Planktonic and physico–chemical dynamics of a markedly fluctuating backwater pond associated with a lowland river (Salado River, Buenos Aires, Argentina)

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Abstract

An investigation was performed in a pond (San Miguel) directly associated with the Salado River (Pampean grasslands). The aim of the study was to analyze river interactions. Physical and chemical conditions and the plankton community were studied in order to determine the effects of changes in hydrological conditions. The main factors that influenced the physical–chemical characteristics of the pond have been identified by means of cluster analysis. Conductivity was the main factor that determined groups in sampling periods. Changes in conductivity were clearly associated with the water-level of the pond and depended on the flow of the Salado River and fluctuations of its conductivity, which is itself a function of evaporation and the inflow of underground water of high conductivity. Other factors that affected the physical–chemical conditions included concentrations of phosphorus and polyphenols, the main allocthonous sources. The concentration of these compounds was decreased in low water conditions. Principal Components Analysis suggested that there were four major regulatory factors in the pond, as follows. First, a dry season, with a prolonged isolation phase and a considerable increase in conductivity, turbidity and suspended solids, during which the abundance of plankton was greatly reduced, as were incorporated benthic species. A high and sudden increase of river flow determines the second regulatory factor, the flood season, when dissolved allocthonous material enters, conductivity decreases and there is a conspicuous dominance of cyanophytes, protozoans and crustaceans. The different degrees of hydrological connection with the Salado River produce changes in dissolved phosphorus forms and the composition of the plankton. The third regulatory factor is an increase in particulate material. This is associated with the highest total phosphorus values as a consequence of the phosphorus–particle relationship. The opposite situation, the fourth regulatory factor (a decrease in particulate material), produces clear water conditions with a dominance of chlorophytes, planktonic diatoms and rotifers.

Key words

backwater pond, grasslands, Pampean river, planktonic and physical–chemical dynamics.

INTRODUCTION

The basin of the Salado River is located in a dry temperate floodplain (Church 1994) and includes a large number of ponds. These are 1000 km^2 in area of normal conditions of river flow. These ponds have several degrees of connection with the Salado River and some are regulated by gates to maintain water levels and low salinity values. Certain ponds without regulation dry completely in summer, when the flow of the Salado River is low and its inflow ceases. Evaporation and groundwater relationships have an important effect in summer (Dangavs & Merlo 1980). There are several land uses in the basin: in the headwater region, agriculture activities predominate and, from the middle reaches to the mouth of the river, cattle breeding. Several towns with industries are located near the river margins in the headwater region and in the middle reaches. The hydrological regimen of the Salado River is very variable. It includes changes of flow of < 100 $m^3 s^{-1}$ during dry periods and > 1500 $m^3 s^{-1}$ during periods of flooding. Local variations in conductivity and transport of dissolved and particulate materials are also involved during both periods. Over the past decades, there have been few studies of the planktonic community (Conzonno & Claverie 1987; Romero & Arenas

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1990, 1994b; Izaguirre & Vinocur 1994a) and the physical and chemical characteristics of ponds of the Salado River basin (Conzonno & Fernández Cirelli 1987; Conzonno & Claverie 1990; Romero & Conzonno 1997).

There have been other investigations of backwaters and coastal marshes or ponds. All have great fluctuations in conditions that affect the physical and chemical characteristics and the planktonic communities of these waterbodies that are related to floods and droughts (Heiler *et al.* 1994, 1998b; Quintana *et al.* 1998b; Tockner *et al.* 1999). These waterbodies are important systems for clarifying planktonic responses to disturbances.

The study pond reported herein is not regulated in its connection with the river and its basin has not been disturbed by humans. This type of waterbody has not been studied previously in the basin of the Salado River. The present investigation aimed to identify the main changes undergone by the pond according to hydrological conditions and to determine which variables are responsible for this behaviour. The results of the present study will contribute to our knowledge of the ecological function of a pampean pond directly connected to the river prior to regulation. A regulation project will be initiated in the upper basin of the Salado River and this will affect the discharge frequencies and the natural connectivity conditions of ponds associated with the river.

STUDY AREA

A natural channel (2 km) connects San Miguel pond (backwater) directly to the lower course of the Salado River (Fig. 1). The pond has an area of 95 ha and a shoreline length of 9.25 km. The pond is shallow and its maximum depth was 120 cm during the study period. Direct communication with the river stops when the flow is below 20 $m^3 s^{-1}$, a common condition during the dry period. The pond has a deflation origin. Fossil dunes surround the pond and isolate it from the main river channel, the principal source of water for the pond. The surface sediments are clayey, thus facilitating water storage during isolation.

The Salado River is a typical lowland river and the major autochthonous river of Buenos Aires province. It is the southern tributary of Río de la Plata Basin. Its length is approximately 700 km, with a slight slope (mean 0.107 m km^{-1}). Its watershed is approximately of 150 000 km^2. During the sampling period, river discharge fluctuated between 20 and 400 $m^3 s^{-1}$. The climate is humid–temperate. Mean annual precipitation is 899 mm (from 1952 to 1996; J. C. Cullen, pers. comm, 1997).

Indigenous trees (*Celtis tala* and *Acacia caven*) grow on the calcareous soils around the pond. During floods, the littoral zone is colonized by emergent hydrophytes (*Scirpus californicus*, *S. americanus* and *S. maritimus*); during the dry period, halophilous plants (*Salicornia ambigua*, *Chenopodium macrospermum and Heliotropium eurassianun*) are present in the basin.

In the pond basin, human activities are of low intensity. Extensive cattle breeding is the predominant local activity and there are no local sources of fertilizers. Waterfowl are common and they include permanent and migratory species (black-necked swans, neotropical cormorants, maguari storks, kelp gulls, coscoroba swans, red-gartered coots, southern screamers, white-faced ibis and ducks and plovers).

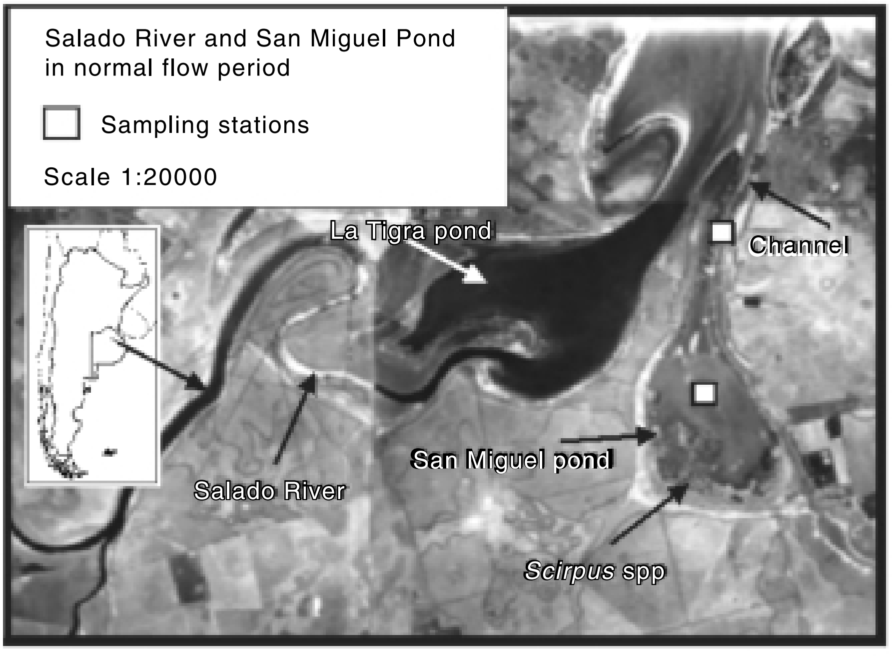

Fig. 1. Location of the sampling stations in San Miguel pond.

The pond is a spawning zone for mullet (*Mugil lisa*) and common carp (*Cyprinus carpio*). Both are abundant under conditions of a high water level.

METHODS

A sampling station was established in the middle of the pond (36°02′S 57°56′W) and samples were collected between May 1995 and May 1997. The following physical and chemical parameters were measured *in situ* (Horiba multimeter): pH, water temperature, conductivity, dissolved oxygen and turbidity. Transparency was estimated with a Secchi disc. Soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP) and total phosphorus (TP) were determined by the ascorbic acid method. The last two fractions were digested with acidic persulphate (American Public Health Association (APHA) 1995). Dissolved polyphenols and chlorine were determined according to APHA (1995). Whatmann GF/C filters were used for spectrophotometric determination of chlorophyll a concentrations (APHA 1995). The concentration of total suspended solids was measured according to APHA (1995). Concentrations of sodium and potassium were determined with a flame spectrophotometer. The dissolved organic matter was measured in an indirect way using colour concentration at an optical density of 440 nm with filtered water and Whatmann GF/C filters (Kirk 1983). Duplicate phytoplankton samples were collected with a 2 L Van Dorn bottle. Duplicate zooplankton samples were obtained with a 30 µm mesh net and 100 L was filtered. Phytoplankton and zooplankton counts were performed using the method of Utermohl (Utermöhl 1958) and Sedgwick-Rafter chambers, respectively. During the dry period, samples were obtained in the sector (channel) of the pond connected with the Salado River (Fig. 1). Multivariate analyses of cluster and principal components was performed. Principal Components Analysis (PCA) was made on correlation matrix and cluster analysis (CA) with a standardized matrix. Complete linkage and Euclidean distance were used in the cluster analysis. Cluster analysis was performed with measured physical factors to identify the main environmental forcing variables without the interference of internal organism variables.

RESULTS

The pond had an alkaline pH (8.23–9.20); conductivity ranged from 940 to 14 800 µS cm^{-1} and turbidity varied between 0 and 990 NTU (nephelometric turbidity units), with

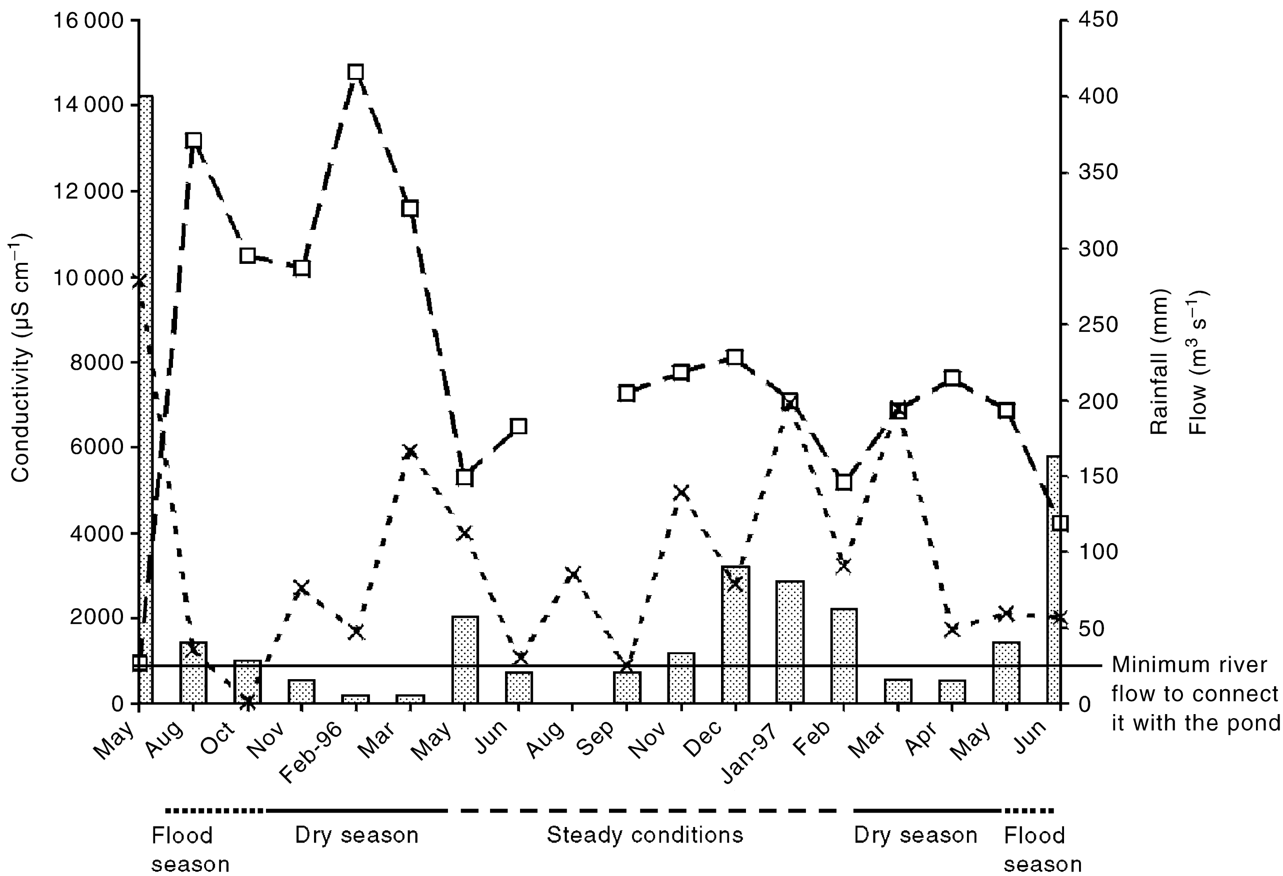

Fig. 2. Stages of the San Miguel pond during the sampling period according to changes in conductivity (-□-), rainfall (-×-) and flow (▨) of the Salado river.

highest values in November 1995. Transparency was low at 0.05–0.3 m. Dissolved oxygen was near saturation levels, except in autumn 1996 and 1997, in spring 1996 and in summer 1997. Soluble reactive phosphorus concentrations ranged from 14 to 104 µg L^{-1}, the average being 38.4 µg L^{-1}. Total phosphorus concentrations varied between 81 µg L^{-1} in March 1997 to 503 µg L^{-1} in December 1996. Total dissolved phosphorus ranged between 36 µg L^{-1} in March 1997 to 269 µg L^{-1} in October 1995. The percentage of SRP was highly variable with reference to TP; maximum percentages occurred under conditions of high water levels (39% May 1995; 51% August 1995; 44% June 1997). Water colour was yellowish brown because of the presence of organic soluble compounds. The values of colour measured with optical density at 440 nm ranged between 0.015 and 0.155 absorbance. The concentration of dissolved polyphenols substances varied between 0.5 and 3.9 mg L^{-1}; highest values coincided with maximum flow.

During 1995–1996, hydrological conditions of the river and the pond underwent changes due to low rainfall. River flow reached minimum values in the summer of 1996 (< 50 m^3 s^{-1}; Fig. 2).

Conductivity and concentrations of chloride, sodium and potassium fluctuated over a wide range. Maximum values were reached in the summer of 1996, during the dry period, when conductivity was 14 800 µS cm^{-1}, while the

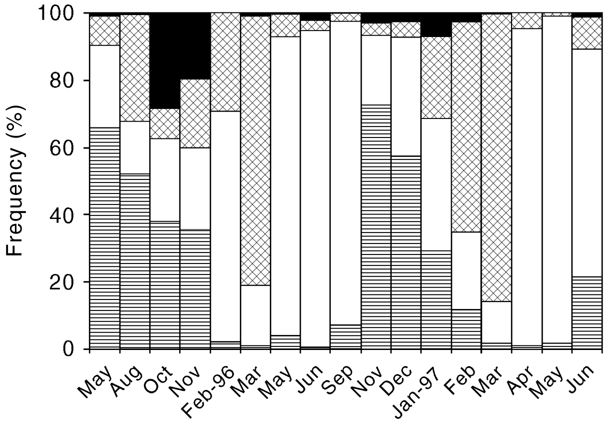

Fig. 3. Average percentage representation of phytoplankton groups (▤, cyanophytes; □, chlorophytes; ⊠, diatoms; ■, euglenophytes).

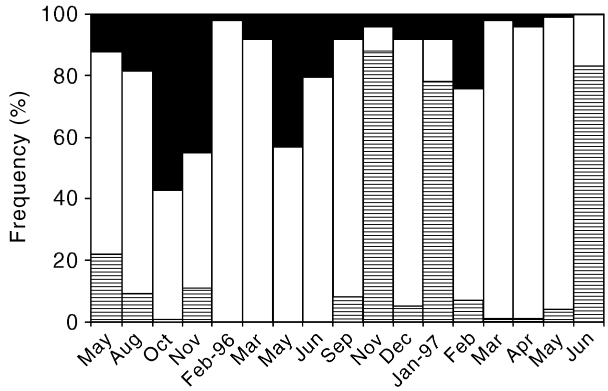

Fig. 4. Average percentage representation of zooplankton groups (▤, protozoans; □, rotifers; ■, crustaceans).

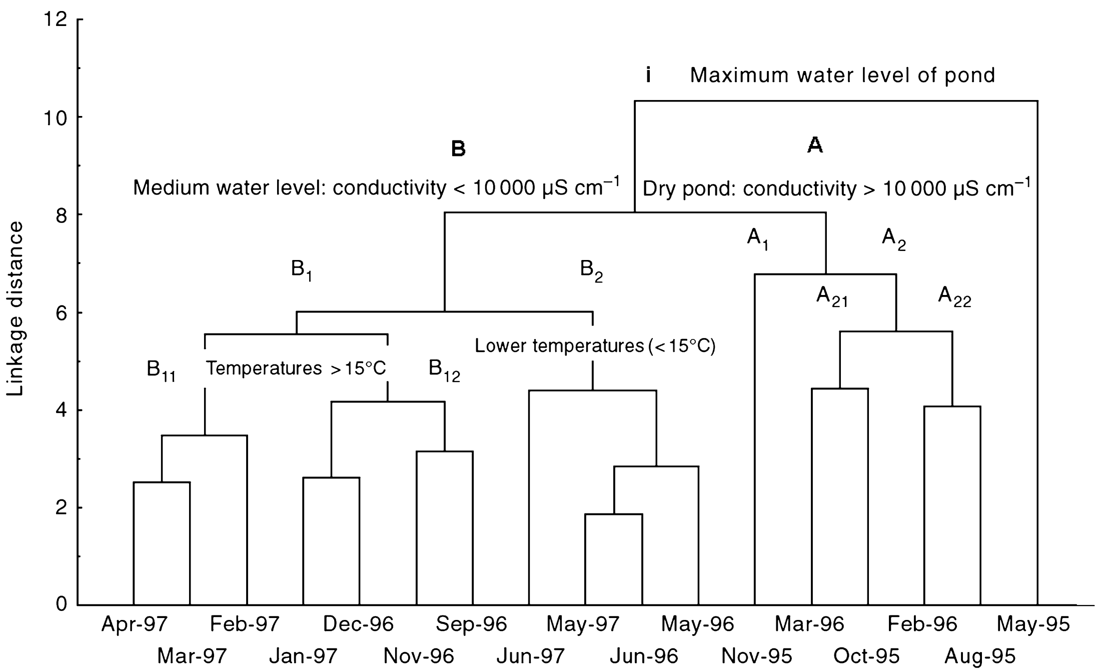

Fig. 5. Groups of physical and chemical parameters of San Miguel pond during the sampling period, as obtained by cluster analysis.

concentration of chloride, sodium and potassium was 3623, 2622 and 108.6 mg L^{-1}, respectively. Minimum values were found after heavy rain (240 mm in April 1995) and inflow of large amounts of river water (maximum river flow 400 $m^3 s^{-1}$ in May 1995), when conductivity was 940 µS/cm, and the concentration of chloride, sodium and potassium was 920, 192 and 16.5 mg L^{-1}, respectively. Except in May 1995, the pond was always mesohaline. The soil in the watershed is halomorphous and the water-table had high values of conductivity (14 300 µS/cm) and TP (488 µgL^{-1}; Fig. 2).

Phytoplankton was characterized by large numbers of coccoid green algae (*Monoraphidium contortum*, *M. minutum*, *Scenedesmus acutus*, *S. acuminatus*, *Kirchneriella obesa*, *K. aperta*, *Pediastrum boryanum*, *P. duplex*) and cyanophytes (*Anabaena sphaerica*, *Anabaenopsis circularis*, *A. tanganikae*, *Aphanocapsa delicatissima*, *Chroococcus dispersus*, *Merismopedia tenuissima*, *Oscillatoria tenuis* and *O. limnetica*). Maximum densities were recorded in autumn 1996 (175 248 individuals mL^{-1}) and minimum densities were found in late spring 1995 (1624 ind mL^{-1}), when the pond was dry. Chlorophytes showed the highest average percentage (49%), with maximum values found during conditions of clear water (Fig. 3). Cyanophytes and diatoms provided a similar contribution to the phytoplankton composition (23%). Cyanophytes occurred during the flood season, but planktonic diatoms (*Cyclotella meneghiniana*, *Nitzschia acicularis*, *Aulacoseira granulata* var. *angustissima*) dominated when the pond was isolated and benthic diatoms (*Entomoneis alata*, *Nitzschia amphibia*) were dominant during the dry period. Euglenophytes, which showed the lowest average values (5%), were recorded in late spring and early summer (Fig. 3).

Zooplankton was dominated by rotifers, in terms of both number of species and density, in most samples, representing 66% of all samples during the sampling period (Fig. 4). *Synchaeta* cf. *pectinata*, *Polyarthra vulgaris*, bdelloideans, *Brachionus caudatus*, *B. plicatilis*, *B. pterodinoides*, *B. angularis*, *Keratella tropica*, *Trichocerca pusilla* and *Filinia longiseta* were conspicuous. Cyclopoid copepods, mainly nauplii and adults, codominated with rotifers on certain occasions. Crustaceans represented an average percentage of 16% (Fig. 4). Protozoans represented 19%, with values over 70% on three occasions (November 1996 and January and June 1997; Fig. 4). The zooplankton reached a maximum density in November 1996 (11 230 ind L^{-1}), due to the presence of Tintinidae ciliates (*Codonaria fimbriata*) at 9882 ind L^{-1}, and in March 1997 (7720 ind L^{-1}), with *S.* cf. *pectinata* (2964 ind L^{-1}), *B. plicatilis* (1464 ind L^{-1}) and *F. longiseta* (1468 ind L^{-1}) as codominants. The density of zooplankton decreased in

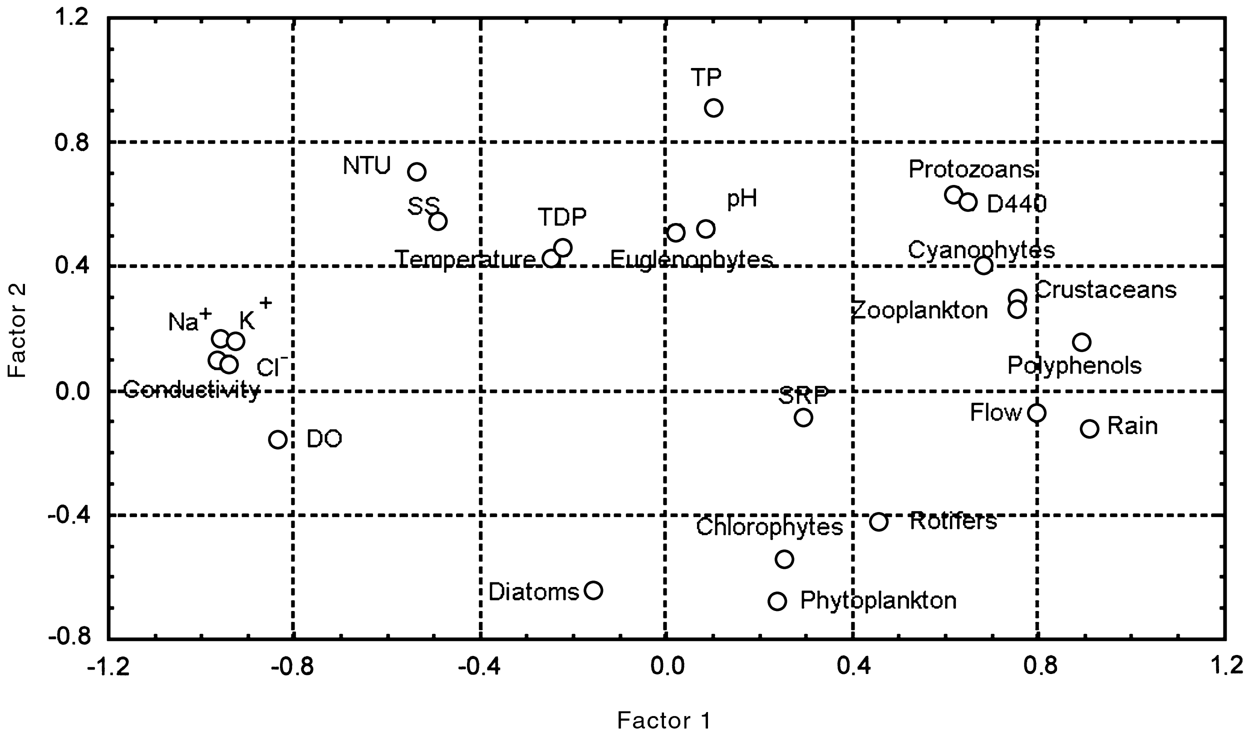

Fig. 6. Bidimensional Principal Components Analysis (PCA) representation of parameters and variables related with the dry and flood seasons (factor 1) and the importance of particulate material (factor 2). NTU, nephelometric turbidity units; SS, suspended solids; DTP, total dissolved phosphorus; TP, total phosphorus.

June 1996 to 167 ind L^{-1}, clearly dominated by *K. tropica* at levels of 128 ind L^{-1}.

Multivariate analysis

Conductivity was the main factor separating groups in the cluster diagram (Fig. 5). Two principal groups were identified: (i) group A, with a conductivity > 10 000 µS cm^{-1}; and (ii) group B, with a conductivity < 10 000 µS cm^{-1}. The sample taken in May 1995 (group i) was separated from other groups because the Salado River had reached its maximum flow (400 $m^3 s^{-1}$) and minimum conductivity (940 µS cm^{-1}) at that point.

Group A

This included all samples taken in 1995, except May, and those obtained during the summer months of 1996. The Salado River flow was low and the volume of the pond began to decrease, until it was completely dry, except for the connection sector with the river (channel), from December 1995 to March 1996. The bottom of the pond was colonized by halophytes (Chenopodiaceae).

This group comprised two subgroups: (i) group A1 (November 1995), with maximum values for turbidity and suspended solids (999 NTU and 1.08 g L^{-1}, respectively); and (ii) group A2, with lower values. Group A2 was further split into groups A21 and A22. Group A21 (March 1996 and October 1995) had the same values of conductivity (10 000 µS cm^{-1}) and low concentrations of SRP (< 30 µg L^{-1}), while group A22 (August 1995 and February 1996) showed higher conductivity values (13 000 µS cm^{-1}) and twice the concentration of SRP (approximately 60 µg L^{-1}).

Group B

This included two subgroups defined by water temperature. Subgroup B1 had temperatures > 15°C and subgroup B2 had temperatures < 15°C. Group B1 was comprised of samples obtained during seven spring–summer months, with different conductivity values (< 7000 and > 7000 µS cm^{-1}), while group B2 was comprised of 4 months (late autumn–winter) with dissimilar concentrations of SRP.

After identifying the main physical factors responsible for the changes that took place in the pond, a PCA, including densities of phyto- and zooplankton groups, was undertaken.

On the first axis (25% of the total variance), the same situation of low and high water was observed for physical–chemical parameters, adding rain and flow as other external water sources. Zooplankton, at positive coordinates of the axis, was better correlated with the water volume of the pond. Ciliates and crustaceans were correlated with this condition for different reasons. Ciliates, mainly represented by tintinides, were incorporated from the Salado River and crustaceans were favoured by minor

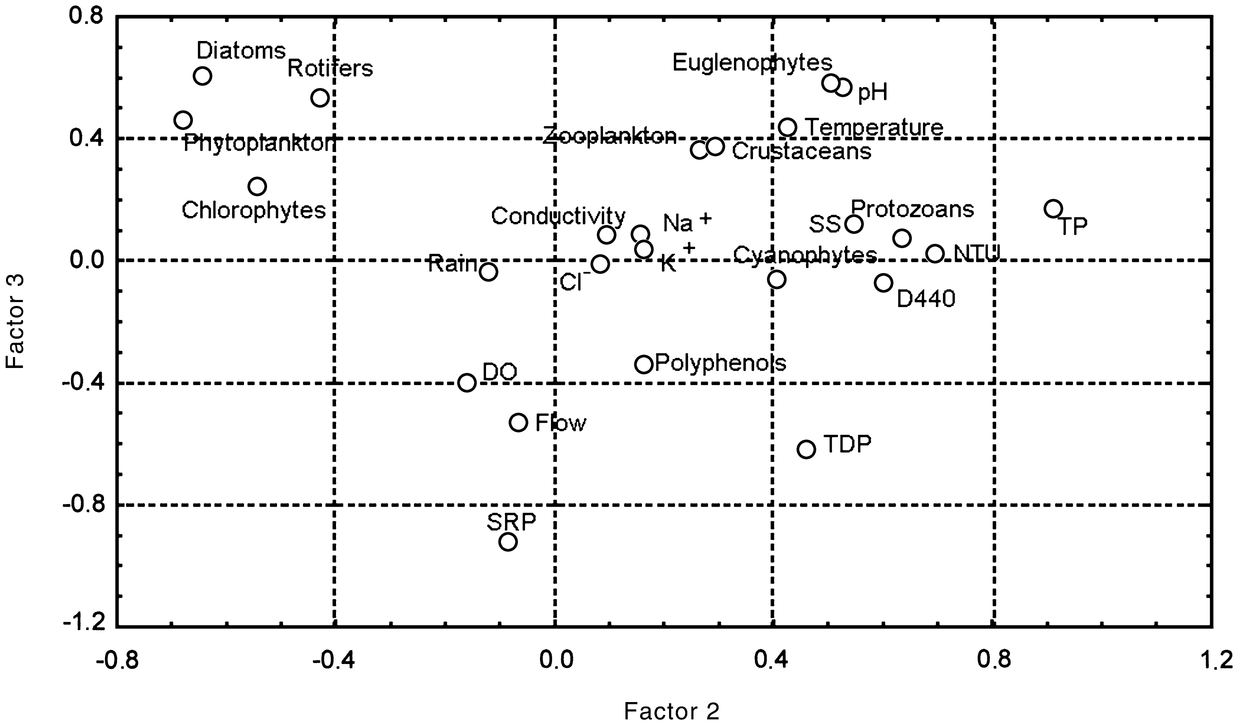

Fig. 7. Bidimensional Principal Components Analysis (PCA) representation of parameters and variables related with the importance of particulate material (factor 2) and connection with the Salado river (factor 3). NTU, nephelometric turbidity units; SS, suspended solids; DTP, total dissolved phosphorus; TP, total phosphorus.

conductivity values. Phytoplankton did not show a defined relationship with these conditions (Fig. 6).

The second axis (17% of the variance) showed changes in suspended solids. The relationship of suspended solids with organisms was closer than that for variables on the first axis. It is interesting to note that euglenophytes and ciliates were located in the negative part of the axis, related to high concentrations of particles and organic matter, which represent their main food. Only cyanophytes would be favoured by conditions of high turbidity, while other algae groups, namely chlorophytes and diatoms, were situated at the other extreme of the axis, because these algae prefer less turbid waters. Crustaceans, mainly *Cyclopoid nauplii*, were located on the negative part of the axis, relating to the consumption of bacteria as complementary food (Fig. 6).

The third axis (13% of the total variance) represented a condition of water inflow with high dissolved phosphorus values related to river flow. Plankton was negatively related to this condition and the density of plankton decreased, while some diatoms and rotifers (*B. plicatilis*) showed a positive relationship with this condition (Fig. 7).

DISCUSSION

Limnological characteristics of San Miguel pond were related to the hydrological cycle of the Salado River, like other backwater systems (Heiler *et al.* 1994). This influence was detected on the plankton community, phosphorus concentrations and salinity conditions.

The natural behaviour of the Salado River showed remarkable decreases in conductivity during periods of flooding because of the contribution of surface run-off and increases in conductivity during dry periods because of the contribution of underground water. These conditions, similar to coastal environments, were also reflected in San Miguel pond, with marked changes in volume, conductivity and suspended and solute materials (Quintana *et al.* 1998b). Nevertheless, these changes were not related to estuary effects, despite the location of the estuary 40 km from the pond.

Changes in conductivity in the pond were clearly associated with the water level of the pond, which depends on river flow. Evaporation and the contribution of ground water are factors to be taken into account when considering conductivity when the pond is isolated from the river because of the hydrological characteristics of the region (Dangavs 1973; Dangavs & Merlo 1980). Conductivity, temperature, particulate materials, suspended solids and the concentration of SRP influence the dynamics in the pond.

There were a number of different zooplankton rotifer species and individuals in the pond, which coincides with the results of Heiler *et al.* (1994) in a Danubian backwater. The same species were recorded, except for the

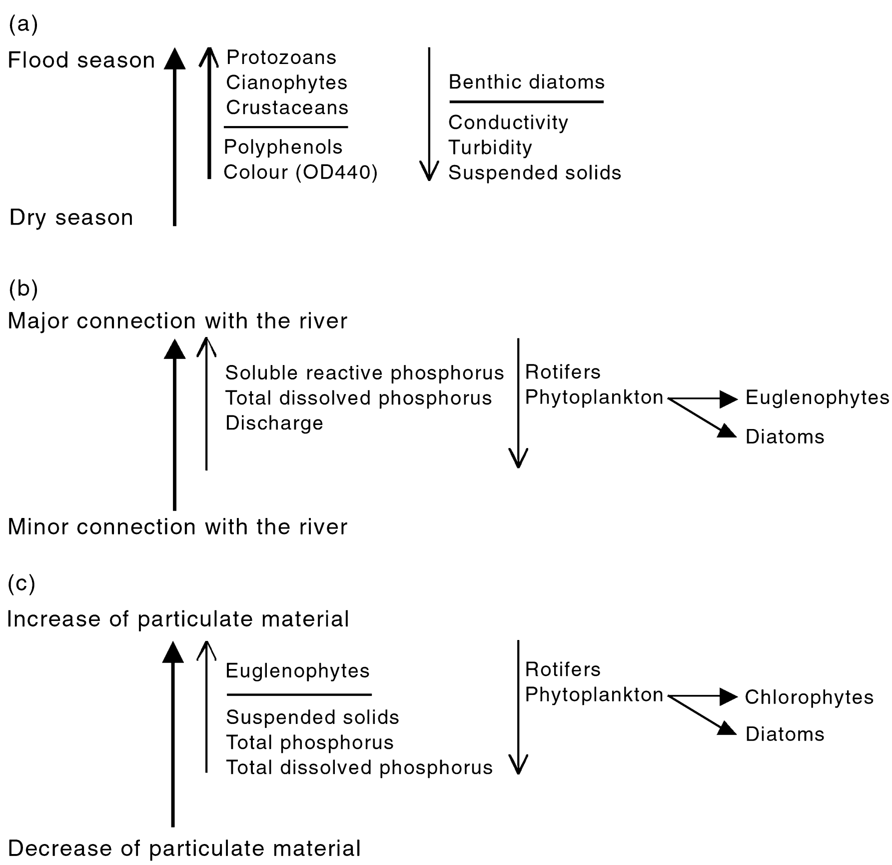

Fig. 8. Proposed scheme for the different phases as determined in the pond during the sampling period. (a) Main groups of organisms and physical and chemical characteristics affected during hydrological seasonal changes. (b) Main organism groups, phosphorus fractions and water input influenced by connection of the pond to and isolation of the pond from the main course of the Salado river. (c) Main planktonic group, concentrations of suspended solids and phosphorus fractions altered by changes in particulate materials.

presence and abundance of *B. plicatilis* during periods of high salinity. A high density of rotifers was associated with maximums in the numbers of chlorophytes and diatoms (Nogrady; Lair *et al.* 1998), emphasizing the importance of internal biological variables for rotifers (José de Paggi & Paggi 1998). Connection with the river, increases in colour and turbidity, as well as increases in the concentration of soluble polyphenols are detrimental factors affecting the density of rotifer because these conditions affect directly the abundance of chlorophytes. In contrast with rotifers, ciliates responded positively to external variables such as rains and river flow with control of colour, turbidity and conductivity. The increase in water colour associated with dissolved organic compounds was related to an increase in bacteria and their consumption by ciliates (Pratt & Cairns 1985; Dyer *et al.* 1986; Lair *et al.* 1998). *Codonaria fimbriata* (tintinidae ciliate), a common plankton component in the Samborombón bay (Río de la Plata Estuary), was recorded at high densities on two occasions.

Crustaceans were abundant during the flood season with low concentrations of suspended solids and low conductivity values. *Daphnia spinulata* was only recorded in May 1995 with the lowest values of suspended solids and conductivity (Quintana *et al.* 1998a), while *Moina micrura*, *Ceriodaphnia* cf. *dubia* and *Acanthocyclops robustus* were found under conditions of medium values of suspended solids. This characteristic was also noted by Hart (1992) and Lougheed & Chow-Fraser (1998). The dominance of predator cyclopoid species allows us to interpret a trophic relationship with various zooplankton prey (Wickham 1995). In agreement with Heiler *et al.* (1994), zooplankton attained high densities when the pond was isolated from the river and maintained a high and medium water level.

Chlorophytes and cyanophytes prevailed, coinciding with the results of studies performed by Izaguirre & Vinocur (1994a) and O'Farrel (1993) in other ponds of this basin. Planktonic algae have a dissimilar behaviour related to factors that determined different conditions in the pond. Cyanophytes were related to an increase in river discharge, a decrease in conductivity and a higher water level in the pond. Under these conditions, high levels of colour and dissolved polyphenols were also recorded. Consequently, cyanophytes were favoured and their density increased. In contrast, chlorophytes and diatoms have a strong relationship with suspended solids. An increase in suspended solids was related to river inflow. This disturbance caused a decline in the numbers of chlorophytes (Happey-Wood 1991) and diatoms (Patrick 1977). Therefore, cyanophytes were favoured by increases in turbidity (Reynolds 1984). Diatoms achieved their maximum levels when the river connection was low; this behaviour was also observed in the alluvial plain environments of the Paraná River (Anselmi de Manavella & García de Emiliani 1995). The density of diatoms was highest in late summer of March 1996 and 1997, despite hydrological differences between these two years. The same species dominated when the pond was dry and conductivity reached 11 600 µS cm^{-1} in March 1996 and when the pond had a high water level and conductivity was 6868 µS cm^{-1} in March 1997. This situation suggests that these algae have more association with a seasonal component than with salinity and hydrological conditions. The species richness and density of euglenophytes was relatively insignificant. These algae were related to pH and water temperature. The last relationship (of euglenophytes with pH and water temperature) could explain why the abundance of euglenophytes changed seasonally (Barone & Nacelli Flores 1994). In addition, euglenophytes were less abundant during periods of river connection. Their high density coincided with conditions of isolation and a decrease in the concentration of SRP (García de Emiliani 1997).

The results of the present study suggest that the major regulatory factor in the pond is the onset of the dry season, because of a prolonged phase of isolation that produces an important increase in conductivity, turbidity and suspended solids. A marked decrease of the abundance of euplanktonic forms is observed and an incorporation of benthic species (diatoms: *E. alata, N. amphibia, Cocconeis placentula*; rotifers: *B. plicatilis* and bdelloideans) occurs. A high and sudden increase in river flow characterizes the flood season with an inflow of dissolved allocthonous material and a decrease in conductivity. This situation favours a conspicuous dominance of cyanophytes (*Raphidiopsis mediterranea, O. limnetica*), protozoans (*Arcella hemisphaerica*, *Difflugia gramen*) and crustaceans (*M. micrura, D. spinulata*; Fig. 8a). Changes in the form of dissolved phosphorus and the composition of plankton were correlated with different degrees of hydrological connection with the Salado River. Increases in SRP and TDP associated with a decrease in some planktonic groups were observed within the channel. Euglenophytes (*Euglena deses, E. oxyuris, E. tripteris*), diatoms (*Amphora ovalis, Caloneis oregonica, Gyrosigma attenuatum, Surirella ovata*) and rotifers (*B. angularis, B. caudatus, B. calyciflorus, Trichocerca* sp.) prevail during pond isolation (Fig. 8b). The quantity of particulate material related to the aforementioned phases must be included as one of main factors determining important changes in environmental conditions and dominance replacement of planktonic groups. The increase in particulate material is associated with the highest TP values as a consequence of the phosphorus–particle relationship. Euglenophytes (*Euglena gasterosteus, E. retronata*) were related to this condition, but the reason for this has not yet been indentified. The opposite situation (a decrease in particulate material) produces clear water conditions, with the dominance of chlorophytes (*M. minutum, Scenedesmus bicaudatus, S. intermedius*) and planktonic diatoms (*C. meneghiniana, N. acicularis*). Rotifers (*P. vulgaris, K. tropica, F. longiseta, Synchaeta* sp.) are the most abundant zooplankton group as a trophic response(Fig. 8c).

As demonstrated above, the pond is highly dynamic, including its biological and physical conditions. The system supports extreme conditions and, despite being an open system during most of the year, it responds to lentic characteristics. Endorheic conditions (dry season) alternate with conditions of a typical pampean pond (normal flow phase; Izaguirre & Vinocur 1994b). The present results allow us to assume that other basin ponds could also show endorheic behaviour in non-regulated conditions.

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