

Table I. Mean and standard deviation (SD) values of main physico - chemical variables estimated at both sampling stations, during the study period. The numbers in parentheses after NO_3^{2-} and TDP mean values are the numbers of analyses with concentrations greater than the detection limit (0.5 and 0.05 mg L^{-1}, respectively). Asterisks indicate significant differences in mean values ($p < 0.05$, * Student Test, ** Mann - Whitney Rank Sum Test).

	Station 1		Station 2	
Variable	**Mean**	**SD**	**Mean**	**SD**
Secchi disk (m)	0.09	0.09	0.12	0.04
Depth (m)	0.26*	0.08	0.49*	0.09
BOD_5 (mg L^{-1})	8.98*	4.39	14.29*	4.51
Oxygen Saturation (%)	54.99	16.59	67.73	15.89
CO_3^{2-} (mg $CaCO_3$ L^{-1})	16.39**	42.15	126.96**	73.07
HCO_3^- (mg $CaCO_3$ L^{-1})	597.06	118.03	494.06	151.06
Cl^- (mg L^{-1})	102.08	48.75	106.66	55.97
Na^+ (mg L^{-1})	178.78	27.90	165.23	29.66
K^+ (mg L^{-1})	7.85	1.27	8.50	2.88
NO_3^{2-} (mg L^{-1})	6.49 (9)	5.92	1.46 (6)	1.32
SO_4^{2-} (mg L^{-1})	8.23	3.57	10.91	5.31
Ca^{2+} (mg L^{-1})	22.9	9.10	23.56	9.82
Mg^{2+} (mg L^{-1})	30.66	10.47	26.21	11.74
Total dissolved phosphorus (TDP, mg L^{-1})	0.179 (12)	0.113	0.143 (11)	0.135
pH	7.99*	0.39	8.65*	0.43
Hardness (mg $CaCO_3$ L^{-1})	171.9	70.43	168.28	54.72
Conductivity (µS cm^{-1})	648.9	512	665.28	47.16
Turbidity (FTU)	560**	133.2	76.78**	22.56
Solid residue (105° C) (mg L^{-1})	742.1*	96.7	499.28*	54.72

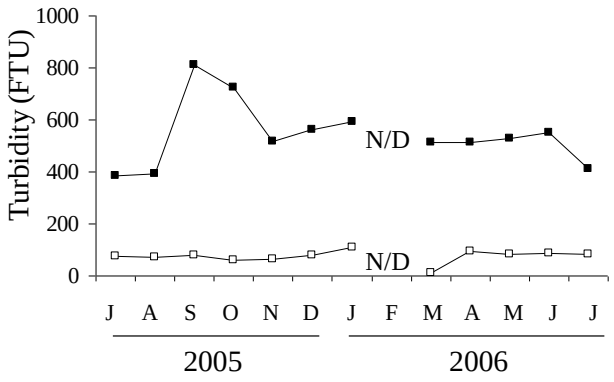

Figure 2. Turbidity values from Station 1 (black symbols) and Station 2 (white symbols), during the sampling period. N/D: no data.

Although BOD_5 values were higher at Station 2 (t= 3.15, p < 0.0041), mean oxygen saturation (%) did not differed between sites, reaching the highest scores in August 2005 (92.78 and 106.84 % at Station 1 and 2, respectively). TDP ranged from undetectable concentrations to 0.380 mg L^{-1}, being these values usually higher at Station 1. In the last three months of the sampling (May – July 2006), TDP values were higher at Station 2, reaching similar concentrations than those observed at Station 1. Similarly, NO_3^{2-} concentrations were usually higher at Station 1 and their values ranged from undetectable to 14.1 mg L^{-1} in November 2005. At Station 2, NO_3^{2-} was only detected in 40 % of the samples at low concentrations.

In relation to ionic composition, Station 1 had mainly Na^+ and HCO_3^- as dominant ions (71 % of the samples). Higher values of Mg^{2+} (> 34 mg L^{-1}) were estimated during December 2005, March, June and July 2006 while CO_3^{2-} ion was only present during June 2006. On the other hand, Station 2 waters had Na^+, CO_3^{2-} and HCO_3^- as predominant ions (64 % of the samples). Mg^{2+} concentrations were only important in June 2006 and CO_3^{2-} was always in a lower concentration than HCO_3^-.

Periphyton communities

A total of 135 algal taxa were identified during the present study, being this number always higher in bulrushes belonging to Station 1. Diversity was similar in both sites with very fluctuating scores, ranging from 0.77 to 2.38.

Periphyton from both sampling stations was dominated by diatoms (Table II). *Rhoicosphenia abbreviata* (Agardh) Lange - Bertalot predominated in the community at Station 1 during the whole sampling, with relative densities up to 50 % during all the study period. *Navicula cryptocephala* Kützing and *N. zanoni* Hust were present in relative abundances higher than 25 %. In contrast at Station 2, no species could be recognized as dominant during the whole sampling period but four diatom species, *Epithemia adnata* (Kützing) Brébisson, *E. sorex* Kützing, *Navicula zanoni* and *Synedra acus* Kützing, were mostly present with relative abundances of 10 %, except in two or three sampling occasions where their relative abundances ranged from 25 to 50 %.

Cyanobacteria were more representative in periphyton from Station 2, especially during autumn and summer. The more abundant taxa were similar in both sampling areas, being *Anabaena aphanizomenoides* Forti, *Calothrix* sp.$_1$, *Leibleinia epiphytica* (Hieronymus) Compère and *Lyngbya* sp.$_1$ the more common ones. Similar situation was observed in chlorophytes and euglenophytes. We registered high densities of *Oedogonium* sp.$_1$ and *Trachelomonas oblonga* Lemm. in both sampling stations during the whole period (Table II).

Concerning periphyton biomass, DW values from Station 2 were significantly higher in most of the samples than those of Station 1 (Figure 3a). Comparing the temporal trend of both sites, DW had a similar tendency with two definite increments in spring (November – December 2005) and autumn (May – June 2006). Likewise, AFDW content (Figure 3b), Chl*a* (Figure 3c) and TAA (Figure 3d) from Station 2 were significantly different from those of Station 1. The same dynamics described for DW was observed for these three descriptors.

Relationships between environmental variables and periphyton growing on Schoenoplectus californicus

A regression analysis showed significantly negative relationships between turbidity and periphyton DW, AFDW, Chl*a* and TAA (Figures 4a - d, respectively). For DW and AFDW, R^2 values were higher than 0.5 while for Chl*a* and TAA, these scores were lower.

Respect to multivariate analysis, a Redundancy Analysis (RDA) suggested that two environmental variables (turbidity and CO_3^{2-} concentration) made significant contributions to explain the variance in periphyton species. Table III shows the results of RDA using these two environmental variables selected. The eigenvalues of axis 1 and 2 explained 26.7 % of the cumulative percentage variance in the periphyton community data. Species - environment correlations of RDA axes 1 and 2 were high and together accounted for 100 % of the variance in the periphyton - environment relationship.

Table II. Code of identification, mean density and standard deviation (SD) values (for all the study period, expressed as number of individuals per cm^2) of the more frequent periphyton taxa (observed in more than 5 % of samples or with relative abundances greater than 1 %) on *Schoenoplectus californicus* from both sampling stations.

		Station 1		Station 2	
Code	**Taxa**	**Mean**	**SD**	**Mean**	**SD**
	Cyanobacteria				
AN	*Anabaena aphanizomenoides*	1	1	393	892
CA	*Calothrix sp*$_1$.	1	1	1346	1599
LE	*Leibleinia epiphytica*	478	947	164	266
L1	*Lyngbya* sp.$_1$	10	19	3009	8615
OSL	*Oscillatoria limosa*	-	-	558	1933
OS	*Oscillatoria* sp.$_1$	1	3	605	1772
	Chlorophytes				
OED1	*Oedogonium* sp.$_1$	595	718	1750	2292
Pl	*Planktonema lauterbornii*	106	368	4	15
RZ	*Rhizoclonium sp.*	43	149	-	-
ST	*Stigeoclonium sp.*	160	344	24	35
	Euglenophytes				
TO	*Trachelomonas oblonga*	50	56	4466	4277
	Diatoms				
AO	*Amphora ovalis*	19	18	190	579
BP	*Bacillaria paradoxa*	361	827	4	7
CP	*Cocconeis placentula*	2	2	203	477
CM	*Cyclotella meneghiniana*	68	88	1884	2546
CEX	*Cymbella excisa*	26	40	2764	4890
EAD	*Epithemia adnata*	2	2	14968	18256
ESX	*E. sorex*	2	3	20045	29143
EP	*Eunotia pectinalis* var. *pectinalis*	331	728	1	2
GAC	*Gomphonema acuminatum*	640	1120	818	1457
GAN	*G. angustatum*	604	814	1045	1646
GC	*G. constrictum*	1068	1372	2357	3761
GGRA	*G. gracile*	1	1	676	2342
GP	*G. parvulum*	1930	3403	556	849
MV	*Melosira varians*	954	1258	3036	8679
NCR	*Navicula cryptocephala*	3385	5162	9261	15449
NZ	*N. zanoni*	2873	3336	21331	26041
NI	*Nitzschia inconspicua*	153	531	-	-
NS	*N. sigma*	205	423	1	3
NSM	*N. sigmoidea*	234	315	15	36
NT	*N. tryblionella*	79	257	1	1
NPUM	*N. pumila*	-	-	10280	35610

Table II (*Cont.*)

RA	*Rhoicosphenia abbreviata*	28276	30329	805	2309
RG	*Rhopalodia gibba*	1	1	2	4
SA	*Synedra acus*	1032	2415	21005	30902
SYC	*S. capitata*	-	-	1911	6619
UU	*Ulnaria ulna*	763	1874	2055	3962

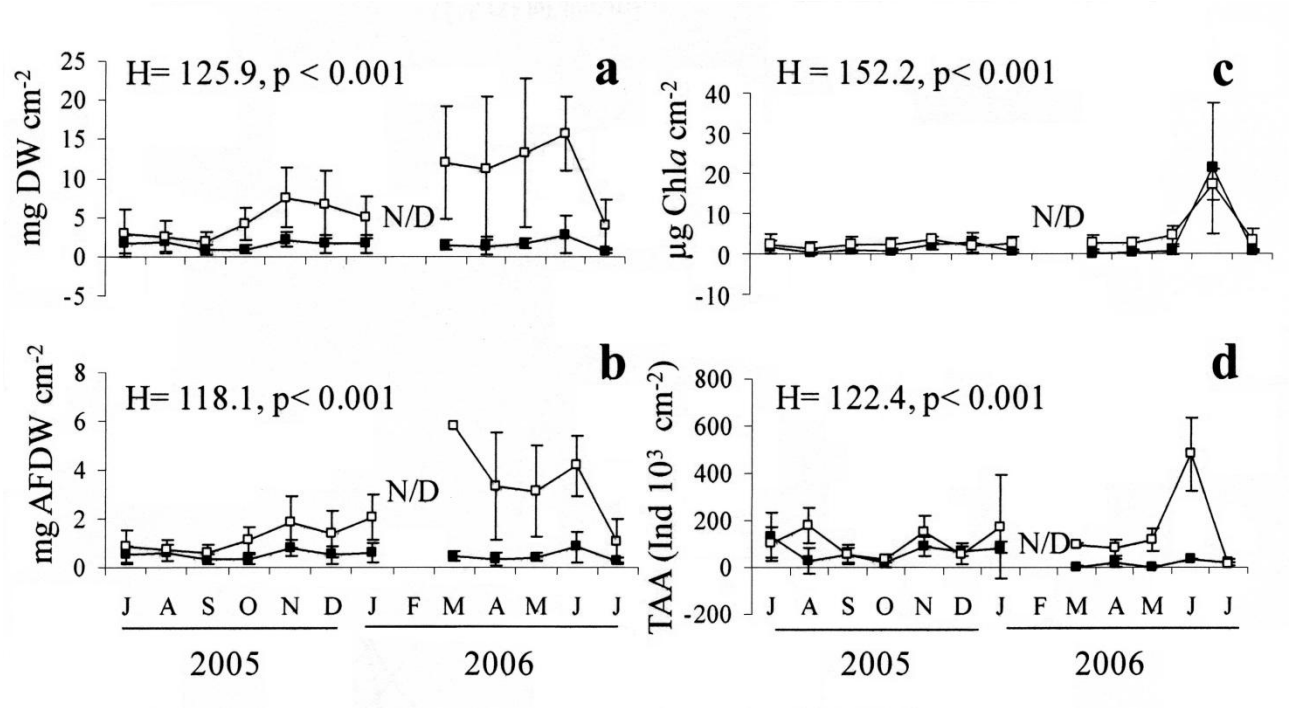

Figure 3. Temporal variations of periphyton biomass and density on *Schoenoplectus californicus* from Station 1 (black symbols) and Station 2 (white symbols). a: Dry weight (DW), b: Ash free dry weight (AFDW), c: Chlorophyll *a* concentration (Chl*a*) and d: Total algal abundance (TAA). N/D: no data.

Figure 5 shows the RDA diagram based on 37 periphytic taxa and two significant environmental variables. Turbidity correlated with the RDA axis 1 (r= -0.83) and grouped samples from Station 1, dominated by erect and prostrate periphyton algae like *Eunotia pectinalis* (Dyllwyn) Rabenhorst var. *pectinalis*, *Rhoicosphenia abbreviata*, *Nitzschia tryblionella* Hantzsch and *N. sigma* (Kützing) W. M. Smith, among others (negative side of the axis 1), and samples from Station 2, characterized by a more diverse periphyton with cyanobacteria, euglenophytes and diatoms like *Cocconeis placentula* Ehrenberg, *Epithemia adnata* and *E. sorex*, among others (positive side of the axis 1).

Concentration of CO_3^{2-} was the environmental variable correlated with RDA axis 2 (r= 0.54) that grouped samples mainly from Station 2, characterized by a periphyton community formed by cyanobacteria like *Anabaena aphanizomenoides*, *Calothrix sp*$_1$. and *Lyngbya* sp.$_1$, euglenophytes like *Trachelomonas oblonga* and diatoms like *Epithemia adnata* and *E. sorex* (positive side of axis 2) and samples mainly from Station 1 with a periphyton dominated by diatoms like *Bacillaria paradoxa* Gmelin, *Eunotia pectinalis* var. *pectinalis* and *Rhoicosphenia abbreviata*, among others (negative side of the axis 2). Table IV shows the Spearman correlation coefficients from the relationship between these periphytic taxa on *Schoenoplectus californicus*, and turbidity and CO_3^{2-} concentration.

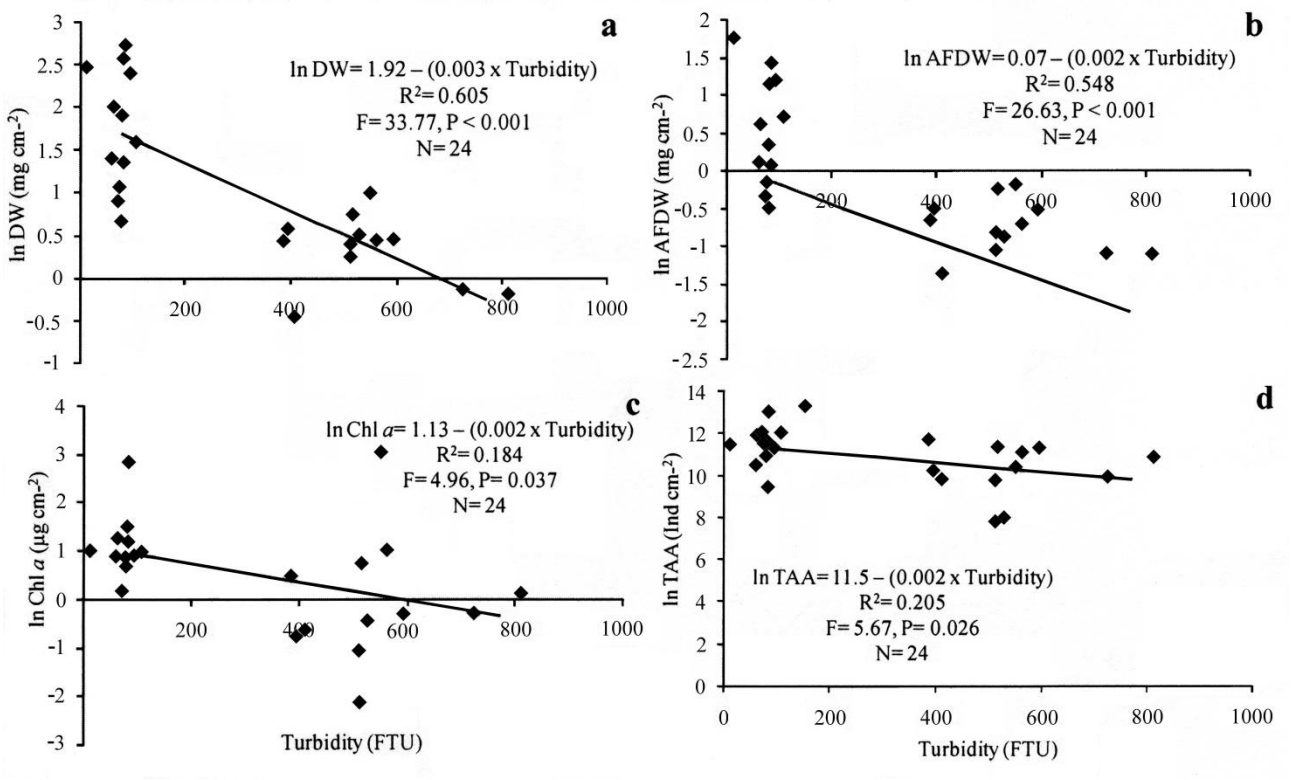

Figure 4. Relationships between periphyton attributes on *Schoenoplectus californicus* and turbidity (in FTU) in Stations 1 and 2. a: ln of dry weight (ln DW), b: ln of ash free dry weight (ln AFDW), c: ln of chlorophyll *a* concentration (ln Chl*a*) and d: ln of total algal abundance (ln TAA). Only the significant regression line and equations are presented.

Table III. Summary of the statistics for the first four RDA axes with the two sampling stations, 12 months, 37 periphyton taxa and two forward - selected environmental variables (turbidity and CO_3^{2-} concentration).

RDA axis	**1**	**2**	**3**	**4**
Eigenvalues	0.193	0.074	0.185	0.112
Species – environment correlations	0.851	0.693	0	0
Cumulative percentage variance				
- of periphyton attributes	19.3	26.7	45.2	56.4
- of periphyton attributes – environment relation	72.3	100	0	0

Discussion

In our study, turbidity and CO_3^{2-} concentration clearly affected the algal species assemblage and the amount of periphyton growing on *Schoenoplectus californicus* from Los Padres Lake. These two environmental variables showed spatial differences in this eutrophic shallow waterbody, not only due to different geomorphological characteristics (Miglioranza *et al*. 2004) but because of differences in pH values (Escalante, unp. data), and in land uses in their catchment (Osterrieth *et al.* 2000).

All the periphyton descriptors used here (DW, AFDW, Chl*a* and TAA) had significantly lower values on *S. californicus* from Station 1. The negative relationship between these descriptors and turbidity may be attributable either to (1) the abrasive effect of the solid particles suspended in the water column that destabilize the substrate and prevent the periphyton to settle (Pizarro & Vinocur 2000) or to (2) the limited light penetration in the water column that might determine a low periphyton biomass dominated by heterotrophic components (Sánchez *et al.* 2010). We think that a combination

of these two effects could have taken place at Station 1. In here, soil composition has a greater proportion of mud and clay (Miglioranza *et al.* 2004) and its location near from the inflow area of Los Padres Stream, promoted the resuspension of lake sediments and limited light penetration in the water column. Hill (1996) pointed out that turbidity, originated by resuspension of silt and other inorganic particles, substantially reduces light penetration and severely restricts periphyton algal development in a variety of aquatic environments.

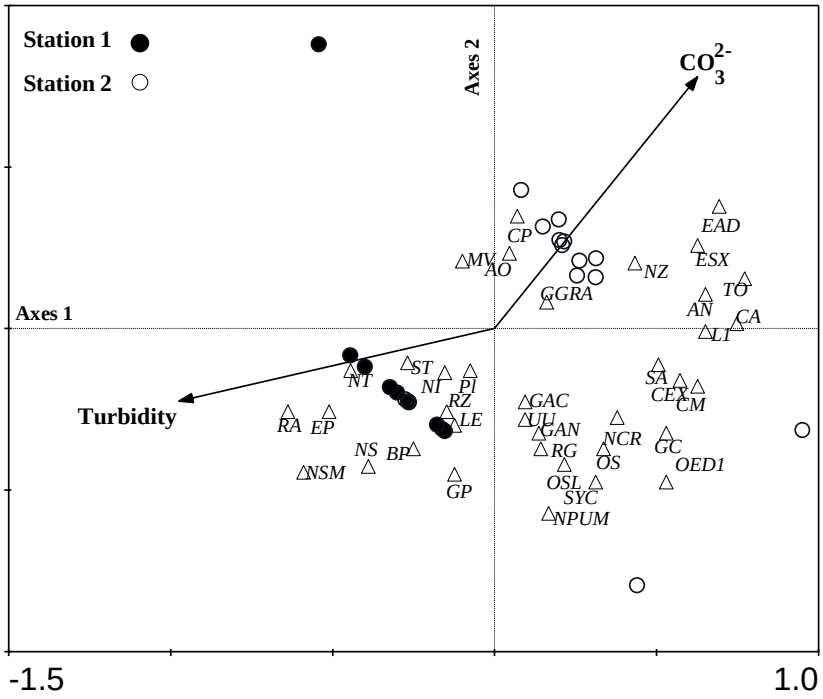

Figure 5. Representation of the first and second RDA axes for the periphyton community on *Schoenoplectus californicus* and environmental variables from Stations 1 and 2. For taxa abbreviations see Table II.

In spite of the significant differences registered in periphyton biomass in Los Padres Lake, stems from both sampling stations showed a similar dynamics, in agreement with the results obtained by Gómez *et al*. (2003) for the same macrophyte from the Río de la Plata estuary. Maxima values of DW, AFDW, Chl*a* and TAA were registered during autumn and spring, synchronically with senescence and growth stage of *Schoenoplectus californicus* (Tur & Rossi 1976), showing strong interactions between macrophyte life cycle and their epiphytes (Burks *et al.* 2006). Thus, during autumn most of stems of *S. californicus* presented senescence signs, releasing from their tissues organic compounds that enhanced periphyton development (Burkholder 1996). While, in late spring and summer aquatic vegetation increased its aerial biomass, generating new substrate for periphyton colonization (Rodusky 2010).

Regardless the location but comparing DW, AFDW and Chl*a* values, our results suggest that periphyton growing on *S. californicus* has a high proportion of detritus and heterotrophic organisms and a minor fraction of autotrophic ones. This fact agrees with the results obtained by Guariento *et al.* (2011), who working in a tropical black water lake in Brazil, found a periphytic biofilm dominated by heterotrophic organisms (mainly bacteria and small protozoans) in heavy light attenuation conditions. In Los Padres Lake, Secchi disk readings at both sampling stations indicated that only about the 25 % of water column was illuminated. Under this scenario the non-autotrophic organisms dominated periphyton community, and restricted the presence of autotrophic ones to the subsurface portions of the stems (Esquius *et al.* 2010).

Table IV. Algal physiognomies and Spearman correlation coefficients of the relationships between the more frequent periphytic taxa (observed in more than 5 % of samples or with relative abundances greater than 1 %) on *Schoenoplectus californicus*, and turbidity and CO_3^{2-} concentration. Correlation coefficient is not shown when the relationship was not significant (NS). * $p < 0.05$; ** $p < 0.001$; *** $p < 0.0001$. FC: filamentous and chain-forming taxa, Pl: planktonics, Ad: adnates, Er: erects and P: prostrates.

		Environmental variables	
Physiognomy	**Taxa**	**CO_3^{2-}**	**Turbidity**
FC	*Anabaena aphanizomenoides*	0.56**	-0.68***
FC	*Calothrix sp*$_1$.	0.59**	-0.87***
FC	*Leibleinia epiphytica*	NS	NS
FC	*Lyngbya* sp.$_1$	0.58**	-0.59**
FC	*Oscillatoria limosa*	NS	NS
FC	*Oscillatoria* sp.$_1$	NS	NS
FC	*Oedogonium* sp.$_1$	NS	-0.49*
FC	*Planktonema lauterbornii*	NS	NS
FC	*Rhizoclonium sp.*	NS	NS
FC	*Stigeoclonium sp.*	NS	NS
Pl	*Trachelomonas oblonga*	0.55**	-0.7***
Ad	*Amphora ovalis*	NS	NS
FC	*Bacillaria paradoxa*	-0.53**	NS
Ad	*Cocconeis placentula*	NS	NS
Pl	*Cyclotella meneghiniana*	NS	NS
Er	*Cymbella excisa*	NS	NS
Er	*Epithemia adnata*	0.65***	-0.85***
Er	*E. sorex*	0.6**	-0.81***
FC	*Eunotia pectinalis* var. *pectinalis*	-0.78***	0.81***
Er	*Gomphonema acuminatum*	NS	NS
Er	*G. angustatum*	NS	NS
Er	*G. constrictum*	NS	NS
Er	*G. gracile*	NS	NS
Er	*G. parvulum*	NS	NS
FC	*Melosira varians*	NS	NS
P	*Navicula cryptocephala*	NS	NS
P	*N. zanoni*	NS	-0.47*
P	*Nitzschia inconspicua*	NS	NS
P	*N. sigma*	-0.61**	0.41*
P	*N. sigmoidea*	-0.7***	0.58**
P	*N. tryblionella*	-0.69***	0.68***
P	*N. pumila*	NS	NS
Er	*Rhoicosphenia abbreviata*	-0.61**	0.73***
P	*Rhopalodia gibba*	NS	NS
Er	*Synedra acus*	NS	NS
Er	*S. capitata*	NS	NS
Er	*Ulnaria ulna*	NS	NS

In the periphyton communities from Los Padres Lake, diatoms constituted the dominant group according to its species' richness and abundance. This matches up with the results previously published (Claps 1984, 1987, Tesolín & Tell 1996, Gómez *et al*. 2003, Esquius *et al*. 2008) for periphyton attached to different macrophytes in lentic and lotic environments of Argentina. Besides, cyanobacteria, chlorophytes (mainly filamentous ones), and euglenophytes were more abundant in bulrushes from Station 2, probably because of the higher water stability observed. As pointed out before, Station 2 was delimited near the dam of La Tapera Stream which enhances algal accumulation into the periphyton matrix, particularly planktonic, chain-forming and filamentous ones (Esquius 2009, Esquius *et al*. 2010).

Turbidity constitutes an important variable that affected periphyton species assemblage in this eutrophic shallow lake. In our study we found that in Station 1, this community was dominated by erect and prostrate diatoms. On the contrary, that one developed in stems from Station 2 showed a more diverse specific composition and physiognomy. We associated density increments in some taxa (e.g., *Eunotia pectinalis* var. *pectinalis*, *Rhoicosphenia abbreviata* and *Nitzschia tryblionella*) to higher turbidity scores, being this variable correlated negatively with main erect, filamentous and chain-forming taxa (like *Calothrix sp*$_1$., *Oedogonium* sp.$_1$ and *Epithemia adnata*, among others). The prevalence of a community with the dominance of erect and prostrate algae, as observed in Station 1, contributed to form a more cohesive periphyton and thereby increasing its resistance to turbidity effects (Peterson 1996).

Multivariate analyses revealed that also CO_3^{2-} concentration is an important environmental factor influencing the composition of periphyton species upon *Schoenoplectus californicus* in this Pampean shallow lake. As regards CO_3^{2-} hardness, it has been reported as an important structuring parameter for periphyton (Goldsborough & Robinson 1996), and particularly for diatoms (Gevrey *et al*. 2004). In this study, density of cyanobacteria and diatoms were significantly linked with CO_3^{2-} concentrations, being these associations always positive for the first taxonomic group. This ion appears to be important in the development of cyanobacterial blooms, and in the growth and sporulation of some species (Ferrari *et al*. 2002, Czerny *et al*. 2009).

The present study provides a first approach to the knowledge and understanding of periphyton dynamics on *Schoenoplectus californicus* from Los Padres Lake Basin and its relationships with some environmental variables. Differences in turbidity values and CO_3^{2-} concentration have a direct impact on periphyton structure (mainly on biomass and algal species composition) in this eutrophic shallow lake.

Acknowledgements

We would like to thank to A. Licciardo, P. V. Weigand, M. L. Josens, A. Cannepuccia and G. Bernava. We also thank to the staff of Physiology, Ecology and Microbiology laboratories from FCEyN, UNMdP for providing us their facilities. This work is part of PhD. Thesis of the first author and was supported by a scholarship from CONICET (Argentina), a grant PIP´00-Nº2875 from CONICET and a grant EXA 340/06 from Universidad Nacional de Mar del Plata to AHE.

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Received August 2011
Accepted April 2012
Published online June 2012