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Epixylic algae from a polluted lowland river of Buenos Aires province (Argentina)

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Resumé – Algues épixyliques d'une rivière polluée des basses terres de la province de Buenos Aires (Argentine). Nous avons analysé l'influence des variations spatiales et temporelles des propriétés physico-chimiques de l'eau sur la composition spécifique des algues du périphyton fixées sur des supports en bois (épyxilon) dans une section de l'aval de la rivière Luján (Buenos Aires, Argentina) et dans une rivière tributaire, les deux cours d'eau étant exposés à différents degrés d'eaux résiduaires. Des échantillons d'algues et d'eau ont été prélevés mensuellement pendant un an (juillet 2000-juillet 2001). Durant cette période, la qualité de l'eau des deux rivières a été très mauvaise et les caractéristiques physico-chimiques ont été celles d'un cours d'eau urbain pollué. Quant à la richesse spécifique, tous les sites ont montré une dominance de Bacillariophyceae, puis de Cyanobacteria, de Chlorophyta et d'Euglenophyta. Les algues présentes sont caractéristiques des rivières polluées. Nous avons observé des espèces adaptées au desséchement lié à la forte fluctuation du niveau de l'eau de la rivière. Selon les analyses de redondance (RDA), la composition et la richesse spécifique montrent une réponse plus forte à la variabilité spatiale et temporelle des caractéristiques limnologiques du système qu'aux décharges polluantes domestiques et/ou industrielles. Ceci pourrait s'expliquer par une adaptation de toute la communauté épixylique du bas Luján à des cours d'eau pollués qui sont fréquemment sujets à des pics de polluants.

Algues épixiliques / Argentina / facteurs environnementaux / pollution / rivières des basses terres

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Summary – We analyzed the influence of spatial and temporal variations in the physical and chemical properties of the water on the specific composition of the periphytic algae attached to wooden posts (epixylon) in a section of the low river Luján (Buenos Aires, Argentina) and a tributary, both of which were subject to varying degrees to wastewater. Algae and water samples were taken monthly from July 2000 to July 2001. During this period the river Luján and its tributary had very poor water quality and their physical and chemical characteristics were typical of polluted urban rivers. In terms of taxa richness, all sites showed a dominance of Bacillariophyceae, followed by Cyanobacteria, Chlorophyta and Euglenophyta. Algal taxa were typical of polluted rivers and some were adapted to desiccation due to strong fluctuations in the hydrological level of the river. The RDA (Redundancy Analysis) indicated that species composition and richness exhibited a stronger response to seasonal and spatial variability of the limnological characteristics of the system rather than to inputs of domestic and/or industrial pollutants. This result was most likely due to the entire epixylic communities from the low river Luján being composed of algae adapted to polluted watercourses with frequent peaks in pollutants.

Argentina / epixylic algae / environmental factors / lowland rivers / pollution

INTRODUCTION

Periphytic algae are the most successful group of primary producers in streams habitats. Their ability to thrive in streams is the result of adaptation to a complex series of interactions among hydrological factors (Biggs, 1996). The growth of lotic periphytic algae is controlled by counteracting processes of biomass accrual and biomass loss. The availability of resources, particularly nutrients and light, is of fundamental importance for biomass accrual, while disturbance is the principal factor contributing to biomass loss. The latter is frequently caused by the effect of physical factors, such as substratum instability and associated abrasion, high water velocities, and scouring by suspended sediments (Biggs, 1996).

The composition of periphytic algal assemblages shows patterns of variation over a wide range of spatial and temporal scales. Microscale changes are mainly associated with variation in the type of substratum, while mesoscale variations can result from morphometric characteristics of the streams, which affect the metabolic processes of algae (Biggs *et al.*, 1990). On the other hand, temporal variation may occur as response to predictable changes (e.g. differences in water temperature due to seasonality in temperate regions) (Lowe & Pan, 1996) and non-predictable changes. Effects determined by anthropogenic activities may also be of great influence on the biota. For example, the discharge of wastes into natural waters by human populations results in pulses of organic and inorganic matter into the system, which may affect periphytic assemblages in many different forms (Abel, 1996). Human activity largely affects water quality via the release of substances that are either beneficial to plants in small quantities (e.g., nutrients), or extremely toxic (e.g., heavy metals, pesticides, etc.) (Sabater, 2000).

Periphytic algae possess many attributes that make them ideal organisms for water quality monitoring. Periphytic algae are sessile and cannot avoid potential pollutants by migration; therefore, the composition of periphytic assemblages reflects the history of the environmental conditions at a particular site. The effect of water pollution on the periphyton structure (specific composition, species richness, diversity and biomass) has been thoroughly studied in rivers (John *et al.*, 1990; Vis *et al.*, 1998; Winter & Duthie, 2000).

For Argentina, there are few studies involving an integrated analysis of the biota and environmental variables in urban polluted rivers. Some researchers approached this topic using phytoplankton as an indicator of water quality in rivers, such as the Reconquista (Loez & Salibián, 1990; Loez & Topalian, 1999) and the Matanza (Conforti *et al.*, 1995). Little research has been conducted using periphyton as a biological monitor (Gómez & Licursi, 2001; Pizarro & Alemanni, in press). The river Luján, a typical lowland watercourse of the Buenos Aires province, is one of the most important urban rivers in Argentina because it flows across an area hosting a large human population, and receives both urban and industrial wastes. The water quality of this river has previously been analyzed using chemical, physical and biological variables (Andrade, 1986; Del Giorgio *et al.*, 1991; Frida *et al.*, 1996; Josch *et al.*, 1997; Feijóo *et al.*, 1999; Giorgi *et al.*, 1999; Giorgi, 2000; O´Farrell *et al.*, 2002). The purpose of the present work was to analyze the effect of spatial and temporal variation in the physical and chemical properties of the water on the specific composition of the periphytic algae attached to wooden posts (epixylon) in a section of the low river Luján (Buenos Aires, Argentina) and in a tributary, both of which were subject to varying degrees of exposure to wastewater.

MATERIALS AND METHODS

Study site. The river Luján is a polluted lowland watercourse that rises in the North-East of Buenos Aires (59° 37´ W; 34° 43´ S), joins the river Paraná Delta and ends into the Río de la Plata estuary (Fig. 1). A detailed description of the river Luján and its catchments can be found in O´Farrell *et al.* (2002). The river Luján is subject to water-level fluctuations ranging between 1-2 m above sea level. In the middle and upper reaches of the river the hydrological regime is controlled by rainfall and underground seepage, whereas in the lower reach (60 km) it is influenced by the discharge fluctuations of the river Paraná, the tidal regime of the Río de la Plata, and strong southeastern winds called “sudestada”. The “sudestada” is a short-term hydro-meteorological phenomenon associated with the occurrence of winds from the southeastern quadrant, which pushes the Río de la Plata waters towards the city’s coastline. This produces a “hydraulic plug”, which prevents the normal drainage of the watercourses in the Río de la Plata estuary (Gentile & González, 2001). As a consequence of this phenomenon, there is reflux of the rivers in their outlets, leading to a decrease in their water discharge, an increase in the hydrometric level and the modification of the hydrological characteristics of the system. The river Reconquista, another polluted watercourse in Argentina (Loez & Topalian, 1999), empties in the river Luján through a relief channel affecting the water quality of the final section of the river under study.

The stream Claro is one of the tributaries of the river Luján, with a mean discharge up to 11 m^3 sec^{-1}. This stream discharges a high amount of urban and industrial pollutants, turning this stretch into one of the most polluted parts of the river Luján (O´Farrell *et al.*, 2002).

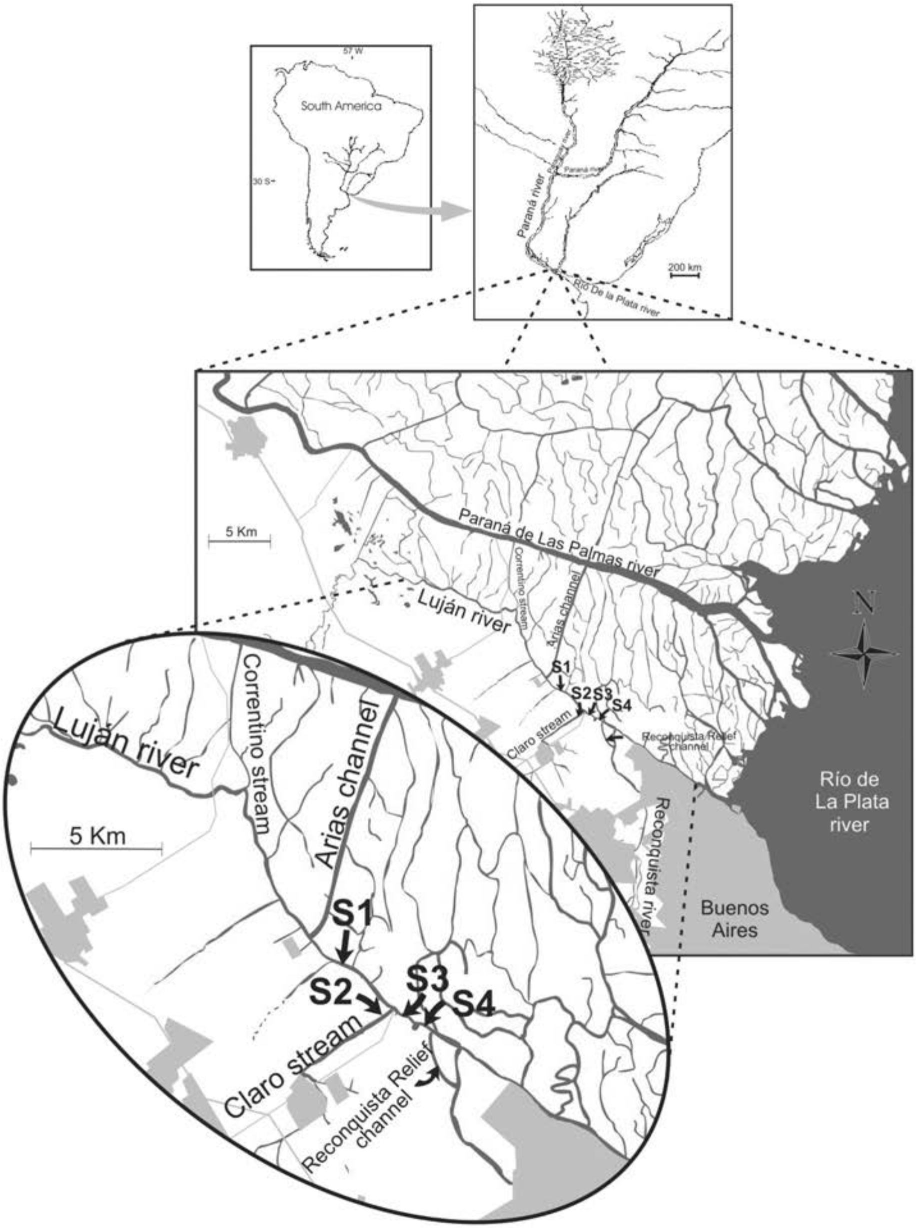

Fig. 1. Map showing the location of the lower river Luján and stream Claro. Sampling sites (S) are marked with arrows.

Field work and laboratory analyses. Periphytic samples were collected from wooden posts widely distributed along the river Luján and the stream Claro. These posts are mainly used to tie up boats and ships. They were chosen as sampling substratum because the bottom of the water courses considered consisted of mud; stones or other types of hard substrata were generally absent. Until present, few studies have considered potential interactions between wood and epixylic algae. However, since wood is likely to be chemically inert as a source of nutrients (N and P) for algae (Vadeboncoeur & Lodge, 2000), we assumed that the interaction, if any, was negligible. In addition, the wood surface provided a variety of attachment sites associated with rough and smooth microareas (Sabater *et al.*, 1998; Sinsabaugh *et al.* 1991). Therefore, wood offered more possibilities for the attachment of taxa that were most sensitive to the effect of hydrodynamism than other types of substrata.

The sampling sites were located on the right riverbank of the lower tract of the river and on the stream Claro. The first sampling site (S1) was located in the river Luján, about 2 km upstream the mouth of the stream Claro; the second sampling site (S2) was placed at stream Claro, approximately 200 m upstream from its outlet in the river Luján; the third point (S3) was located in the river Luján, approximately 1 km downstream from the mouth of stream Claro, and the last sampling site (S4) was located about 1 km downstream of S3 (Fig. 1).

A total of 40 samples (10 at each site) were taken approximately monthly from July 2000 to July 2001. Samples of epixylon and water were taken simultaneously on each sampling date.

Current velocity was measured at each sampling site using a neutrally buoyant float. Water discharge was estimated as current velocity × width × mean depth x 0.8 (Allan, 1995). Temperature, pH and conductivity were measured *in situ* using HANNA HI 8314 and HI 8033 portable meters. Water transparency was measured by a Secchi disk. Dissolved oxygen was determined following the Winkler method and concentrations of suspended solids were obtained by filtering the water samples through pre-dried glassfibre filters (Whatman® GF/C) (APHA, 1992).

Water samples for chemical analyses were collected subsuperficially, in acid-washed polyethylene bottles. Anions (nitrates and phosphates) and cations (sodium, potassium, magnesium, calcium) concentrations were determined by ionic-chromatography using a DIONEX DX-100 instrument with a conductivity detector, a sample injection valve and a 25 µl sample loop. Two plastic anion or cation columns were coupled in series to serve both as precolumn (DIONEX AG-4 or CG-10 respectively) and analytical chromatographic column (DIONEX AS-4 or CS-10 respectively). For anion detection, the suppressor was regenerated using 50 mN H_2SO_4 with a flow rate of 12.5 ml min^{-1} and a mixture of 4 mM HCO_3^{2-}/CO_3^{2-} was chosen as the eluent with a flow rate of 2 ml min^{-1}. The eluent used for cation detection was a mixture of DL-2,3-diaminopropionic acid monohydrochloride (DAP.HCl)/HCl in a concentration ratio of 2 mM DAP.HCl/40 mM HCl with a flow rate of 1 ml min^{-1}, and in this case the suppressor was regenerated using 0.1 M of tetrabutylammonium hydroxide (TBAOH) with a regenerant flow rate of 10 ml min^{-1}. For both anion and cation determinations, an isocratic method was used. For total phosphorus (TP) and nitrogen (TN), a previous simultaneous oxidation of nitrogen and phosphorus compounds by persulfate was performed (Koroleff, 1983). Ammonia ($N\text{-}NH_4^+$) was spectrophotometrically determined by the phenate method (APHA, 1992). All the standard solutions were prepared using analytical reagent-grade chemicals.

Dissolved oxygen (DO) was estimated with a colorimetric method using potassium dichromate as the oxidant agent (APHA, 1992).

Water samples for the analysis of phytoplanktic chlorophyll *a* were filtered through Whatman® GF/F filters in the laboratory. Filters were frozen for 24 h to disrupt the algal membranes. Hot ethanol (70°C) was used for the extraction of the pigment, and after 24 h at 4°C, chlorophyll *a* was measured by spectrophotometry before and after acidification with HCl (0.1 N) (to correct for phaeopigment). The final concentrations were calculated using equations given by Marker *et al.* (1980).

In order to collect algal samples at each site, firmly attached and associated algae from a wooden post were scraped with a fine brush and/or scalpel approximately 10 cm below the water level. An area of 25 cm^2, marked to prevent its resampling on following dates, was scraped. Part of the sample was examined in the laboratory *in vivo,* and after light microscope observations, it was fixed with 4% formalin to complete the identifications at a later time.

The taxonomic analysis was carried out following Bourrelly´s criteria (1970, 1972, 1981). The classification system of Van Den Hoek *et al.* (1995) was also considered. For specific and infra-specific identifications the following literature was used: Hustedt (1930, 1942), Kramer & Lange-Bertalot (1986, 1988, 1991 a and b) and Patrick & Reimer (1966, 1975) for the Bacillariophyceae; Ettl (1983) and Komárek & Fott (1983) for the Chlorophyta; Geitler (1932), Desikachary (1959) and Anagnostidis & Komárek (1988) for the Cyanobacteria, and Huber-Pestalozzi (1955) and Tell & Conforti (1986) for the Euglenophyta. Samples for diatom identification were treated with 50% H_2O_2 and permanent slides with NAPHRAX® were prepared (Battarbee, 1986).

Since the algae that were scraped from posts may have been affected by the fluctuation of the water level, the desiccation resistance of the species was estimated following Van Dam *et al.* (1994), Ettl & Gärtner (1995) and Whitton & Potts (2000).

Data analyses. The relationship between algal composition (based on presence/absence data) and environmental variables was investigated using Redundancy Analysis (RDA) (3.11 version, ter Braak, 1990). We used the 55 algal taxa, which were in five or more samples an are marked with an asterisk in Table 3, and 16 environmental variables (pH, conductivity, water discharge, dissolved oxygen, suspended solids, TN, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, TP, $P\text{-}PO_4^{3-}$, Mg^{2+}, Ca^{2+}, Na^+, K^+, phytoplanktonic chlorophyll *a* and DO). The 12 water samples collected during the “sudestada” events (December 2000, March and July 2001) were discarded, since these events cause short-term changes in the environmental conditions that could mask the relationship between environmental variables and epixylon. To detect the effect of “sudestada” on the environmental variables, a non-parametric Kruskal-Wallis test (Zar, 1996) was performed for phytoplanktic chlorophyll *a* concentrations and physical and chemical variables. We compared the mean values of each variable for samples affected and non-affected by “sudestada” as levels of the factor effect of “sudestada”.

For this study, RDA was preferred over other ordination techniques because in RDA the axes are linear combinations of the environmental variables. In RDA, these variables were treated as “environmental constraints” and algae were treated as “biological responses”. Before running the analysis, the variable inflation factors, correlation coefficients and forward selection were used to detect and remove environmental variables that were too strongly correlated to be used together in the ordination (ter Braak, 1991).

A further matter of interest is whether the differences in algal composition can be fully explained by the environmental variables, or whether the variation that remains after fitting these variables is systematically related to the sites, which represented different degrees of algal exposure to industrial and domestic wastes. S1 represented the site with the lower exposure to domestic and industrial wastes in the studied stretch of the river, S2 represented the highest degree of exposure to pollution, S3 had an intermediate degree and S4 represented a lower degree of exposure than S3. In order to clarify this problem, a partial RDA was carried out with the environmental variables as covariables, and the four sites as the explanatory variables. This technique allowed us to partition the total variance into their components according to: 1) variance due solely to the effects of physical and chemical water variables, 2) variance due solely to the effects of sites, 3) variance due solely to the effects of physical and chemical water variables covarying with sites, and 4) unexplained variance. The difference between the eigenvalues derived from constrained and partial canonical ordinations represented the interaction between these groups (mutual variance) and the unexplained variance, which was calculated as the difference between the total variance and the variance explained in the partial canonical ordination.

RESULTS

Table 1 shows the ranges, mean values and standard deviations of the physical and chemical variables analysed. Water discharge values were always higher in river Luján than at S2, where these never exceeded 14 m^3 sec^{-1} (Fig. 2a). The pH values were circumneutral and showed low variability at all sites. The highest and most variable mean conductivity value was recorded at S2 (Fig. 2b and Table 1). Concentrations of suspended solids reached the maximum value of 193 mg l^{-1} (S3) during May 2001 (Fig. 2c). In general terms, the highest mean concentrations of dissolved oxygen were registered at S1 (Table 1). $N\text{-}NH_4^+$ concentrations were generally high at S2 although the highest value (1.2 mg l^{-1}) was recorded at S4 (December 2000) (Fig. 2d). $N\text{-}NO_3^-$ mean concentration was the highest and showed the largest variability at S3 (Table 1). TN showed the highest mean concentrations at S2, S3 and S4 and the highest variability at S2 (Table 1). $P\text{-}PO_4^{3-}$ concentrations peaked in July, August and May 2000 (Fig. 2e). The highest mean concentration was 0.14 mg l^{-1} at S2 (Table 1). TP followed the same pattern of concentration changes as orthophosphate, reaching at S2 the maximum value of 0.8 mg l^{-1} in May 2001 (Fig. 2f).

Although the highest mean value of Na^+ concentration was measured at S4 (Table 1), the greatest variation was observed at S2 due to the occurrence of peaks in August 2000 and May 2001 (Fig. 2g). Ca^{2+} mean concentrations were the highest at S2 and the highest variability was found at S2 and S3. Although K^+ and Mg^{2+} mean concentrations were similar at all sites, K^+ variability was the highest at S2 and S3 while Mg^{2+} variability was the highest at S2. Na^+ concentration was always higher than that of the rest of the cations while, in general, Ca^{2+} concentration was higher than those of K^+ and Mg^{2+} (Table 1).

Phytoplanktic chlorophyll *a* showed the highest mean value at S2 and reached a maximum of 16.7 μg l^{-1} in February 2001. Although all sites had a high

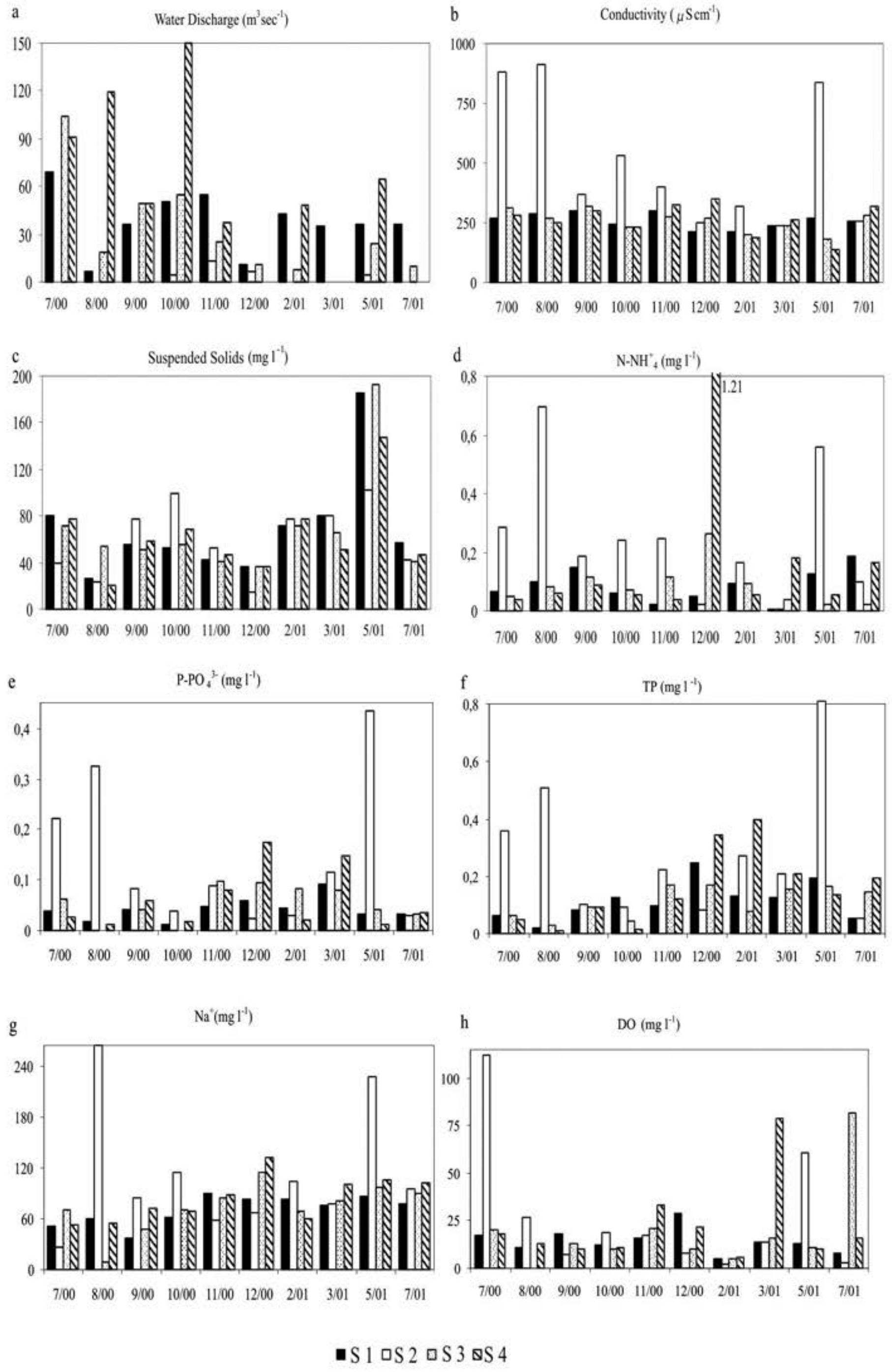

Fig. 2. Spatial and temporal variations of **a**: water discharge, **b**: conductivity, **c**: suspended solids, **d**: N-NH_4^+, **e**: P-PO_4^{3-}, **f**: TP, **g**: Na^+ and **h**: DO (S: sampling sites).

Table 1. Physical and chemical variables and phytoplanktic chlorophyll *a* concentration at each site (S). For each variable, range, mean and standard deviation (between brackets) are reported.

	S 1	*S 2*	*S 3*	*S 4*
Water discharge ($m^3\ s^{-1}$)	7-60 (37.9 ± 18.7)	ND-14 (2.9 ± 4.5)	ND-104 (30.5 ± 31.3)	ND-150 (55.9 ± 51.7)
Water temperature (°C)	8.7-27 (18.9 ± 6.5)	5.6-26.8 (18.8 ± 7.2)	8.3-26.6 (18.7 ± 6.4)	8.4-26.3 (18.5 ± 6.3)
pH	6.3-7.65 (7 ± 0.4)	6.44-7.73 (7.1 ± 0.3)	6.45-7.74 (6.9 ± 0.4)	6.46-7.66 (7.1 ± 0.3)
Conductivity ($\mu S\ cm^{-1}$)	255-301 (259.1 ± 31.6)	238-912 (499.2 ± 275.5)	183-320 (258.7 ± 44.6)	135-348 (264.3 ± 65.6)
Secchi depth (m)	0.16-0.4 (0.25 ± 0.07)	0.1-0.33 (0.23 ± 0.07)	0.15-0.37 (0.25 ± 0.07)	0.12-0.3 (0.23 ± 0.05)
Suspended solids ($mg\ l^{-1}$)	36-185 (68.9 ± 44.5)	14-102 (60.8 ± 30.7)	36-193 (67.9 ± 45.7)	21-148 (63.1 ± 34.7)
Disolved oxygen ($mg\ l^{-1}$)	5.21-9.26 (7.5 ± 1.4)	1.2-9.1 (5.5 ± 2.4)	4-9.6 (7.2 ± 7.1)	3.5-8.9 (6.8 ± 2.1)
$N\text{-}NH_4^+$ ($mg\ l^{-1}$)	0.05-0.09 (0.09 ± 0.05)	0.01-0.7 (0.25 ± 0.2)	0.02-0.26 (0.09 ± 0.07)	0.04-1.2 (0.19 ± 0.4)
$N\text{-}NO_3^-$ ($mg\ l^{-1}$)	0.24-0.55 (0.39 ± 0.09)	0.07-1.1 (0.42 ± 0.3)	0.4-0.8 (0.52 ± 0.5)	0.2-0.5 (0.36 ± 0.09)
TN ($mg\ l^{-1}$)	0.6-2.8 (3.2 ± 0.8)	1.3-10.3 (4.5 ± 2.8)	0.9-8.7 (4.2 ± 2.3)	0.7-6.7 (4.5 ± 2.1)
$P\text{-}PO_4^{3-}$ ($mg\ l^{-1}$)	0.03-0.04 (0.04 ± 0.02)	0.02-0.4 (0.14 ± 0.1)	ND-0.1 (0.05 ± 0.04)	0.01-0.2 (0.06 ± 0.06)
TP ($mg\ l^{-1}$)	0.03-0.24 (0.1 ± 0.07)	0.05-0.8 (0.3 ± 0.2)	0.03-0.2 (0.1 ± 0.06)	0.01-0.4 (0.2 ± 0.1)
Na^+ ($mg\ l^{-1}$)	36.8-87.2 (80.1 ± 17.4)	26.9-264.1 (79.5 ± 75.3)	8.5-115.2 (79.8 ± 29.2)	52.5-132.6 (100.6 ± 26.4)
K^+ ($mg\ l^{-1}$)	1.5-7.8 (3.7 ± 1.7)	0.9-9.8 (4.4 ± 3.1)	0.3-12.3 (4.1 ± 3.2)	2.4-8.5 (4.1 ± 2.1)
Mg^{2+} ($mg\ l^{-1}$)	1.6-4.2 (3.2 ± 0.84)	0.8-10.7 (4 ± 2.7)	1.7-4.2 (3.5 ± 1.2)	0.5-5.3 (3.5 ± 1.4)
Ca^{2+} ($mg\ l^{-1}$)	5.6-13.8 (9.9 ± 2.5)	2.3-24.3 (12 ± 6.1)	3.2-9.3 (6.4 ± 3.4)	6.3-12.3 (9.2 ± 1.8)
Phytoplanktonic chlorophyll a ($\mu g\ l^{-1}$)	ND-9.8 (5 ± 3.38)	ND-16.7 (7.7 ± 5.77)	ND-7.98 (2.6 ± 2.78)	ND-8.7 (3.1 ± 3.14)
DO ($mg\ l^{-1}$)	5-29 (14.3 ± 6.5)	ND-112 (27 ± 34.4)	ND-21 (20.9 ± 23.5)	6-33 (21.8 ± 21.5)

variability in chlorophyll *a* values, the highest variation was observed at S2 (Table 1).

The highest mean values of DO were recorded at S2 (Table 1) with peaks in July 2000 and May 2001 at S2, March 2001 at S4, and July 2001 at S3 (Fig. 2h).

Some of the above mentioned variables showed strong differences between "sudestada" and "non-sudestada" samples. During "sudestada", an

Table 2. Mean values ± standard deviation of the physical and chemical variables and phytoplanktic chlorophyll *a* concentrations registered during "non-sudestada" and "sudestada" events. Significant differences (* $p < 0.05$ ** $0.05 < p < 0.10$) using Kruskall-Wallis values test are shown in the last column.

	Non-sudestadas	*sudestadas*	*p*
n	28	12	
Na$^+$ (mg l^{-1})	82.20 ± 52.41	91.62 ± 18.78	*
pH	6.95 ± 0.34	7.25 ± 0.34	**
K$^+$ (mg l^{-1})	3.74 ± 2.34	4.98 ± 2.86	**
Mg$^+$ (mg l^{-1})	3.41 ± 1.82	3.79 ± 1.23	**
Water velocity (m sec^{-1})	0.29 ± 0.19	0.06 ± 0.07	*
Suspended solids (mg l^{-1})	72.11 ± 42.06	49.00 ± 19.53	*
Phytoplanktonic Chl. a (μg l^{-1})	5.33 ± 21.81	2.96 ± 2.69	
DO (mg l^{-1})	18.25 ± 21.81	13.17 ± 8.89	
Conductivity (μS cm^{-1})	344.43 ± 202.37	264.08 ± 37.79	
Dissolved oxygen (mg l^{-1})	6.82 ± 1.97	6.60 ± 2.37	
N-NH$_4^+$ (mg lv^1)	0.14 ± 0.15	0.19 ± 0.33	
N-NO$_3^-$ (mg l^{-1})	0.41 ± 0.33	0.47 ± 0.19	
P-PO$_4^3$– (mg l^{-1})	0.07 ± 0.10	0.08 ± 0.05	
TP (mg l^{-1})	0.17 ± 0.18	0.17 ± 0.08	
Ca$^+$ (mg l^{-1})	9.44 ± 4.79	9.36 ± 2.55	
TN (mg l^{-1})	2.61 ± 2.44	2.81 ± 1.17	

increase in pH and in the concentrations of Mg^{2+}, Na$^+$ and K$^+$ was recorded in the water. On the other hand, water velocity and mean values of suspended solids were lower during "sudestadas" than during the rest of the samplings (Table 2).

Taking into account algal species, varieties and forms, we identified a total of 114 algal taxa, 36% of which were found at all sites. Of these 114 taxa, 17.6% and 22.7% occurred simultaneously at three and two sites, respectively, while 7%, 7%, 1.8% and 7.9% were recorded exclusively at S1, S2, S3 and S4, respectively. Table 3 lists the epixylic algae with their respective constancies (the percentage of presence at each site in the whole study as a measurement of persistence in time). Bacillariophyceae represented 62.3% of all taxa recorded, followed by Cyanobacteria (30.7%), Chlorophyta (6.1%) and Euglenophyta (0.9%). A similar spatial pattern of percentages was also observed at each site. From the total algal taxa found, 64 were characterized according to their drying tolerance using available literature and among these, 62.5% were drying tolerant algae and 37.5% were non-tolerant algae (Table 3).

Some temporal differences in the percentages of algal groups were detected at each site (Fig. 3). At S1 Bacillariophyceae were the dominant group at all samplings dates, except May 2001 and July 2001. At S2, although Bacillariophyceae was dominant at most dates, Chlorophyta dominated in March and Cyanobacteria in July 2001. At S3, diatoms were the dominant group at all dates, except for July 2001, when Cyanobacteria dominated the community. Finally, at S4, Bacillariophyceae was the dominant group for most dates, except December 2000, March, May and July 2001, when Cyanobacteria were dominant.

The simplest significant model from the RDA had four variables (suspended solids, conductivity, pH and P-PO$_4^{3-}$) and explained a large amount of the epixylon compositional variation. The first two axes extracted by RDA,

Table 3. List of the epixylic algae and their constancy at the four studied sites (I, 0 to 20%; II, 21 to 40%; III, 41 to 60%; IV, 61 to 80% and V, 81 to 100% of the samplings). The drying tolerance of some taxa is represented by: (Dr) tolerant; (Nr) non-tolerant and (-) no data available. (*) species used in the RDA. Bac: Bacillariophyceae, Chl: Chlorophyta, Cya: Cyanobacteria and Eug: Euglenophyta.

				S1	*S2*	*S3*	*S4*
Bac	-	*	*Achnantes inflate* (Kützing) Grunow	II	I	I	II
Bac	Nr	*	*Aulacoseira granulata* var. *angustissima* (O.M) Simonsen	I	II	I	I
Bac	Nr	*	*Aulacoseira granulata* var. *granulata* (Ehrenberg) Simonsen	III	III	III	II
Bac	Dr	*	*Bacillaria paradoxa* Gmelin	II	I	II	I
Bac	Nr	*	*Craticula accomoda* (Hustedt) D. G. Mann	I	III	I	I
Bac	-	*	*Cyclostephanus invisitatus* (Hohn & Hellerman) Theriot, Stoermer & Håkansson	I	I	II	I
Bac	Nr	*	*Cyclotella meneghiniana* Kützing	II	III	III	II
Bac	Nr	*	*Encyonema silesiacum* (Bleisch in Rabenhost) D. G. Mann	I	I	I	I
Bac	Dr	*	*Eolimna subminuscula* (Manguin) Lange-Bertalot	I	I	I	I
Bac	-	*	*Fragilaria capucina* Desmaziers	III	II	I	I
Bac	Nr	*	*Gomphonema clavatum* Ehrenberg	II	I	I	I
Bac	-	*	*Gomphonema lujanensis* Maidana & Reichardt	I	II	I	I
Bac	Dr	*	*Gomphonema parvulum* Kützing	II	II	II	II
Bac	Dr	*	*Hantzschia amphyoxis* (Ehrenberg) Grunow	I	I	I	I
Bac	Dr	*	*Luticola mutica* var *ventricosa* (Kützing) Cleve & Grunow	II	II	II	II
Bac	Dr	*	*Luticula goeppertiana* (Bleisch) H.L. Smith	IV	III	III	III
Bac	Dr	*	*Mayamea atomus* (Kützing) Lange-Bertalot	I	III	I	I
Bac	Nr	*	*Melosira varians* Agardh	II	II	II	II
Bac	Nr	*	*Navicula cryptocephala* Kützing	II	II	II	I
Bac	Dr	*	*Navicula recens* (Lange-Bertalot) Lange-Bertalot	IV	III	IV	III
Bac	Dr	*	*Nitzschia brevissima* Grunow	I	II	I	I
Bac	Dr	*	*Nitzschia clausii* Hantzsch	III	II	II	II
Bac	Dr	*	*Nitzschia filiformis* (W. M. Smith) Van Heurk	II	II	III	III
Bac	Dr	*	*Nitzschia palea* (Kützing) W. Smith	III	IV	III	III
Bac	Dr	*	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot	II	III	II	I
Bac	-	*	Pennate diatom with nodule 1	III	II	II	II
Bac	-	*	Pennate diatom without nodule 1	I	I	II	I
Bac	Nr	*	*Pinnularia gibba* Ehrenberg	II	III	II	III
Bac	Nr	*	*Ulnaria ulna* (Nitzsch) Compére	III	II	II	III
Chl	-	*	*Basicladia chelonum* (Collins) Hoffman & Tilden	II	II	II	III
Cya	Dr	*	*Chlorogloea mycrocystoides* Geitler	II	II	I	II
Cya	-		*Leibleinia gracilis* (Meneghini) Anagnostidis & Komarek	I	I	I	I
Cya	Dr	*	*Leptolyngbya fragilis* (Gomont) Anagnostidis & Komarek	I	I	I	I
Cya	Dr		*Leptolyngbya laminosa* (Gomont) Anagnostidis & Komarek	IV	IV	III	V
Cya	-		*Leptolyngbya scotti* (Fritsch) Anagnostis & Komarek	II	II	I	II
Cya	Dr	*	*Phormidium autumnale* (C. Agardh) Trevisan ex Gomont	IV	III	III	IV
Cya	-	*	*Phormidium formosum* Bory ex Gomont	IV	II	III	III
Cya	Dr	*	*Phormidium kützingianum* (Kirchner) Anagnostidis & Komarek	IV	III	II	III
Cya	-	*	*Phormidium subfuscum* Kützing ex Gomont	I	I	II	I
Cya	Nr		*Planktothrix rubescens* (De Candolle ex Gomont) Anagnostidis & Komarek	II	I	I	I
Cya	-	*	*Tolypothrix limbata* Thuret	I	I	I	II

				S1	*S2*	*S3*	*S4*
Bac	-	*	*Berkella linearis* Ross & Sims	I	I	I	
Bac	Nr		*Fallacia pygmaea* (Kützing) D. G. Mann	I	I	I	
Bac	Dr		*Navicula schoeteri* Meister	I	I	I	
Bac	Dr	*	*Staurosirella pinnata* (Ehrenberg) Williams & Round	I	II	II	
Cya	-		*Oscillatoria proteus* Skuja	I	II	I	
Bac	-		Centric diatom 1	I	I		
Bac	Nr		*Craticula cuspidata* (Kützing) D. G. Mann	I	I		
Bac	Dr		*Diploneis puella* (Schumann) Cleve	I	I		
Bac	Dr		*Pinnularia viridis* (Nitzsch) Ehrenberg	I	I		
Cya	Dr		*Chroococcus minutus* (Kützing) Nägeli	I	I		
Cya	-		*Phormidium dimorphum* Lemmermann	I	I		
Bac	-		*Amphipleura lindheimeri* Grunow	I			
Bac	-		*Cymbella turgidula* Grunow	I			
Bac	-		*Eunotia luna* Ehrenberg	I			
Chl	Dr		*Elakatothrix inflexa* Hindák	I			
Cya	-	*	*Leptolyngbya tenuis* (Gomont) Anagnostidis & Komarek	III			
Cya	-		*Oscillatoria sancta* Kützing ex Gomont	I			
Cya	-		*Phormidium molle* (Kützing) Gomont	I			
Cya	-		*Pleurocapsa* cf. *minor* Hansgirg	I			
Bac	-		*Cyclotella stelligeroides* Hustedt		I		
Bac	Nr		*Navicula rostellata* Kützing		I		
Bac	-		*Nitzschia rosentockii* Lange-Bertalot		I		
Bac	-		*Planothidium hauckianum* (Grunow) Round & Bukhtiyarova		II		
Cya	-		*Gloeocapsa aeruginosa* Kützing		I		
Cya	Dr		*Nostochopsis lobatus* Wood		I		
Cya	-		*Phormidium amphibium* C. Agardh ex Gomont		I		
Cya	-		*Raphidiopsis mediterranea* Skuja		I		
Bac	Nr		*Cocconeis pediculus* Ehrenberg			I	
Bac	Nr		*Sellaphora pupula* (Kützing) Mereschkowsky			I	
Bac	-		*Eunotia didyma* var. *elegantula* Hustedt				I
Bac	-		*Hydrosera whampoensis* (Schwartz) Deby				I
Chl	-		*Cladophora* sp.				I
Chl	-		*Oedogonium* sp.				I
Chl	-		*Scenedesmus acutus* Meyen				I
Cya	-		*Chamaesiphon carpaticus* Starmach				I
Cya	-		*Isocystis salina* Iwanoff				I
Cya	-		*Oscillatoria subbrevis* Schmidle				I
Cya	-		*Phormidium simplicissimum* Gomont				I
Bac	Dr	*	*Denticula kützingii* Grunow	I	II		I
Bac	-		*Encyonema minuta* Hilse ex Rabenhorst	I	I		I
Bac	Nr	*	*Staurosilla leptostauron* (Ehrenberg) Williams & Round	II	I		I
Bac	Dr		*Nitzschia amphibia* Grunow	I	I		I
Bac	Dr	*	*Luticula nivalis* (Ehrenberg) D. G. Mann	I		I	II
Bac	Dr	*	*Nitzschia debilis* (Arnott) Grunow	II		I	I
Bac	Nr		*Nitzschia sigma* (Kützing) W. M. Smith	I		I	I
Bac	-	*	*Pleurosigma elongatum* Smith	II		I	I
Cya	-		*Pseudoanabaena lonchoides* Anagnostidis	I		I	I
Bac	Nr	*	*Eunotia monodon* Ehrenberg	I			II

				S1	*S2*	*S3*	*S4*
Bac	-		*Tabularia affinis* (Kützing) Snoeijs	I			I
Cya	-	*	*Phormidium attenuatum* Fritsch	I			I
Cya	-	*	*Phormidium martensianus* (Meneghini ex Gomont) Anagnostids & Komarek	I			I
Cya	-		*Phormidium retzii* (C. Agardh) Gomont	I			I
Bac	Nr		*Nitzschia acicularis* (Kützing) Smith		I	I	
Bac	Dr		*Nitzschia capitellata* Hustedt		I	I	
Bac	Dr		*Surirella minuta* Brébisson		I	I	
Cya	-		*Aphanothece conferta* Richter & Richter		I	I	
Cya	-		*Phormidium subincrustatum* Fritsch & Richter		I	I	
Chl	-		*Chlamydomonas* sp.		I	I	
Eug	-		*Euglena viridis* Ehrenberg		I	I	
Bac	Nr	*	*Nitzschia angustata* Grunow		II	I	I
Bac	Nr	*	*Pseudostaurosira brevistriata* (Grunow) Williams & Round		II	I	I
Bac	Nr	*	*Staurosira construens* Ehrenberg		I	I	I
Bac	Dr	*	*Surirella angusta* Kutzing		I	II	I
Chl	Dr	*	*Trebouxia arboricola* Puymaly		II	I	I
Cya	Dr	*	*Leptolyngbya frigida* (Fritsch) Anagnostidis & Komarek		I	I	I
Bac	Nr		*Actinocyclus normanii* (Gregory ex Greville) Husted fa subsalsus		I		I
Bac	Dr	*	*Eunotia intermedia* (Kraske) Nörpel & Lange-Bertalot		II		I
Bac	Dr		*Fallacia monoculata* D. G. Mann		I		I
Bac	Dr		*Gomphonema gracile* Ehrenberg		I		I
Bac	Dr		*Planothidium lanceolatum* (Brébisson) Lange-Bertalot		I		I
Bac	Dr		*Rophalodia musculus* (Kützing) Müller		I		I
Cya	-		*Phormidium allorgei* (Frémy) Anagnostidis & Komarek		I		I
Cya	Dr		*Phormidium priestleyi* Fritsch		I		II
			% Bacillariophyceae	67,6	69	70,8	65,4
			% Cyanobacteria	29,7	27,4	24,6	28,2
			% Chlorophyta	2,7	2,4	3,1	6,4
			% Euglenophyta	0	1,2	1,5	0

represented in a species-environmental variables biplot, explained 71.3% of the variance (Axis 1: 48.2% and Axis 2: 23.1%). Eigenvalues for Axis 1 and 2 were 0.11 and 0.05, respectively. A Monte Carlo test applied to the distribution of algal data was significant for the first axis ($p = 0.005$) and trace matrix ($p = 0.005$). Four water variables showed significant intraset correlations: suspended solids ($r = -0.73, p < 0.05$, df = 26) and conductivity ($r = 0.40, p < 0.05$, df = 26) for Axis 1, and pH ($r = 0.72, p < 0.05$, df = 26) and P-PO_4^{3-} ($r = -0.44, p < 0.05$, df = 26) for Axis 2 (Fig. 4).

Axis 1 revealed that temporal variation, presumably related to seasonal variability in suspended solids concentration and conductivity, had a strong effect on the assemblage composition. Samples collected mainly in the winter season (September, August and July) and a few samples collected in spring and summer were located along the positive side of Axis 1, which showed low suspended solids concentration and high conductivity values. These samplings were characterized by a high frequency of *Eunotia intermedia*, *Fragilaria capucina*, *Gomphonema parvulum*, *Mayamea atomus*, *Melosira varians*, *Navicula cryptocephala*, *Nitszchia*

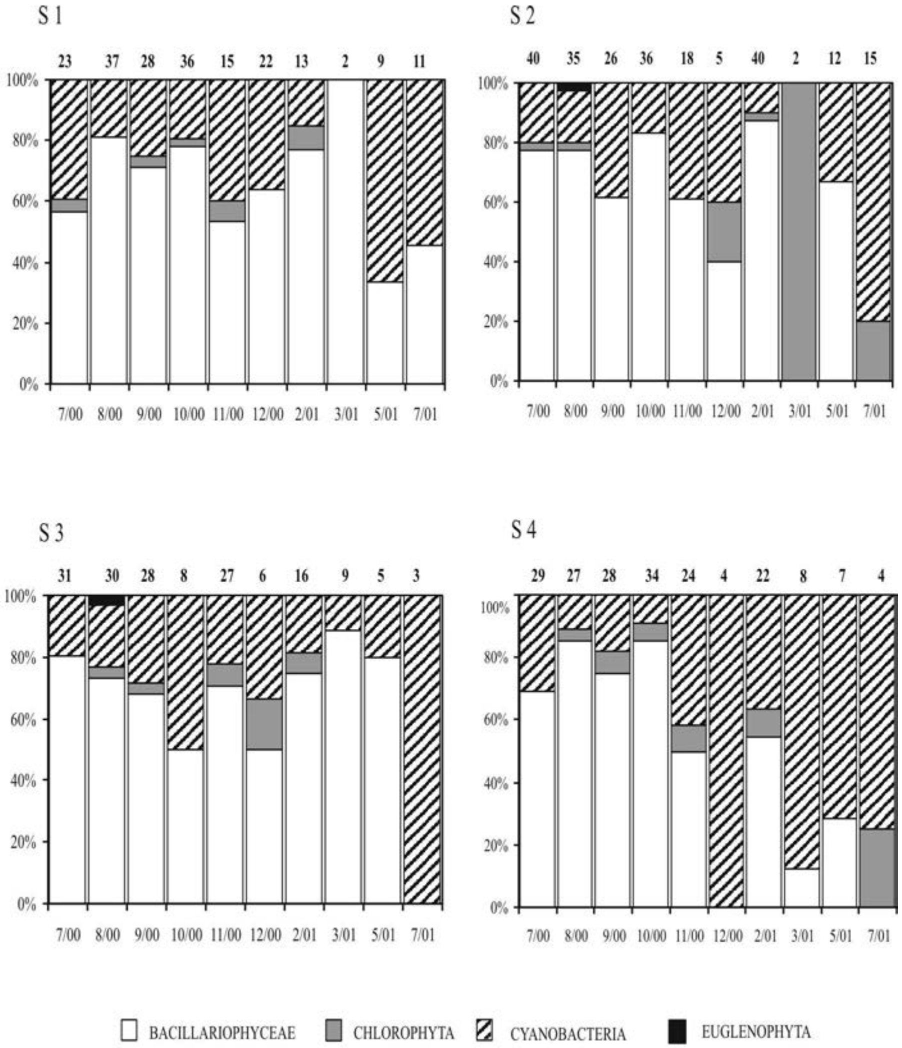

Fig. 3. Relative percentage of abundance by algal Class or Division at each sampling site throughout the study. Species richness values at the top of each column are indicated in bold (S: study site).

brevissima, *N. filiformis*, *Porphyrosiphon martensianus*, *Pseudostaurosira brevistriata*, pennate diatom with nodule 1, pennate diatom without nodule 1 and *Ulnaria ulna.* These taxa were absent or less frequent in autumn, summer and spring samplings, which were located along the negative side of Axis 1, and showed high values of suspended solids and low values of conductivity. There was a positive significant correlation between the Axis 1 of the RDA and species richness ($r = 0.97$, $p < 0.0001$, df = 26), indicating that richness increased during winter, as suspended solids concentrations diminished and conductivity values increased.

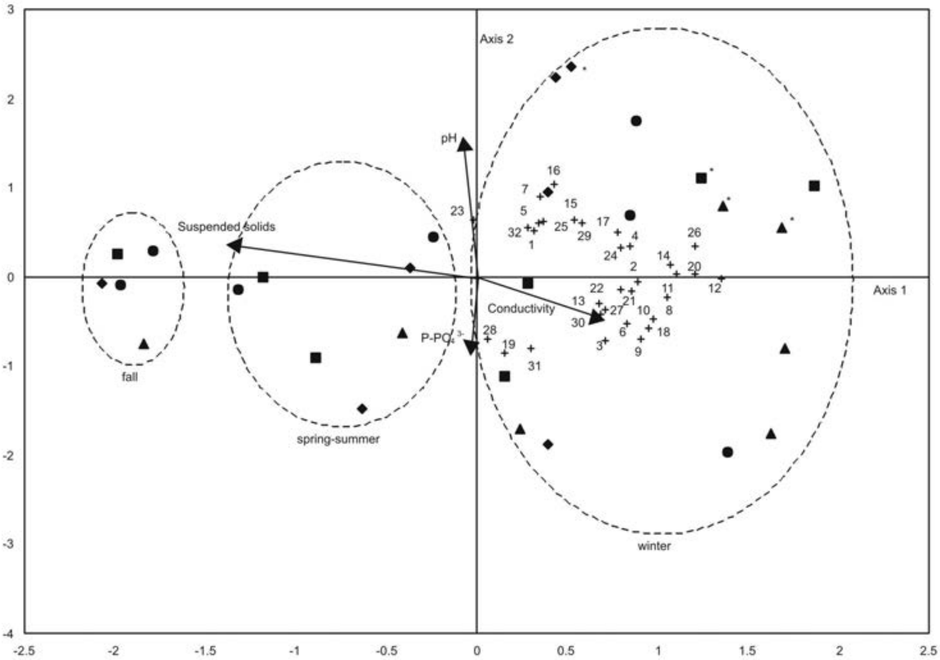

Fig. 4. RDA ordination showing species and sample scores. Significant environmental variables are indicated by rows. Square: S1, triangle: S2, circle: S3, rhombus: S4. Sites with * belong to spring samplings. Only species with scores > 0.7 for Axis 1 and > 0.5 for Axis 2 are displayed: 1 *Bacillaria paradoxa*, 2 *Eunotia intermedia*, 3 *Pseudostaurosira brevistriata*, 4 *Fragilaria capucina*, 5 *Staurosira construens*, 6 *Staurosirella pinnata*, 7 *Gomphonema lujanensis*, 8 *Gomphonema parvulum*, 9 *Craticula accomoda*, 10 *Mayamea atomus*, 11 *Luticula goeppertiana*, 12 *Navicula recens*, 13 *Nitzschia angustata*, 14 *Nitzschia brevissima*, 15 *Nitzschia clausii*, 16 *Nitzschia debilis*, 17 *Nitzschia filiformis*, 18 *Nitzschia palea*, 19 *Nitzschia umbonata*, 20 Pennate diatom with nodule 1, 21 Pennate diatom without nodule 1, 22 *Pinnularia gibba*, 23 *Pleurosigma elongatum*, 24 *Ulnaria ulna*, 25 *Cyclostephanus invisitatus*, 26 *Melosira varians*, 27 *Chlorogloea mycrocystoides*, 28 *Phormidium attenuatum*, 29 *Phormidium kützinguianum*, 30 *Porphyrosiphon martensianus*, 31 *Leptolyngbya frigida*, 32 *Phormidium subfuscum*.

Axis 2 showed the importance of spatial variation in the assemblage composition determined by the effect of a combined gradient of pH and P-PO$_4^{3-}$. Axis 2 led to a clear segregation of the winter samples located on the positive side of the Axis 1. Samplings located on the positive side of Axis 2 showed high values of pH and were also characterized by a high frequency of *Bacillaria paradoxa*, *Cyclostephanus invisitatus*, *Gomphonema lujanensis*, *Phormidium subfuscum* and *Pleurosigma elongatum*. These species were absent or less frequent at the sites located on the negative side of Axis 2, characterized by an increase of water acidity and P-PO$_4^{3-}$ concentration.

Monte Carlo tests obtained from partial RDA (Axis 1 and the matrix trace were non-significant, $p > 0.5$), run with the physical and chemical measurements as covariables and sites as environmental variables, showed that the physical and chemical water characteristics were enough to explain the differences in algal composition observed among samples.

Variance partitioning analysis revealed that the physical and chemical variables of the water explained the largest proportion of the total variance (22%) in the algal composition, while sites (representing the different degrees of exposure to domestic and industrial wastes) explained a small portion of the total variance (10%). The variance explained by the interaction of these two types of variables and the unexplained variance, were 0.5% and 68%, respectively.

DISCUSSION

Throughout the entire study period, results of the physical and chemical variables and chlorophyll *a* concentrations clearly indicated signs of poor water quality in the river Luján and in the stream Claro. Values were similar to those obtained for typical polluted urban rivers (Lange-Bertalot, 1979; Economou-Amilli, 1980; Lobo *et al.*, 1995), in which peaks of certain variables are possibly caused by pulses of pollutants (Wrona *et al.*, 2000). The "sudestada" events diminish the water quality through an increase in the concentration of some cations (Na^+, K^+ and Mg^+) and pH of the water because "sudestada" produces a "hydraulic plug", which modifies the normal drainage of the watercourses in the Río de la Plata estuary (Gentile & González, 2001).

The stream Claro (S2) showed more peaks in Na^+, Ca^{2+}, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$ and TP than the rest of the sites. This is believed to be the consequence of a combination of low water discharge of the stream into the river Luján and a high frequency of domestic and industrial inputs. The relative proportion of cation concentrations did not correspond to that found in non-polluted freshwater environments, where $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ (Wetzel, 1981). We consider that in the studied area the high concentrations of sodium are probably the consequence of domestic waste inputs, as they usually contain this cation (Abel, 1996; Wrona *et al.*, 2000). On the other hand, S2 seems to be the most variable site from a trophic point of view because at this section the stream fluctuated from oligotrophic to hypereutrophic conditions, depending on the concentrations of TP and phytoplanktonic chlorophyll *a* at each sampling date (Vollenweider, 1968; Lee *et al.*, 1978).

Percentages of algal classes and divisions recorded were similar among sites. The environmental deterioration of the studied area is suggested by the dominance of Bacillariophyceae, which is typical in rivers with characteristics similar to those of river Luján (Deniseger *et al.*, 1986; Lobo *et al.*, 1995; Sabater, 2000), together with the presence of some Cyanobacteria adapted to extreme environments (Vincent, 2000; Wynn-Williams, 2000). The whole diatom community consisted of widespread generalist species, which are commonly observed in running waters and in organically polluted rivers (Prygiel & Coste, 1997; Kwandrans *et al.*, 1997). In particular, *Cyclotella meneghiniana*, *Luticola goeppertiana, Melosira varians* and *Pinnularia viridis* are facultatively nitrogen-heterotrophic taxa that need periodic pulses of organically-bound nitrogen. *Nitzschia palea* and *N. umbonata* are strictly heterotrophic diatoms that live in waters with low levels of dissolved oxygen (Van Dam *et al.*, 1994) and belong to the poli-saprobic zone. In addition, the diatom *Pinnularia gibba* is very common in hypertrophic environments. Among the Cyanobacteria, *Leptolyngbya frigida*, *Nostochopsis lobatus*, *Phormidium autumnale*, *P. priestleyi* and *Porphyrosiphon* *martensianus* can be found in thermal, light and/or water restricted places (Vincent, 2000; Whitton, 2000; Wynn-Williams, 2000).

The high proportion of taxa resistant to desiccation suggests that the studied community was well-adapted to relatively predictable water fluctuations (Junk *et al.*, 1989; Pizarro, 1999). Among the taxa resistant to desiccation we found the diatoms *Hantzschia amphyoxis* and *Nitzschia palea,* which are strictly aerophytic species, and the chlorophyte *Trebouxia arboricola*, capable of forming symbiotic associations (lichens) with some fungi (Ettl & Gärtner, 1995).

The results of the RDA show that temporal variation, presumably linked to seasonality, was the predominant effect determining the algal structure of the epixylon in the low river Luján. The algal composition and richness were strongly associated with suspended solids concentration and conductivity, two variables with proxy seasonal effects. The increase in suspended solids during spring, summer and fall, probably associated with the decrease in the water discharge of the river (a correlation, $r = -0.72$, $p < 0.05$, between water temperature and water discharge was observed by Rodríguez (2002)), would produce a decrease in richness. This was probably due to abrasion and light interference, which tend to modify the structure of the community (Biggs, 1996). The increase in algal richness during winter is believed to result from a decrease in environmental constraints, mostly linked to low suspended solids concentrations. Algal development was enhanced by high conductivity values because the algae registered in winter samplings are typical of saline environments with high ionic and organic matter concentrations in the water. Among the diatoms, the following taxa are typical of saline or brackish and/or nutrient-enriched water: *Craticula accomoda, Fragilaria capucina, Gomphonema parvulum* and *Nitzschia brevissima*.

Two additional non-seasonal variables affecting the algal structure of the epixylon during summer were pH and $P\text{-}PO_4^{3-}$. High pH values defined an algal community with dominance by typically alkaliphilic and alkalibiont diatoms such as *Nitzschia debilis*, *Bacillaria paradoxa*, *Pseudostaurosira brevistriata* and *Staurosira construens*. All these taxa were absent at sites with high orthophosphate concentrations. At these sites, the community was dominated by the diatoms *Cyclotella meneghiniana*, *Luticola mutica* var. *ventricosa*, *Mayamea atomus* and *Ulnaria ulna* and by the cyanobacteria the *Leptolyngbya fragilis* and *Porphyrosiphon martensianus*. Similarly to what was observed in lakes and rivers by other authors, some diatoms responded to changes in pH (Planas, 1996; Verb & Vis, 2000) and phosphate concentrations and conductivity (Round, 1991). On the other hand, Cyanobacteria are well adapted to extreme conditions and can be found both at high or low pH values as well as in highly or poorly enriched environments (Whitton & Potts, 2000).

In brief, our study indicates that the species composition and richness exhibited a stronger response to seasonal and spatial variability of the hydrological characteristics of the system than to inputs of domestic and/or industrial pollutants. This result was likely due to the fact that the entire epixylic communities of the low river Luján and stream Claro are mostly composed of algae adapted to polluted watercourses, with frequent peaks of pollutants.

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