Limnological changes in two shallow lakes from an urban reserve throughout a complete hydrological cycle: proposals for restoration and management

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Abstract: We analysed the fluctuations of the limnological variables and phytoplankton structure in two shallow lakes located in an urban ecological reserve from Buenos Aires city (Reserva Costanera Sur) during a complete hydrological cycle. The results of this investigation showed that the changes in the water level strongly affect the limnological variables and the structure of the phytoplankton communities. In both shallow lakes, the water level was inversely correlated with conductivity ($p < 0.05$). During the rising waters, a progressive colonisation by floating macrophytes was observed affecting the dissolved oxygen concentrations. We analysed the fluctuation of the algal groups and dominant species, evaluating the changes in the structure in the context of the phytoplankton functional groups, and we observed that the water level was one of the main variables explaining the variations in the community. We propose some alternatives for the management and restoration of the shallow lakes of this reserve.

Keywords: urban reserve; shallow lakes; phytoplankton; hydrological cycle; phytoplankton functional groups; restoration; management.

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1 Introduction

The studies were conducted in two shallow lakes from an urban ecological reserve "Reserva Ecológica Costanera Sur" (RECS), located in Buenos Aires city, that was originated by evolution in a filling coastal area adjacent to Rio de la Plata estuary. Owing to its biological interest, in 1986 it was officially declared as ecological reserve, having as the main objectives the biodiversity conservation and recreation.

The area includes four wetlands of variable area formed in land depressions without direct connection with the river, which are fed by the precipitations and runoff. Their hydrological levels are extremely variable and dependent on the precipitation regime, exhibiting periodically drought periods.

Owing to their location within a city, the shallow lakes from the RECS share some of the characteristics of the urban lakes and are subjected to an intense impact derived from the human activities. In general, urban lakes can be described as artificial water bodies, relatively small and shallow, without well-differentiated littoral and pelagial zones, which are usually exposed to a rapid eutrophication (Quirós, 2007; Ringuelet, 1962). Because of their small volume they are very affected by the environmental conditions of the region, showing important fluctuations in temperature and hydrometric level.

The continuous monitoring of this type of aquatic systems is crucial due to the tendency to develop massive growing of certain algal species or macrophytes (Myrbo, 2003). Nevertheless, the behaviour of each urban lake depends on its particular characteristics: catchment area, nutrient inputs, morphometry and trophic status. On the other hand, the objective of each urban lake may differ according to their particular uses (Schueler and Simpson, 2001), among them, recreation, water supply, flooding control and biodiversity conservation.

In particular, the shallow lakes of the RECS are located in a city that during the last decades has experienced a progressive increase of its population, and consequently an intensification of the urbanisation. Moreover, the touristic activity has also been intensified the last years.

In general, there is scarce information about the urban lakes from Buenos Aires. One of the studies (Izaguirre et al., 1986) analysed the fluctuations of the phytoplankton and the main limnological features in two ponds of the city located in important parks, and reported the development of massive algal blooms, particularly in spring and summer. Other published studies were purely taxonomical, reporting the floristic algal composition of some ponds (e.g., Mosto, 1975; Vinocur, 1988).

In relation to the aquatic environments of the RECS, the shallow lake ‘Los Coipos’ was the most intensively studied. In this lake, Fazio and O’Farrell (2005) analysed the structure and dynamics of the phytoplankton comparing two periods: one previous and one posterior to an artificial filling of the lake with water extracted from one of the aquifers of the region (‘Puelches’). As this aquifer in this zone has relatively high saline content, the shallow lake suffered a ‘secondary salinisation’, that according to Kraemer et al. (2001) is an increase in salinity as a consequence of human interventions. The authors concluded that the decrease in the number of phytoplankton genera was associated with the increase in conductivity, and only when the pumping stopped there was a recovering in the algal richness. Recently, Avigliano (2011) studied the phytoplankton community during an annual cycle in the same lake, starting from a period of drought, and analysed the changes during the increase in water level; the results of this study revealed important fluctuations in the limnological variables and in the phytoplankton structure, which were mainly associated with the hydrological changes.

In this study, we analysed the limnological changes in other two shallow lakes of the reserve (‘Los Patos’ and ‘Las Gaviotas’, hereinafter LP and LG) during a complete hydrological cycle (drought – rising waters – water level decrease – drought). We also evaluated the phytoplankton changes, particularly analysing variations in the algal groups and the dominant species. On the other hand, as the shallow lakes are key environments for the conservation of the biodiversity of the reserve, in this paper, we also propose some alternatives for their restoration and management.

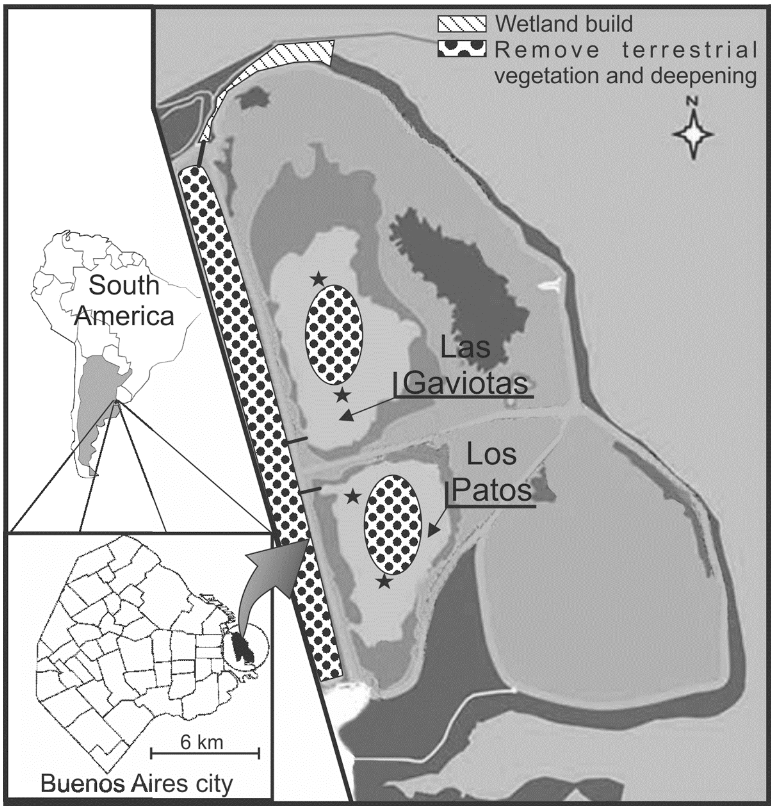
2 Study area

The ecological reserve RECS (34º36′30″S; 58º21′W) is located in the western margin of the Rio de La Plata, at the East extreme of the Buenos Aires city (Olveira et al., 2005). It has an area of 353.26 ha, where the depressed zones originated four shallow water bodies (0.5–1.5 m depth), among which LP (32.39 ha) and LG (39.32 ha) are the focus of this study (Figure 1). These lakes are very shallow (mean depth of ~0.5 m), although their water levels vary according to the temperature and precipitation regime, since they are not connected with the Rio de La Plata estuary, nor even during flooding.

The shallow lakes are usually colonised by rooted macrophytes such as *Typha latifolia*, *Panicum elephantipes*, *Polygonum* spp. and *Sagittaria montevidensis*, as well as by floating macrophytes such as *Pistia stratiotes* and *Azolla filiculoides* (Faggi and Cagnoni, 1987; Sarrias et al., 1996).

From a biogeographical point of view, the reserve is included in the Pampean Province (Cabrera and Willink, 1980), thus the characteristics of the water bodies are similar to those of other Pampean shallow lakes. They are polymictic and their depths vary according to the proportion of flooded surface. Owing to their shallowness, the water bodies of this region are very susceptible to be colonised by plants, and are characterised by sediments rich in organic matter (Quirós et al., 2006).

Figure 1 Map of the study area indicating the location of the main water bodies of the RECS. Sampling sites are indicated with stars



In particular, the shallow lakes of the reserve have usually the lowest water levels in summer, whereas in autumn and winter typically there is an increase in their hydrometric levels (Filipello and López de Casenave, 1993).

The precipitation regime of the region is influenced by the two phases of the ENSO (El Niño–Southern Oscillation), thus affecting the water level of the shallow lakes of the reserve (Avigliano, 2011).

The last years the shallow lakes from the RECS have experienced a decrease in their biodiversity. These changes started during a very dry summer that provoked an important decrease of the water levels of the shallow lakes, followed by the advancement of the neighbouring grasslands.

3 Materials and methods

In the two shallow lakes (LP and LG) samplings were conducted from November 2009 to December 2010, with an approximately monthly periodicity. Samples were collected in two sampling points that were established at the pelagial zone of each shallow lake (Figure 1).

The following physical and chemical variables were measured on each occasion in situ: temperature, conductivity and dissolved oxygen with YSI 85 portable instruments. Water depth was measured at each sampling point with a graduated stick. Samples for nutrient analyses were collected from the subsurface layer, and the dissolved nutrients (phosphates, nitrates + nitrites and ammonium) were analysed by spectrophotometry using a Hach (DR 2800) spectrophotometer and the corresponding kits of chemical reagents. In the case of the total phosphorus (TP) and total nitrogen (TN), we have performed a previous digestion of the sample, following the protocols described in APHA–AWWA–WEF (2005).

Phytoplankton samples were also collected from the subsurface at each sampling point in plastic bottles, and were preserved with acidified Lugol's iodine solution (1% final concentration), conserved in the dark and cold until their analyses. Phytoplankton counting was carried out in 10 ml sedimentation chambers with an inverted microscope (Zeiss), following the Utermöhl (1958) method. The counting error was established according to Venrick (1978), accepting a maximum error of ~20%. In all cases, we estimated the abundance of the different algal groups. On the other hand, we have quantified the abundance of the dominant and more frequent species (abundances approximately >30% in each sample), analysing their classification according to the phytoplankton functional groups proposed by Reynolds et al. (2002), updated by Padisák et al. (2009).

3.1 Statistical analyses

The correlation between pair of biological and physicochemical variables was estimated with the parametric Pearson correlation index (Zar, 1999), using the Statistica 7 program.

Redundancy Analysis (RDA) was applied to estimate how much variance of the density of the algal groups was explained by the environmental variables.

Previously, we performed a Detrended Correspondence Analyses (DCA), and as the data showed a linear response we used RDA. Calculations were carried out with the programme CANOCO (ter Braak, 1988). The analysis was based on field data on density of the phytoplankton groups and on the environmental variables corresponding to all sampling dates in each shallow lake (using the average values of the two sampling points). Variables strongly correlated were excluded of the analysis for avoiding co-linearity. Among the algal groups, Chrysophyceae were excluded due to their occasional occurrence and very low abundances in the lakes. The statistical significance of the first axis and of all the axes was tested by a Monte Carlo permutation test. The importance of each variable was assessed using forward selection.

4 Results

4.1 Physical and chemical variables

For most of the physical and chemical variables no significant spatial differences between the two sampling points were found ($p < 0.05$), except in the case of the dissolved oxygen in certain sampling dates.

At the beginning of our studies the shallow lakes were in a rising phase due to the increase of precipitation after a dry period. Both lakes experienced a gradual increase in their water levels, with the exception of a small decrease that occurred in January 2010, reaching their maximum depths in October 2010; later on, the hydrometric level progressively decreased and the shallow lakes dried up completely at the end of the year. Mean hydrometric levels varied from 9.7 cm to 43.1 cm in LP, and from 4.5 cm to 56.5 cm in LG (Figure 2(a)).

Temperature ranges were similar in both shallow lakes and followed the seasonal pattern. In general, very high values were registered in summer (mean 32°C and 30.2°C, for LP and LG, respectively). The lowest values were observed in autumn (mean 12.1°C in LP and 12.7°C in LG; Figure 2(b)).

Fluctuations in conductivity were similar to those of the temperature, with maximum values in summer (mean 9200 µS cm^{-1} and 4733 µS cm^{-1}, for LP and LG, respectively), and minimum in autumn (mean 1644 µS cm^{-1} in LP and 1273 µS cm^{-1} in LG; Figure 2(c)). Both shallow lakes showed an inverse correlation between hydrometric level and conductivity ($r = -0.64$; $p < 0.05$), owing to the higher ion concentration when the water level was lower.

During the study period, concomitantly with the water level increase, a progressive colonisation by floating macrophytes occurred in both shallow lakes, although the coverage differed between them; the cover percentage varied from 0% to 50% in LP and from 40% to 100% in LG.

At the beginning of the study, dissolved oxygen concentrations showed important fluctuations in both shallow lakes. Then, a clear tendency to the anoxia was registered towards the end of the spring, owing to the dense floating plants coverage of the species such as *P. stratiotes* and *A. filiculoides*. In general, oxygen concentrations were lower in LG because during this study the development of the macrophytes was higher in this shallow lake, whereas in LP the surface always maintained some water-free patches. For the whole study period, mean values varied between 0.6 mg l^{-1} and 15.2 mg l^{-1} in LP, and between 0.4 mg l^{-1} and 7 mg l^{-1} in LG (Figure 2(d)).

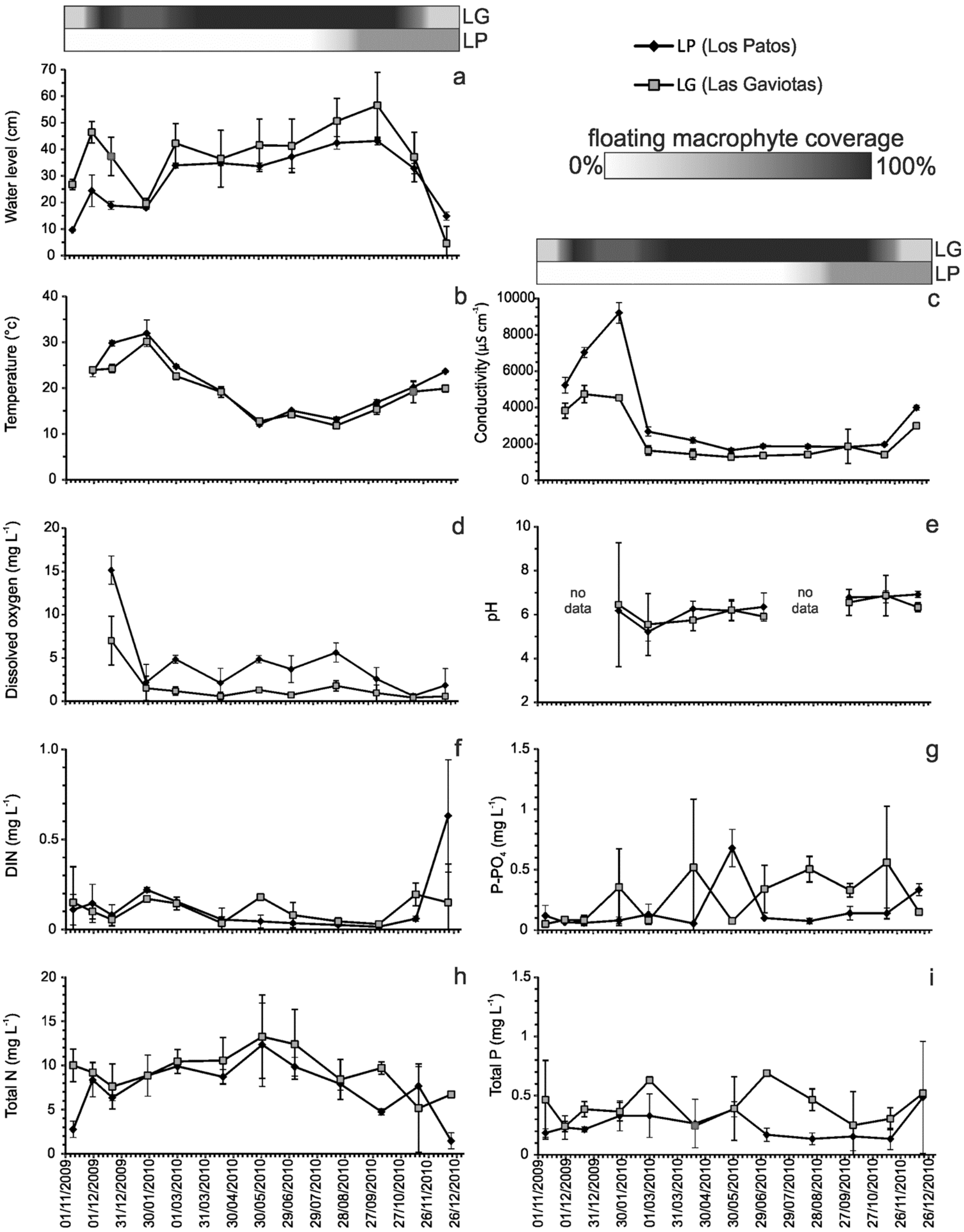
In general, fluctuations in pH values were not very important, varying the waters from slightly acid to circumneutral. Nevertheless, the relatively lower values registered at the initial period may be due to the decomposition of organic matter (Figure 2(e)).

The dissolved forms of nitrogen (nitrates and ammonium) were rather low in both lakes, and no important temporal changes were observed. The maximum mean values of Dissolved Inorganic Nitrogen (DIN) were registered at the beginning and at the end of the study period (0.63 mg l^{-1} in LP and 0.2 mg l^{-1} in LG).

Phosphates showed a rather constant pattern in LP, except for a peak registered in late May 2010, whereas more pronounced fluctuations were observed in LG. Maximum values were registered in May 2010 in LP (mean 0.68 mg l^{-1}) and in November 2010 in LG (0.56 mg l^{-1}). Minimum mean concentrations were found at the beginning of the cycle, with values of 0.06 mg l^{-1} (LP) and 0.05 mg l^{-1} (LG; Figure 2(f) and (g)).

Regarding the concentrations of total nitrogen and total phosphorus (Figure 2(h) and (i)), both lakes exhibited relatively high values. Total nitrogen showed similar patterns in both water bodies, with maximum concentrations registered in May 2010 (mean 12.35 mg l^{-1} in LP and 13.25 mg l^{-1} in LG). Similar to that described for the dissolved form, total *P* showed different patterns in both lakes, with little fluctuations in LP and more marked in LG. Mean values varied from 0.14 mg l^{-1} to 0.49 mg l^{-1}, and from 0.24 mg l^{-1} to 0.69 m l^{-1}, for LP and LG, respectively.

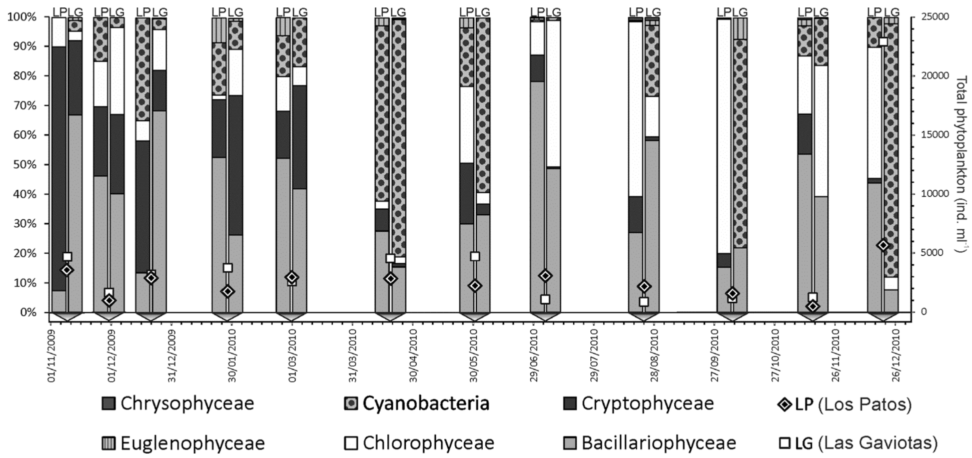
Figure 2 Mean values and standard deviation for the main physical and chemical variables measured in the shallow lakes Los Patos and Las Gaviotas throughout the studied period



4.2 Phytoplankton

In both shallow lakes the dominant algal groups in the phytoplankton, in terms of the species number, were Chlorophyceae, Bacillariophyceae and Cyanobacteria. The class Cryptophyceae was also represented in terms of abundance, but with a lower species richness. Figure 3 shows the total phytoplankton density and the relative percentage of the different algal groups for each shallow lake. In both lakes the phytoplankton abundance followed approximately the same seasonal pattern, although higher values were found in LP (with the maximum difference in December 2010 due to a peak of Cyanobacteria in this lake).

Figure 3 Total phytoplankton abundance and proportion of the different algal groups in the studied shallow lakes throughout the study period



Phytoplankton abundances ranged from 505 Ind. ml^{-1} to 5691 Ind. ml^{-1} in LP, and from 884 Ind. ml^{-1} to 22,938 Ind. ml^{-1} in LG.

In LP, the Cryptophyceae were more abundant at the beginning of the cycle during the water rising phase, with maximum values in November 2009 (2697 Ind. ml^{-1}), whereas the minimum values were found in October–November 2010 (<100 Ind. ml^{-1}). The algal groups Bacillariophyceae y Chlorophyta were also well-represented during the whole study period. In this shallow lake, the Cyanobacteria were more abundant in April 2010.

In LG, Bacillariophyceae were always present with dominance in November and December 2009; their mean abundances varied between 278 Ind. ml^{-1} and 3166 Ind. ml^{-1}. Similar to that observed in the other shallow lake, the Cryptophyceae were more abundant at the beginning of the study, whereas the Cyanobacteria were dominant towards the end of the study period.

In both shallow lakes, the class Euglenophyceae was only occasionally represented, with maximum abundances of 93 Ind. ml^{-1} and 493 Ind. ml^{-1}, for LP and LG, respectively.

The abundance of Chlorophyceae and Bacillariophyceae were positively correlated with DIN ($r = 0.65$; $p < 0.05$), whereas and inverse correlation between Cyanobacteria abundance and depth was found ($r = -0.50$; $p < 0.05$).

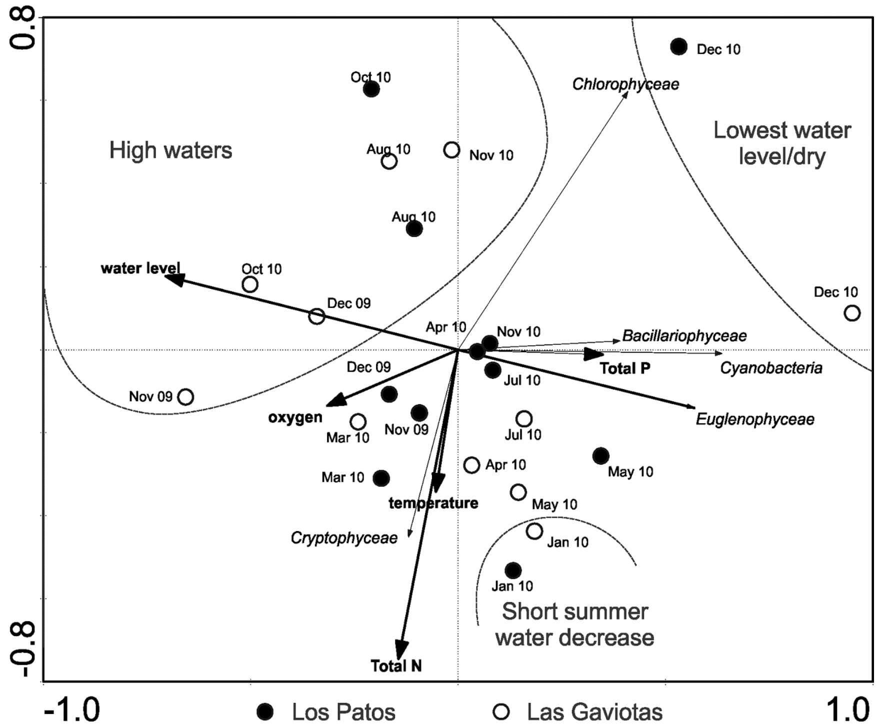
With respect to the species composition, the dominant and more frequent phytoplankton taxa in LG until March 2010, were *Cryptomonas marsonii*, *Nitzschia palea*, *Nitzschia longissima*, *Chlorella* sp. and *Leptolyngbya* cf. *foveolarum*. From April 2010 to the end of the study other taxa became more important in the lake: *Achnanthes hungarica*, *Gomphonema parvulum*, *Cymbella* sp., *Microcystis aeruginosa*, *Microcystis firma* and *Leplolyngbya* sp.

In LP, the community was also dominated by *C. marsonii*, *N. longissima*, *Chlorella vulgaris* and *L.* cf. *foveolarum* from November 2009 until January 2010. In March and April 2010, the species *Gyrosigma* sp. and *Closterium* sp. were also very abundant in this lake; from July to November 2010 the phytoplankton was best represented by *Chlorella* sp., *Chlamydomonas* sp. and *Fragilaria ulna*. At the end of the period (December 2010), the species *M. aeruginosa*, *A. hungarica*, together with *Monoraphidium* spp. and *Gyrosima* sp., attained the higher abundances.

4.3 Multivariate analysis

In the Redundancy Analysis (RDA) based on the abundance of the algal groups and the environmental variables, the first two axes accounted for 98.6% of the variance (axis 1: 96.3%; axis 2: 2.3%). The Monte Carlo test indicated that the environmental variables were significantly correlated with the first axis ($p = 0.05$). The first axis was mainly correlated with water level (intra-set correlation coefficient: −0.45), and the second axis was mainly defined by total *N* and temperature (intra-set correlation coefficients: −0.49 and −0.23, respectively). Figure 4 shows the triplot (first two axes) of the samples and the algal groups with respect to the environmental variables. Most of the samples corresponding to high waters were placed towards the upper left-hand side of the figure, whereas the samples of December 2010 (lowest water levels and beginning of the complete dry) were ordinated together at the upper right-hand side.

Figure 4 Tiplot (algal groups, environmental variables and samples) corresponding to the Redundancy Analyses (first and second axes) based on the abundance of the different algal groups and the environmental variables



5 Discussion

Our results showed that, owing to their shallowness, the studied shallow lakes exhibit strong fluctuations in their limnological properties, which are associated with the environmental changes, mainly temperature and precipitation. This behaviour is typical of shallow water bodies where there exist marked heating and cooling variations of the water column, thus showing rapid responses to the seasonal changes (Morales et al., 2000).

In general, all the shallow lakes of the RECS are characterised by periodical cycles of drought and rising waters in response to the precipitation changes. As we have previously mention, these water bodies usually show their minimum water levels in the warm season (Filipello and López de Casenave, 1993), and in some occasions can dry up completely. In particular, our studies in the shallow lakes LP and LG started at the beginning of a rising water phase (November 2009), ending when the water levels showed the minimum values, previous to a complete drought (December 2010). The same behaviour was described for another shallow lake of this reserve by Avigliano (2011). Subsequently to our studies, owing to the low rainfalls in the region, the shallow lakes of the reserve dried up completely, situation in which they are currently (year 2012, personal observation). From this moment, a progressive process of colonisation with terrestrial plants occurred in the water bodies, following the typical ontogeny described for shallow lakes (Wetzel, 2001). Nowadays, the authorities of the RECS, together with the Government of the Buenos Aires city, are analysing potential management plans to eradicate the terrestrial vegetation that has colonised the water bodies, and to perform a deepening and filling of them with the purpose of maintaining the biodiversity of the reserve.

During our study, the observed changes in the hydrometric levels were reflected in the variations of most of the limnological variables. In particular, the conductivity showed a clear inverse relationship with the water level, in agreement with the pattern described for the shallow lake Los Coipos in the same reserve (Avigliano, 2011). When the hydrometric level decreases, phosphate can co-precipitate with carbonates thus reducing its bioavailability; this situation occurred during the first months of our study. In contrast, the conditions of higher water levels and lower conductivities favour the dissolution of carbonates, releasing nutrients which promote algal growth (e.g., *C. marsonii* and *Chlorella* sp.).

The increase of the hydrometric level facilitated the colonisation of the shallow lakes by floating plants. In turn, the macrophyte coverage had a strong influence on the dissolved oxygen concentration, registering very low values below the plant coverage. Studies carried out in shallow lakes from the Natural Reserve Otamendi, located in the same region, showed a similar pattern, with very low concentrations of oxygen and occasional anoxia in sites densely covered by floating plants (e.g., de Tezanos Pinto, 2008; Izaguirre et al., 2001, 2004). The presence of macrophytes exerts important changes in the water column because drastically reduces the light penetration, thus generating anoxia due to decrease in photosynthesis. These conditions affect the phytoplankton composition due to different of tolerance of the species. In this sense, Zalocar de Domitrovic (1993) has pointed out that the presence of macrophytes is an important structuring factor of phytoplankton. Particularly, investigations conducted in the Otamendi Reserve showed that under low light scenarios and poor oxygen concentrations the phytoplankton composition is drastically affected, observing only species well adapted to these conditions (Izaguirre et al., 2010; O'Farrell et al., 2003, 2007; Sinistro, 2007).

The low levels of dissolved forms of nitrogen (nitrate and ammonium) generally observed in these shallow lakes may be related to the low dissolved oxygen concentrations that favour the denitrification commonly associated with the bottom, which may be particularly important under conditions of a dense floating macrophyte coverage (Veraart et al., 2010).

As it was mentioned, we did not observed important spatial differences between the two sampling points. This behaviour differs from that observed by Avigliano (2011) for the shallow lake Los Coipos, where marked differences among three sampling points along the longitudinal axis of the lake were observed. The discrepancy between this shallow lake and the lakes analysed in our study is due to their morphometric differences. The shallow lakes LP and LG have a higher surface area, are shallower, and their depths are more homogeneous; in addition, these lakes have a higher fetch which favour the homogenisation by the wind. In the case of the phytoplankton, we only observed some specific differences in the composition of the dominant species between the two sampling points, but in general the structure of the phytoplankton was very similar.

Our study showed a marked temporal dynamics of the phytoplankton, with replacements of dominant species throughout the study period. Some species reached their maximum abundances coinciding with low values of dissolved oxygen; particularly, in January and November 2010 when the lowest oxygen concentrations were found, the more abundant species were *C. vulgaris*, *Leptolyngba* cf. *foveolarum*, *Fragilaria* cf. *ulna* and *C. marsonii* in LP, whereas *C. vulgaris*, *C. marsonii*, *Achnantes* cf. *hungarica*, *Fragilaria* cf. *ulna* and *N. palea* were more abundant in LG. The seasonality had also influence on the phytoplankton fluctuations, influencing the dominance of certain algal groups. Factors affecting the phytoplankton dynamics in lakes were well described by many authors. In particular, Reynolds (1988) has deeply analysed the influence of nutrients and light on the phytoplankton structure. This community is very sensitive to the environmental changes, and the responses of the different species depend on their morphological and physiological characteristics: size, nutrient uptake, growing rate and susceptibility to be grazed (e.g., Reynolds, 1984, 2006; Stolte et al., 1994).

There is a broad consensus that the functional approach is an adequate tool to analyse changes in the phytoplankton structure, mainly in environmental biomonitoring (e.g., Izaguirre et al., 2012; Naselli-Flores and Barone, 2011), since communities are more reliable indicators of habitat conditions that are the presence or absence of component species. For this reason, we have analysed the structure of the phytoplankton of the lakes in the context of the functional phytoplankton classification proposed by Reynolds et al. (2002) and updated by Padisák et al. (2009).

Similar to that observed by Avigliano (2011) in the shallow lake Los Coipos, the analysis of the phytoplankton dynamics in the studied shallow lakes clearly evidenced fluctuations in the phytoplankton functional groups. Analysing the changes in the phytoplankton throughout the year, we observed that during the period of rising waters (November 2009), the dominant functional groups were Y (*C. marsonii*) and X1 (*Chlorella* sp.), two opportunistic taxa typically *r*-strategists from the ecological point of view, that can multiply rapidly when conditions are favourable. In particular, the increase of the abundance species of the genus *Cryptomonas* during periods of rising hydrometric levels was also reported by different authors (e.g., O'Farrell et al., 2003; Unrein et al., 2010).

On the other hand, some diatoms belonging to the functional group D (like *N. palea* and *N. longissima*), which are typical in shallow enriched turbid water (Padisák et al., 2009), were well represented in both lakes all over the study period. When the shallow lakes were covered by floating plants, species belonging to the functional groups MP and S1 were also very abundant; the first group includes many littoral or benthic diatoms that are drifted to the plankton in shallow lakes, and in our study was represented by the diatoms *A. hungarica*, *G. parvulum* and *Gyrosigma* sp.). S1 is a group represented by shade-adapted Cyanobacteria (e.g., *Leptolyngbya* spp.). As it was previously mentioned, the two shallow lakes exhibited differences in the proportion of surface covered by floating plants; thus, as LG was more profusely covered by plants from January 2010, we observed differences in the phytoplankton functional groups between both lakes (MP group was best represented in LG).

Towards the end of the study, the functional group M, that includes Cyanobacteria of the genus *Microcystis* typically of eutrophic and hypertrophic water bodies (Padisák et al., 2009), attained higher abundances. This group was represented in the studied lakes by *M. aeruginosa* and *M. firma*, and was very abundant during the whole last warm period in LG (October–December 2010), and in only December 2010 in LP. Interestingly, nitrogen-fixing Cyanobacteria, that can be abundant in some eutrophic lakes, were not present in the studied water bodies. Heterocystous (N_2 fixing) vs. non-heterocystous Cyanobacterial dominance seems to be determined by whether there is a benthic ammonium source available during water column DIN depletion. Vacuolated colonial Cyanobacteria (e.g., some species of *Microcystis* and *Oscillatoria*) can migrate vertically; bringing stored N back to the surface, they may grow more quickly than heterocystous species that stay in the epilimnion fixing nitrogen. Thus, the dominance by fixers is predicted only when both epilimnetic and benthic DIN sources are inadequate to meet demands (Ferber et al., 2004). In the studied lakes the high total *N*/total *P* ratios seem to indicate that nitrogen is not limiting for algal growth.

The period of lowest hydrometric level in both lakes (December 2010) was also characterised by the abundance of the groups M, MP, S1 and X1 (this represented by several green algae of the genus *Monoraphidium*).

The results of the multivariate analysis RDA evidenced that the water level of the shallow lakes was one the most important variables explaining the variability in the algal composition and abundance in the two shallow lakes. This analysis showed that Cyanobacteria, Euglenophyceae and Bacillariophyceae were prevalent under conditions of low water levels, high phosphate levels and lower oxygen concentrations. Cryptophyceae, although present during great part of the year, were more abundant at the beginning of the study, during the period of rising waters in the shallow lakes (November 2009).

Our studies showed that the shallow lakes from the RECS are very influenced by the variations in temperature and by the precipitation regime of the region. This implies that the systems are characterised by marked hydrometric fluctuations, which in turn are responsible of important fluctuations in most of the limnological properties and in the algal assemblages.

Since the water bodies of the reserve are crucial for the biodiversity conservation (mainly birds), a correct management of these systems is essential. It is important to maintain adequate hydrometric levels in the lakes, but at the same time to preserve the typical fluctuations of these types of wetlands.

5.1 Some recommendations for the management and restoration of the shallow lakes from the RECS

Nowadays the shallow lakes of the RECS have a few centimetres depth or are completely drought, and this situation seems not to reverse even during a very rainy period as it was the year 2012. Owing to the need of maintaining the reserve with a relatively high species diversity, mainly aquatic birds (one of the main attractions), the authorities of the RECS are evaluating the possibility of restoring the shallow lakes and to artificially fill them. Under this scenario there are two possibilities. One possibility is pumping water from a non-saline aquifer. As we have previously mentioned, from 1998 to 1999 the old water supply company of Buenos Aires used water from an aquifer that in this region has relatively a high salt concentration; this provoked the secondary salinisation of the shallow lakes of the RECS and important changes in the biota. A second alternative is to fill the shallow lakes using directly the water from the Rio de La Plata; this is probably the most advisable, since originally the water of the shallow lakes came from the river. Nevertheless, owing to the high concentrations of suspended solids and probably of inorganic and organic contaminants in the river water, it would be important to perform a treatment of the water before filling the lakes. Thus, we propose that the water from the river pass through an artificial wetland, which would serve two functions: sedimentation of the solids and treatment of the water. A wetland with freshwater macrophytes would provide an ideal microhabitat for sedimentation, filtration, adsorption and bacterial decomposition of the river's water (Henry, 1999; Vymazal and Kröpfelová, 2008). In this sense, it is important to point out that already exists in the RECS a channel that could be used for development this kind of wetland (Figure 1).

In general, constructed wetlands with surface flow consist of channels with natural soil to support the rooted vegetation and water at a low flow velocity; the presence of the plant stalks and litter regulate water flow and, especially in long narrow channels, ensure plug-flow conditions (Reed et al., 1988; Vymazal and Kröpfelová, 2008). One of their primary design purposes is to contact wastewater (in this case the river water) with reactive biological surfaces (Kadlec and Knight, 1996). Once treated in the wetland, the water could be derived by pipelines to the different shallow lakes.

On the other hand, it is recommended to perform some previous corrections in the shallow lakes that are in an advanced stage of colonisation by terrestrial plants, including the extraction of the vegetation and deepening of the shallow lakes. Analogous solutions were proposed for other systems with similar problems (Biebighauser, 2007).

Once the water levels of the shallow lakes have recovered it is important to monitor them. The presence of aquatic macrophytes, controlling their excessive proliferation is generally beneficial for maintaining the aquatic biodiversity and the system in a clear water state equilibrium as described by the alternative lake equilibria theory (Scheffer, 1993).

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