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Epiphytic algae on the bulrush (*Scirpus californicus* (Mey) Steud) in the Río de la Plata (Argentina): structure and architecture

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Abstract: The objective of this study is to determine which are the characteristic algal communities coating the stems of *Scirpus californicus* (Mey) Steud in the Río de la Plata. Taxonomic composition, disposition of the algae in the biofilm, spatial pattems of abundance and species diversity and life-form strategies were analysed. Samples of periphyton were taken in winter and spring 1999 and summer and autumn 2000, at five sampling sites. Physical-chemical characteristics were measured in summer and autumn 2000. Ten stems of the bulrush were cut randomly and the bottom 15 cm kept and put into a flask with distilled water. The biofilm was removed by brushing, integrating the material collected in each sampling site. The algae that comprised the biofilm analysed showed a simple architecture consisting of a layer dominated mainly by biraphid diatoms, with planktonic diatoms and/or filamentous chlorophytes entrapped in the surface film. The matrix analysed in this study corresponds to early stages of succession characterized by R-selected taxa, considered to be pioneer species and good colonizers in a disturbed system. During spring, winter and autumn, diatoms were dominant, but with different species compositions, while in summer green algae were abundant. The epiphyton of the bulrushes studied was characterized by a low proportion of epiphytic specimens sensu strictu (adnate, stalked and erect forms) exhibiting a high proportion of immigrants from the benthos and plankton.

Introduction

Periphyton of large rivers is much less well known than their phytoplankton, which may be because the phytoplankton is more important in terms of primary production (Vannote et al. 1980). Furthermore, the methodology for investigation of phytoplankton is much simpler (Ács & Kis 1991).

The architecture of the periphyton is complicated, and depends on many factors, including: type of substrate, light conditions, grazing, nutrient supply, current

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velocity in rivers, and/or strength of water movement caused by the wind (Ács et al. 2000). Knowledge of the structure and architecture of the periphyton community is the foundation for interpretation of its functional characteristics (Wetzel 1983).

The Río de la Plata is an ecosystem with fluvio-marine characteristics, being the last section of the Platense watershed, the second most important in South America after the Amazon basin. *Scirpus californicus* (Mey) Steud, Cyperaceae, is a perennial, littoral helophyte, with rhizomes. This macrophyte is widely distributed in Argentina where it grows in swamps and in the littoral zone of ponds and rivers. The stem growth is determined by the age of the bulrush and the season (slower in winter than in summer). The stem length is variable (2.75-1.36 m) and depends on water levels. Its density has been recorded as 136-175 stems M-2 on the Argentinean shore of the Río de la Plata (Tur & Rossi 1976). The studies of periphyton in the Río de la Plata are scarce: Claps (1981, 1984, 1987), Gómez et al. (2002).

In this paper we aim to determine which are the characteristic algal communities coating the stems of Scirpus californicus. We pose the following questions:

- What is the taxonomic composition and spatial disposition of the algae in the biofilm?
- What are the seasonal and spatial pattems of abundance and species diversity?
- What are the life-form strategies, trophic and saprobic preferences of this algal community?

Study area

The Río de la Plata is located on the East coast of South America, between 34° and 36°10' S and 55° and 58^0 10' W. It is 270 km long and its width varies from 32 to 230 km (Urien 1972) (Fig. la). Discharge is in the order of 22,000 m^3 sec^{-1}. The tidal regime in the Río de la Plata is mixed, predominantly semidiurnal (two high and two low tides, per day). Tidal amplitude varies across the river, being higher along the Argentinean side. Water levels and tidal currents can be strongly mod-ified by meteorological events (Guerrero et al. 1997).

The study area is located between 34°55'-35°03' S and 57°43'-57°27' W (Fig. 1b); in this zone freshwater conditions predominate and the tide is the only oceanic influence (Urien 1972). Five sampling sites were established along 30 km of shoreline (Fig. 1b). Site II is 3 km downstream from site I; between sites II and III there are 14.6 km; sites III, IV and V are 6.2 km apart, the latter being furthest downstream. Sampling sites show different exposition to breaking waves: in site I and Il the exposition is moderate, site III is located in a sheltered area where the exposition is low and, finally, in sites IV and V the bulrushes are exposed to higher influence of winds and tide (Table 1, Fig. 2).

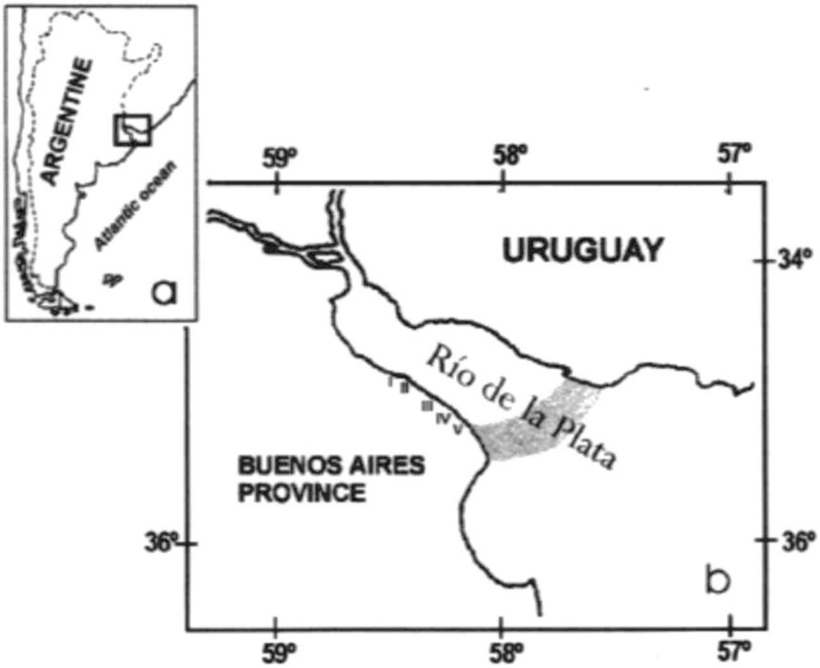

Fig. 1. Location of the Río de la Plata (a) and sampling stations (b). Shading area corresponds to the beginning of the estuary zone (salinity > 0.5‰).

Table 1. Geographical location, physical-chemical characteristics and exposition degree in the sampling sites of the Río de la Plata measured during summer and autumn 2000.

Sampling sites	I	II	III	IV	V
Latitude S	34°55’44"	34°56’31"	35°01’39"	35°03’53"	35°01’20"
Longitude W	57°43’2"	57°40’2"	57°30’22"	57°27’24"	57°31’51"
Conductivity (μS $cm^{-}1$)	860-260	796-304	998-528	944-612	1568-750
pH	6.6-7.1	6.92-7.3	6.94-7.1	6.88-7.3	6.92-7.8
Temperature (°C)	24.2-7.4	24.5-7.5	25.4-7.6	24-7.5	24-7.2
Turbidity (NTU)	55-88	47-92	40-80	62-110	71-150
PO_4^{-3}(mg l^{-1})	0.132-0.31	0.11-0.30	0.125-0.25	0.65-0.22	03-0.18
NO_3 (mg l^{-1})	2.23-7.19	2.9-9.5	3.64-11.34	2.36-1.42	3.3-3.22
NO_2^- (mg l^{-1})	<0.001-0.06	<0.001-0.003	0.003-0.01	<0.001-0.017	0.002-0.007
NH_4^+ (mg 1^{-1})	0.073-9.04	0.097-7.05	0.097-6.18	0.097-0.59	0.005-1.18
Exposition degree to breaking waves	moderate	moderate	low	high	high

Fig. 2. Photograph of sampling sites showing the different exposition degree to breaking waves: moderate in site 1 (a) and II (b), low in site III (c) and high in site IV (d) and V (e).

Material and methods

Samples of periphyton were taken in winter and spring 1999 (July and October) and summer and autumn 2000 (February and May). Ten stems of the bulrush *Scyrpus califomicus* (stem diameter 0.8-1.1 cm) were cut randomly and the bottom 15 cm kept and put into a flask with distilled water. The biofilm was removed by brushing, integrating the material collected in each sampling site, and preserved in formalin (final concentration 4 %).

Cell density was estimated using a Sedwick-Rafter chamber and expressed per cm^2 (APHA 1998).

Subsamples used for diatom identifications were cleaned with H_2O_2, washed thoroughly using distilled water and then mounted on microscope slides with Naphrax. These slides and qualitative sample material of other groups of algae, which were difficult to identify, were examined at 1500 x using a phase contrast microscope with Nomarsky DIC optics.

The surfaces of the bulrush stems were examined with a scanning electron microscope (Jeol T-100 Model), by critical point drying (Boltovskoy 1995), to study the architecture of the biofilm.

The following keys were used for species identification: Hustedt (l930), Frenguelli (1941), Patrick & Reimer (1966, 1975), Krammer & Lange-Bertalot (1986, 1988, 1991a and b) and Bourelly (1972).

The biovolume was calculated according to Hillebrana et al. (1999) and species diversity according to Shannon (1948). For each sampling site the trophic and saprobic preferences of diatom species were established, using the relative abundance average, according to: Sládecek (1973), Lange-Bertalot (1979), Lowe (1974), Gómez (1998), Gómez & Licursi (2001) and Licursi & Gómez (2002).

During summer and autumn 2000 temperature and pH (Hanna HI 8633), conductivity (Lutron CD-4303) and turbidity (Turbidity meter 800-ESD) were measured in situ with portable meters. Water samples were also collected in order to analyse NH_4^+-N, $N0_3^-$-N, NO_2^-N, P04 ^{3}-P (Mackereth et al. 1978).

Species constancy and dominance were calculated according to Ács & Kiss (l991). Correspondence analysis was performed, with cellular density of each taxa, to explore the trends in the epiphytic algae in relation to seasonal changes (Jongman et al. 1995). A cluster analysis was performed with the average of cellular density values to explore differences among sampling sites; Pearson's correlation index and UPGMA linkage procedure were applied. Logarithmic transformation ($X = \log(x+1)$) was applied to the data sets.

Results

Physical-chemical characteristics

The main physical-chemical features of the river are shown in Table 1. The conductivity and turbidity increased downstream. The pH values were close to neutral; the temperature was variable, due not only to seasonal changes but also to inherent ecosystem characteristics such as tide and winds. Nutrient concentrations fluctu-ated along the study area, depending on the mineralization of organic matter that arrives from the riparian ecosystem and the input from upstream. Site III shows the lowest exposition degree to breaking waves, while sites IV and V are more exposed to breaking waves and tide.

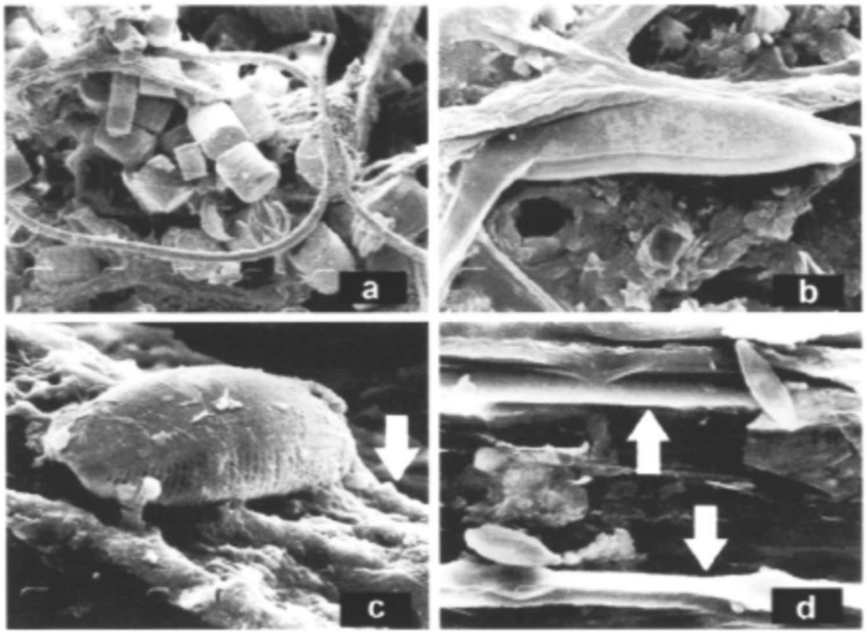

Fig. 3. Scanning electron micrographs of *Scyrpus californicus: (a)* chains of *Pleurosira laevis* slightly entrapped on the biofilm matrix; (b) biraphid diatom *(Hantzschia sp.)* included in the matrix; (c) an adnate component of the biofilm *(Eunotia sp.)* attached on a nervation of the bulrush; (d) nervations of the bulrush chosen by some taxa as their attach-ment substrates.

Taxonomic composition and physiognomy

The submerged portion of the stem that is suitable for colonization showed rapid renewal due to the dynamic growth rate (0.5-2 cm/day) of the bulrush (Hualde et al. in press). The observations in the electron microscope revealed that algae, bacteria, mucilage, organic and inorganic particles were arranged in a simple layer. Frequently chains of diatoms and filaments of chlorophytes remained slightly entrapped on the surface (Fig. 3a and 3b). Irregularities which occur on the stem surface of *Scyrpus californicus (e.* g. nervations and foliar remainders) were chosen by some taxa as their attachment substrates (Fig. 3c and 3d).

The biofilm was dominated by prostrate forms, particularly biraphid diatoms, and filaments, of Chlorophyta or chains of diatoms, principally planktonic taxa.

Table 2. List of taxa, acronym in brackets; physiognomic group (PG): S = stalked, P = postrate, E = erect, A = adnate, F = filamentous, Ch = chains , PU = planktonic unicellular; constancy (C) and dominancy (D): * = < 10%; ** = 10-25%; *** = 25-50%; **** = > 50 % in winter (W), spring (S), summer (Su) and autumn (A).

PG	Taxa			D		C
	Bacillariophyceae	W	S	Su	A	
A	(ADEL) *Achnanthes delicatula,* Simonsen	*				5
A	(ADHA) *Achnanthes delicatula var. hauckiana* Lange-Bertalot	*				5
A	(AHUN) *Achnanthes hungarica* (Grunow) Grunow	*		*		15
A	(ALAN) *Achnanthes lanceolata* (Brébisson) Grunow	*				*5*
A	(AMIN) *Achnanthes minutissima* Kützing				*	10
PU	(ANMN) *Actinocyclus normanii*(Greg. Ex-Greville) Hustedt	*	*	**	**	60
A	*(AOVA) Amphora ovalis* (Kützing) Kützing	*		*		15
A	(AVEN) *Amphora veneta* Kützing				*	10
Ch	(AUGR) *Aulacoseira granulata* (Ehrenberg) Simon		*			*5*
Ch	(AMUZ) *Aulacoseira muzanensis* (Meister) Kram		*			*5*
P	(BPAR) *Bacillaria paradoxa* Gmelin		*			*5*
P	(CBAC) *Caloneis bacillum* (Grunow) Cleve				*	*5*
PU	(CMEN) *Cyclotella meneghiniana* Kützing			*	*	10
P	(CAFF) *Cymbella affinis* Kützing			*		5
P	(CSLE) *Cymbella silesiaca* Bleisch	*	*		*	40
Ch	(DCOF) *Diadesmis confervacea* (Kützing) Grunow			*		5
E	(DHME) *Diatoma hyemalis* (Roth) Heiberg				*	5
P	(DELL) *Diploneis elliptica* (Kützing) Cleve				*	5
P	(DSBO) *Diploneis subovalis* Cleve			*		5
A	(EMON) *Eunotia monodon* Ehrenberg	*			*	10
A	(EUN) *Eunotia sp.*	*				5
E	(FULN) *Fragilaria ulna* (Nitszch) Lange-Bertalot				*	15
S	(GCLA) *Gomphonema clavatum* (Ehrenberg)				*	5
S	(GGLI) *Gomphonema grovei* M. Schmidt var. *lingulatum* (Hustedt) Lange-Bertalot		*	*		25
S	(GPAR) *Gomphonema parvulum* Kützing	*	*	*	*	45
P	(GSPE) *Gyrosigma spencerii* (W. Schmidt) Cleve				*	5
P	(HAMP) *Hantzschia amphioxys* (Ehrenberg) Grunow	*				15
F	(MVAR) *Melosira varians* Agardh	*			*	5
P	(NACO) *Navicula accomoda* Hustedt				*	10
P	(NCAP) *Navicula capitata* Ehrenberg	*		*	*	30
P	(NCPR) *Navicula capitatoradiata* Germain	*	*		*	20
P	(NCRY) *Navicula cryptocephala* Kützing			*	*	25
P	(NERI) *Navicula erifuga* Lange-Bertalot		***	*	*	55
P	(NGOE) *Navicula goeppertiana* (Bleisch) H. L. Smith	*				25
P	(NHAL) *Navicula halophila* (Grunow) Cleve	**	*	*	*	35
P	(NLST) *Navicula leptostriata* Jorgensen		*			10

Table 2 (continued).

PG	Taxa	D				C
		W	S	Su	A	
P	(NNOT) *Navicula notha* Wallace			*		5
P	(NPYG) *Navicula pygmaea* Kützing			*		5
P	(NSBA) *Navicula subadnata* Hüstedt			*		5
P	(NSRH) *Navicula subrhynchocephala* Hüstedt				*	10
P	(NTPT) *Navicula tripunctata (O. F. M.)* Bory				*	5
P	(NAMP) *Nitzschia amphibia* Grunow			*	*	10
P	(NIAN) *Nitzschia angustata* Grunow	*			*	15
P	(NBRE) *Nitzschia brevíssima* Grunow	*				15
P	(NCLA) *Nitzschia clausii* Hantzsch	*	*	*	*	40
P	(NDEB) *Nitzschia debilis* (Arnott) Grunow				*	5
P	(NFIL) *Nitzschia filiformis* (W. M.Smith) Van Heurck		*		*	10
P	(NIGR) *Nitzschia gracilis* Hantzsch				*	5
P	(NLEV) *Nitzschia levidensis (*W. Smith) Grunow			*		10
P	(NNAN) *Nitzschia nana* Grunow	*			**	15
P	(NPAL) *Nitzschia palea* (Kützing) W. Smith	*	*	*	*	60
P	(NPAE) *Nitzschia paleacea* Grunow	*	*		*	15
P	(NSIG) *Nitzschia sigma* (Kützing) W. M.Smith		*			5
P	(PGIB) *Pinnularia gibba* Ehrenberg				*	5
Ch	(PLEV) *Pleurosira laevis* (Ehrenberg) Compere	****	***	**	*	70
P	*(SPUP) Sellaphora pupula* Kützing	*				5
PU	(TRUD) *Thalassiorisa rudolfii* Bachmann			*		10
	Euglenophyceae					
PU	(EUGL) *Euglena sp.*		*		*	10
PU	(PHAC) *Phacus sp.*				*	5
	Chlorophyceae					
F	(ULOT) *Ulotrix sp.*	*	*	*		25
F	(OEDO) *Oedogonium sp.*		*	*		15
F	(COLE) *Coleochaete sp.*			**	**	10

The highest diversity of other physiognomic groups was observed during autumn (Fig. 4).

Trophic and saprobic preferences of diatom species

The analysis of trophic preferences of diatoms found in biofilms showed that in site 111 and IV eutrophic and mesotrophic species reached 75 %, respectively. On the other hand sites 1, II and V exhibited abundance of 30-45 % of mesotrophic and 50% of eutrophic species (Fig. 5a).

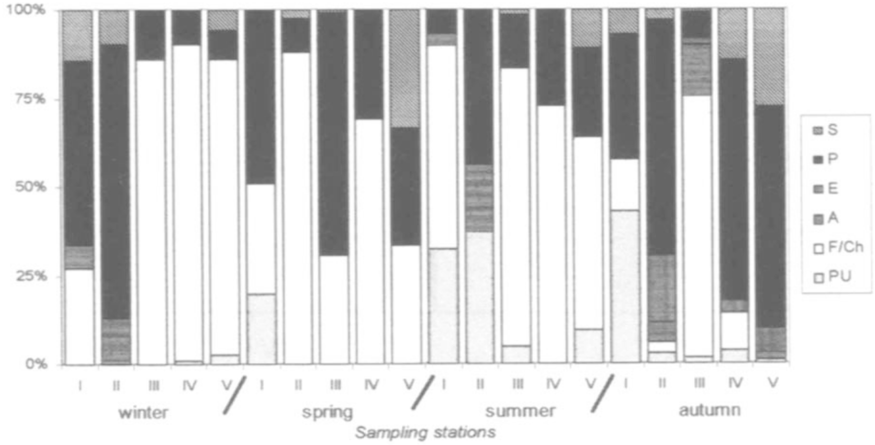

Fig. 4. Physiognomic groups found in stems of the bulrushes analysed: S = stalked, P = postrate, E = erect, A = adnate, F/Ch = filaments of chlorophytes or chains of diatoms, PU = planktonic unicellular. Oligosaprobic species were observed in all sampling station but with less than 6 % of abundance. In site V ß-mesosaprobic species reached 75 %, whilst in the rest a-mesosaprobic and ß-mesosaprobic species reached values higher than 40 % and 35 %, respectively (Fig. 5b).

Seasonal and spatial patterns

During winter, spring and autumn diatoms were the predominant group. The filamentous chlorophytes were dominant in summer (sites I and III) and autumn (site III). *Pleurosira laevis* reached abundance > 50 % in 25 % of the total samples analysed and *Coleochaete sp., Navicula erifuga, Actinocyclus normanii* and *Navicula halophila* were subdominant taxa (Table 2).

The maximum cell density and biomass occurred in spring, at site III (18,700 cells cm^{-2}; 49, 265 10^{4} µm^{3} cm^{-2}). Minimum densities (< 2.5 cell cm^{-2}) and biomass (<17 10^{4} µm^{3} cm^{-2}) were observed at site V during winter, spring and summer (Fig. 6). Cluster analysis revealed the differences of epiphyton development among sampling sites (Fig. 7). Three groups can be distinguished which are associations responding to increased stress factors (breaking waves, tides, winds). The first group, formed by samples from site III, is located in a sheltered place with low exposition. The second group, formed from sites II and I, exhibited moderate exposition, while the third group, which includes sites V and IV, is close to the beginning of the estuary zone being the exposition higher.

The correspondence analysis (Fig. 8) showed the species' seasonal preferences: during autumn *Gyrosigma spenceri, Diploneis elliptica, Navicula subrhynchoce-*

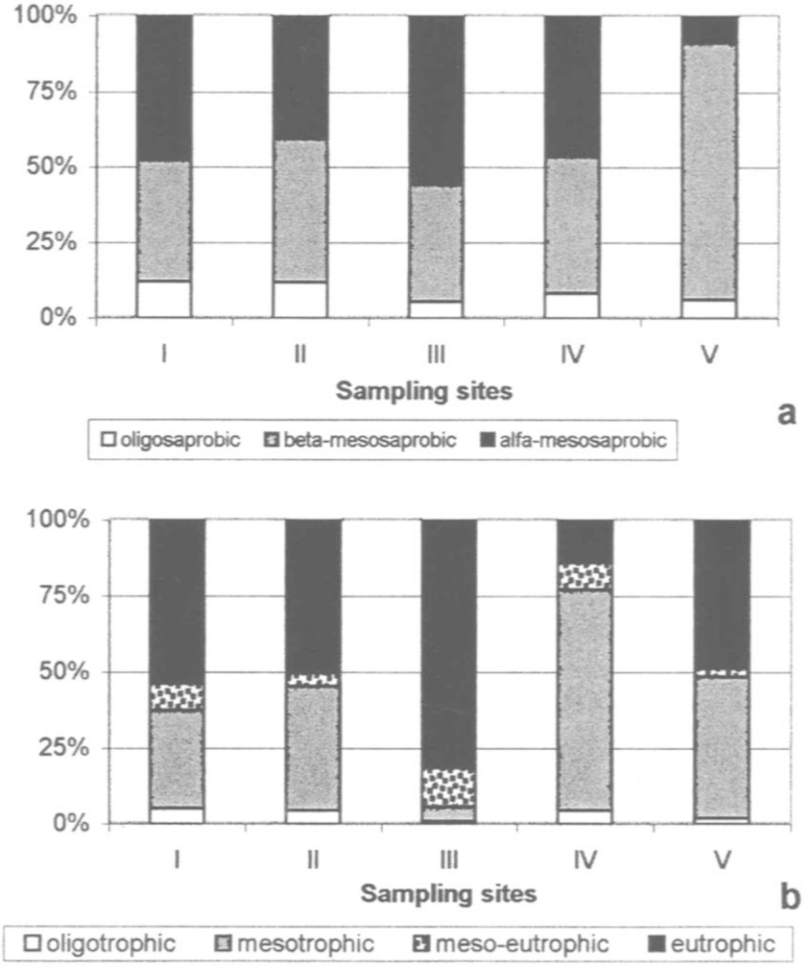

Fig. 5. Trophic (a) and saprobic (b) preferences of diatoms found in the biofilms analysed. The meso-eutrophic category was created for species with mesotrophic and eutrophic status.

phala, Nitzschia angustata, Nitzschia amphibia, Fragilaria ulna, Pinnularia gibba, Nitzschia nana, Navicula tripunctata, Navicula accomoda, Nitzschia debilis, Aulacoseira granulata, Amphora veneta, Achnanthes minutissima, and *Phacus sp.* were frequent in the biofilms. *Pleurosira laevis, Navicula leptostriata, Navicula erifuga, Hantzschia amphioxys, Bacillaria paradoxa, Achnanthes lanceolata, Navicula goeppertiana, Sellaphora pupula, Achnanthes delicatula, A. delicatula* var. *hauckiana, Nitzschia sigma,* and *Aulacoseira muzzanensis* were common in winter and/or spring. Meanwhile, *Ulothrix sp., Oedogonium sp., Coleochaete sp., Cymbella affinis, Navicula notha, Diadesmis confervacea, Diploneis subovalis,*

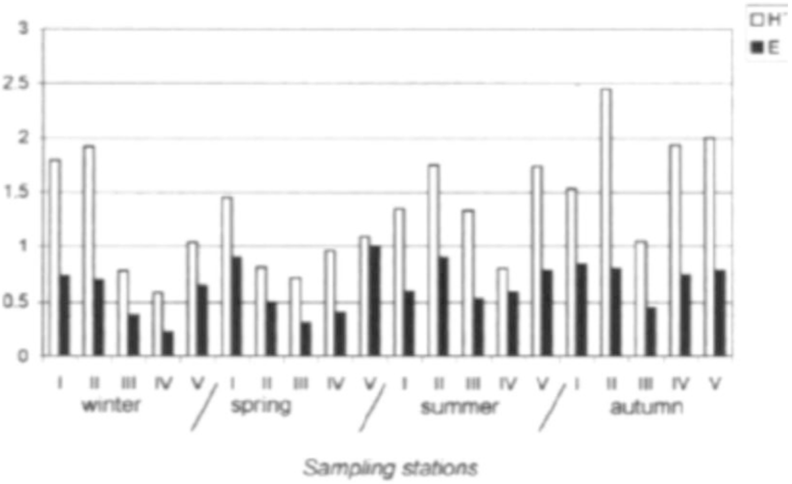

Fig. 6. Cellular density and biomass (expressed as biovolume) of epiphytic algae.

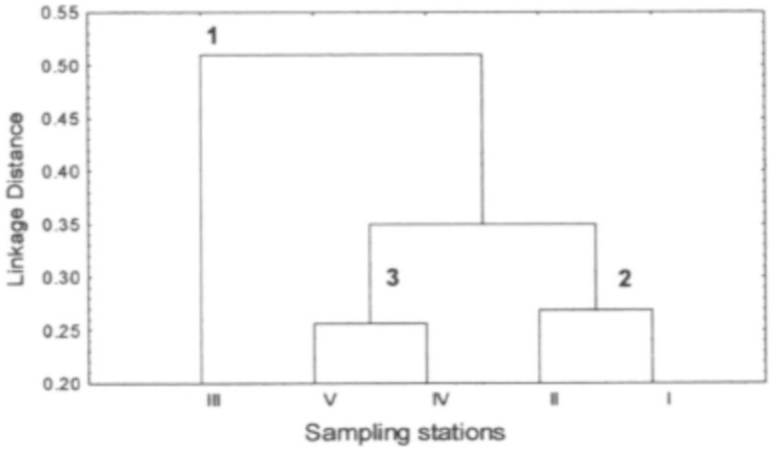

Fig. 7. Cluster analysis showing the spatial heterogeneity in the study area.

Nitzschia levidens, Navicula subadnata and *Navicula pygmaea* were frequent in summer.

Species diversity varied according to season and sampling site. The highest value was observed at site II during autumn (2.45 bits indiv $^{-1}$), and the lowest at site IV during winter (0.58 bits indiv $^{-1}$) (Fig. 9). The lowest eveness values (<0.5) were observed at site IV during winter, when *Pleurosira laevis* was dominant, and at site III during winter, spring and autumn, when *Pleurosira laevis, Navicula erifuga* and *Coleochaete* sp., respectively, were abundant.

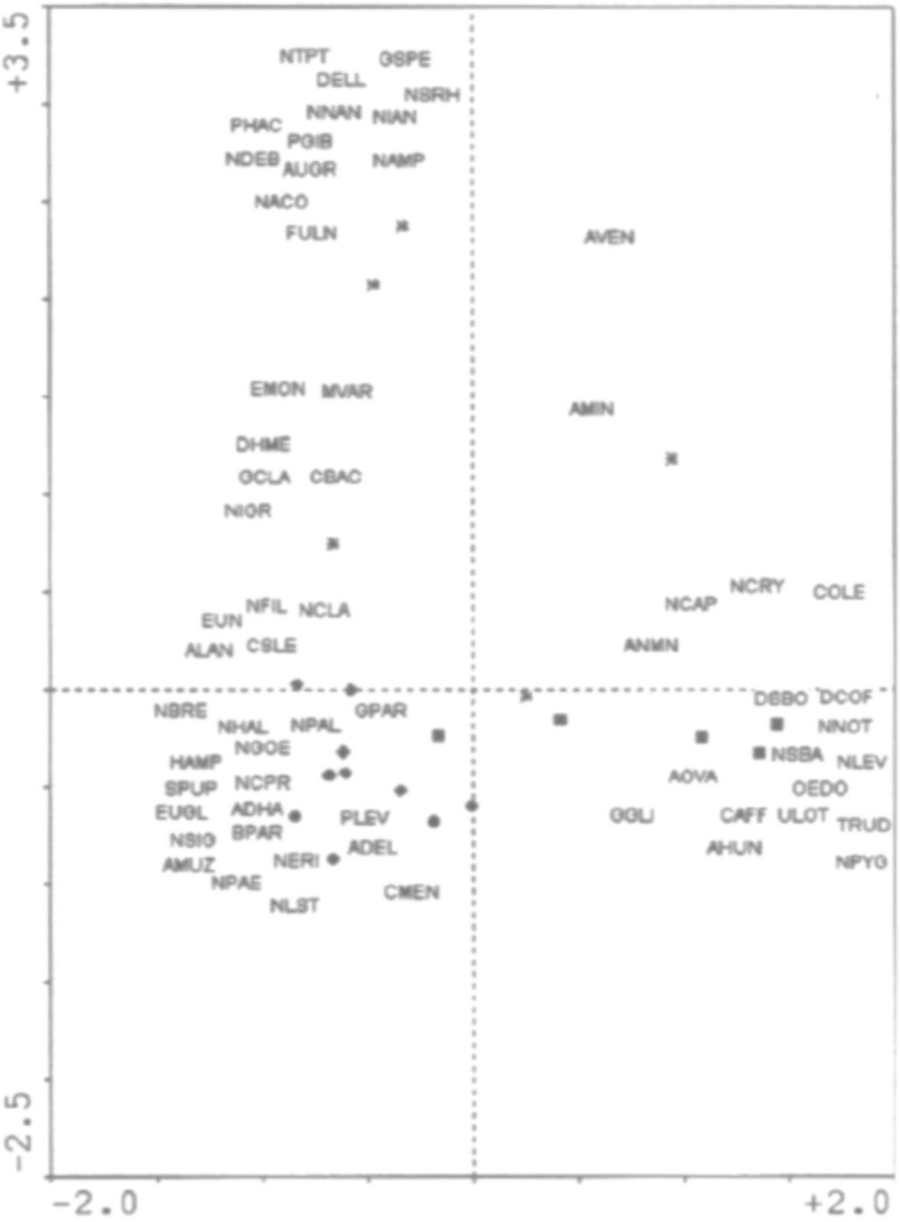

Fig. 8. Correspondence analysis (CA) showing epiphytic algae distribution in relation to winter (diamond), spring (circle), summer (square) and autumn (asterisk). Acronyms are shown in Table 2.

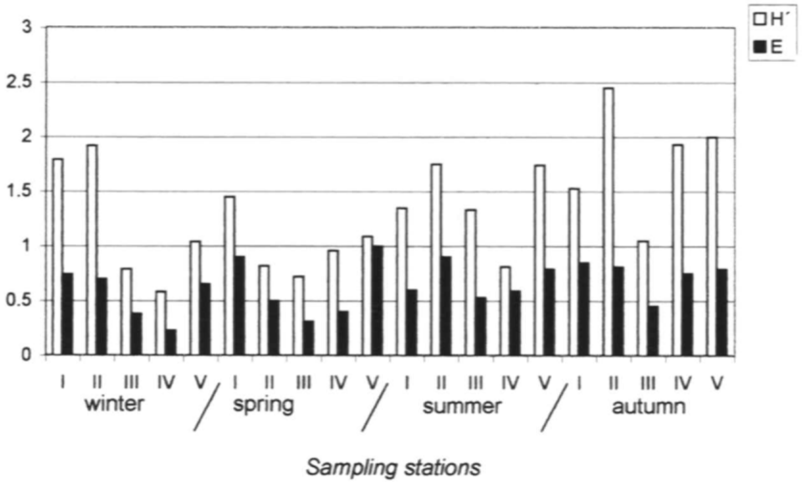

Fig. 9. Diversity (H´: bits. indiv. $^{-1}$) and eveness (E).

Discussion

The observation in the electron microscope revealed that the algae of the biofilm analysed showed a simple architecture consisting of a layer dominated mainly by biraphid diatoms, with phytoplanktonic diatoms and/or filamentous chlorophytes entrapped in the surface film. We did not observe the three-dimensional scheme described by MEULEMANS (1989) in investigations of the periphytic community on reeds in Lake Maarsseveen, nor the architecture described by ÁCS et al. (2000) in studies with artificial substrates in the River Danube after 3 weeks of colonization. The later study also showed that *Skeletonema potamos*, a phytoplanktonic *Pleurosira laevis* and *Actinocyclus normanii* were abundant in plankton samples and also in those of the periphyton (GÓMEZ et al. 2002). The matrix analysed in this study would correspond to early stages of succession, characterized by R-selected taxa, considered to be pioneer species and good colonizers in a disturbed system (BIGGS et al. 1998).

The biraphid motile diatoms found in the biofilms were similar to those observed in benthos samples from the Río de la Plata (unpubl. data) and in epipelon samples of rivers close to the study area reported by GÓMEZ & LICURSI (2001) and LICURSI & GÓMEZ (2002). This similarity could be explained in two ways: (i) the ability of epipelic species to colonize macrophytes (ROUND 1981); (ii) the resuspension of benthic diatoms into the water column, by breaking waves, that then become attached to the bulrush surface. The epiphyton of the bulrushes studied was characterized by a low proportion of epiphytic specimens sensu strictu such as those described by Round (1981) and Patrick (1977), exhibiting a high proportion of immigrants from the benthos and plankton. The epiphytic flora found is representative of water containing few minerals (Lowe 1974) which confirms the freshwater nature of the Río de La Plata in the area studied. A few marine and brackish water specimens were observed at sites IV and V (e. g. *Caloneis bacillum, Cymbella affinis, Gomphonema parvulum, Navicula accomoda, Nitzschia filiformis, Hantzschia amphioxys).* The diatoms found in the epiphyton are characteristics from mesotrophic-eutrophic status and mesosaprobic conditions.

The spatial heterogeneity observed in our study would be determined chiefly by the degree of exposition to breaking waves along the shore and by estuarine influences. The sampling site III showed the highest density value of epiphytic algae, while in sampling sites IV and V density values were lower due to the increasing intensity of stress factors (e. g. tide, breaking waves, winds, turbidity). According to Biggs (1996) the main factor leading to biomass loss is disturbance, and this most often occurs through substratum instability and associated abrasion, high water velocities, and abrasion by suspended sediments. In periphyton studies in clumps of bulrushes, located in Samborombón Bay streams with low exposition to breaking waves and tide, Claps (1981) reported density values of ephiphytic algae > 10^3 cells cm^{-2} , these values were higher than that ones found in our study.

During spring, winter and autumn, diatoms were dominant, but with different species compositions, whiles in summer green algae were abundant. These season-al pattems were similar to those reported by Alzan (1995) and Claps (1981) in temperate rivers. Photoperiod and light intensity are recognized as elements that influence the species seasonality (Sherman & Phinney1971; Hill 1996).

We identified the main factor influencing the structure and architecture of the epiphyton studied the battering action to which the buIrushes are subjected as a consequence of wave motion. Even the daily disturbance caused by tides, and the dynamics of growth of the bulrushes themselves, that produces an unceasing replenishment of the surfaces favourable for settlement, affect the biofilm development. Nutrient levels are not a limiting factor for algae in the Río de la Plata (Carp et al. 1989; Pizarro & Orlando, 1984). The resuspension of sediment particles in the inshore waters did negatively affect the development of epiphytic algae due to increased deposition over the biofilm and decreased light penetration in the water column. According to Kairesalo (1983) the environmental factors related either directly (e. g. surface waves) or indirectly (e. g. temperature and nutrient concentrations) with the force and direction of the wind may greatly affect the species succession, biomass accumulation and production of epiphytic com-munities. Grazing pressure is recognized as a factor capable of modifying the architecture and structure of periphyton (Steiman 1996; Gregory1983; Alzan 1995), but in the Río de la Plata the impact of this factor is limited due to the low density of grazers in the biofilms (Claps 1984).

More studies about the development of biofilms in *Scirpus californicus* and other types of substrata (e. g. stones, artificial substrates, etc.) in the Río de la Plata will be valuables for a better interpretation of the factors regulating the structure and architecture of biofilms in this ecosystem.

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