Research Article

Seasonal variation and influence of turbidity and salinity on the zooplankton of a saline lake in central Argentina

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ABSTRACT. The limnology of saline water bodies at other latitudes is fairly well known, but in Argentina such studies have only recently begun. The applicability of many conclusions regarding the functioning of these environments around the world is limited due to the scant ecological knowledge of some endemic species recorded in the assemblages of Argentine lakes. The aims of this work were to determine the effects of salinity and inorganic turbidity on the taxonomic composition, abundance, and zooplankton biomass in a shallow, hypereutrophic, mesosaline lake in the north of La Pampa province characterized by seasonality, variations in level and salinity, and the lack of macrophytes and fishes, and to compare it with other shallow lakes of the province. We found important differences with other saline lakes: the species richness was lower; the mean abundance of zooplankton was between four and six times higher; and rotifers, which were not affected by salinity or the concentration of inorganic suspended solids, were numerically predominant. Crustaceans, on the other hand, were negatively affected by these environmental factors. Biomass was two-fold higher than that recorded in the same period in two shallow lakes of Pampa, with similar nutrient concentrations but lower salinities.

Keywords: saline lakes, inorganic turbidity, zooplankton biomass, *Boeckella poopoensis*, Argentina.

Variación estacional e influencia de la turbidez y la salinidad sobre el zooplancton de un lago salino de la región central de Argentina

RESUMEN. La limnología de los cuerpos de agua salinos de otras latitudes es bastante conocida, pero en Argentina se ha comenzado a estudiar recientemente. Muchas conclusiones sobre el funcionamiento de estos ambientes a nivel mundial son de aplicación restringida debido a que las asociaciones registradas en los lagos argentinos tienen algunas especies endémicas, cuyo conocimiento ecológico es escaso. Los objetivos de este trabajo fueron determinar los efectos de la salinidad y la turbidez inorgánica sobre la composición taxonómica, abundancia y biomasa zooplanctónica en un lago somero mesosalino hipereutrófico del norte de La Pampa, caracterizado por su temporalidad, variaciones del nivel y salinidad, carencia de macrófitas y peces, y compararlo con otros lagos someros de la provincia. Se encontraron importantes diferencias con otros lagos salinos, la riqueza específica fue menor, la abundancia media del zooplancton fue entre 4 a 6 veces superior y el predominio numérico fue de los rotíferos, que no fueron afectados por la salinidad o la concentración de sólidos suspendidos inorgánicos, a diferencia de los crustáceos, que fueron afectados negativamente por estos factores ambientales. La biomasa fue dos veces más elevada que la registrada en el mismo período en dos lagos someros pampeanos con parecida concentración de nutrientes pero con salinidades menores.

Palabras clave: lagos salinos, turbidez inorgánica, biomasa zooplanctónica, *Boeckella poopoensis*, Argentina.

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INTRODUCTION

Saline water bodies can be defined as those with salinities equal to or higher than 3 g L^{-1} (Hammer, 1986). They are widely distributed in the world and are abundant in arheic and endorheic basins of arid and semiarid regions (Williams, 2002). They are highly influenced by the human activities carried out in their basins, which cause changes in their characteristics, with the consequent loss of biodiversity (Velasco *et al*., 2006).

The limnology of water bodies in other latitudes is relatively well-known, whereas, in Argentina, there are only a few reports on the saline lakes of Buenos Aires (Olivier, 1955; Ringuelet, 1968, 1972) and Santa Fe provinces (José de Paggi & Paggi, 1998), the northwest (Locascio de Mitrovich *et al*., 2005; Villagra de Gamundi *et al*., 2008) and Córdoba province (Bucher, 2006). Therefore, the information on their taxonomic composition, abundance and zooplankton biomass and its variation is still scarce.

We have thus recently started studies on the ecology and zooplankton of saline lakes of La Pampa province, in the semiarid center of Argentina (Echaniz *et al*., 2005, 2006; Vignatti *et al*., 2007). However, in those works, we determined mainly the population density but not the biomass in relation with environmental parameters.

Many of the conclusions on the functioning of saline lakes are applicable for the shallow lakes of La Pampa, but little is known on the ecology of the assemblages recorded in the central region of Argentina, where some species, especially crustaceans, are endemic to the neotropical region (Adamowicz *et al*., 2004; Echaniz *et al*., 2005, 2006; Vignatti *et al.*, 2007).

The aims of this work were to analyze the variations in the main limnological parameters and the zooplankton of an inorganic turbid shallow lake with high salinity, located in the north of La Pampa province, along its annual cycle, and to test the following hypotheses: i) that the high concentration of dissolved solids affects the taxonomic composition and abundance of the zooplankton community, ii) that inorganic turbidity has detrimental effects on the development of zooplankton (Quirós *et al*., 2002; Torremorell *et al*., 2007), and iii) that at nutrient concentrations equal to those of other Pampean water bodies with lower salinity, this lake has a higher biomass of zooplankton, in agreement with that reported by Evans *et al*. (1996) for lakes of Canada.

MATERIALS AND METHODS

Study area

The Prato shallow lake is located in the north of La Pampa province (64º15´W, 35º26´S) (Fig. 1), in a plain region with soft hills and covered with a sand layer of variable thickness (Calmels & Casadío, 2005), in the ecotone between the phytogeographical provinces of the Pampean Plains and the Thorny Forest (Cabrera, 1976). Has a surface of 62.8 ha and a maximum depth of 2.6 m.

The mean annual precipitations of the region are around 700 mm (Casagrande *et al*., 2006), with a maximum in summer, but the potential evapotranspiration is about 800 mm year^{-1} (Roberto *et al*., 1994). The lake is fed by rainfalls and, to a lesser extent, by phreatic waters. It is an arheic water body, which loses water by evaporation or infiltration and suffers large level fluctuations. The land of its basin is used for agriculture and extensive cattle breeding. It has a regular shape, its bottom sediments consists mainly of sands, and there is absence of macrophytes and ichtyc fauna.

Field and laboratory work

Samples were collected monthly from December 2005 until December 2006, except in August, in the three stations located along the longest axis of the lake.

Water temperature, dissolved oxygen concentration (oximeter Lutron® OD 5510), water transparency (Secchi disc), and pH (digital pH meter Cornning® PS 15) were determined in each station. Water samples were taken and kept refrigerated until their analysis in the laboratory.

Two quantitative zooplankton samples were collected in each site with a 10-l Schindler-Patalas trap, with a 0.04 mm mesh size, and one qualitative sample with a net 22 cm in diameter and a similar mesh size. All the samples were anesthetized with CO_2 and kept refrigerated until fixation, with the aim to avoid contractions that may deform the individuals collected.

Salinity was determined by means of the gravimetric method with drying at 104°C. Chlorophyll-*a* concentration was measured by extraction with aqueous acetone and spectrophotometry (spectrophotometer Metrolab 1700) (Arar, 1997; APHA, 1999), total nitrogen by means of the Kjeldahl method, and total phosphorus by digestion with potassium peroxodisulfate in acid medium and UV-visible spectrophotometry (APHA, 1999).

The content of suspended solids was determined with fiberglass filters (Microclar FFG047WPH), dried at 103-105°C until constant weight and calcined at 550ºC (EPA, 1993). Macro-and microzooplankton (Kalff, 2002) were counted under a stereoscopic and a conventional optical microscope, in Bogorov and Sedgwick-Rafter chambers respectively.

Conventional measurements of the individuals of each species sampled were taken with a Carl Zeiss ocular micrometer, and length-dry weight formulae were used to determine zooplankton biomass (Dumont

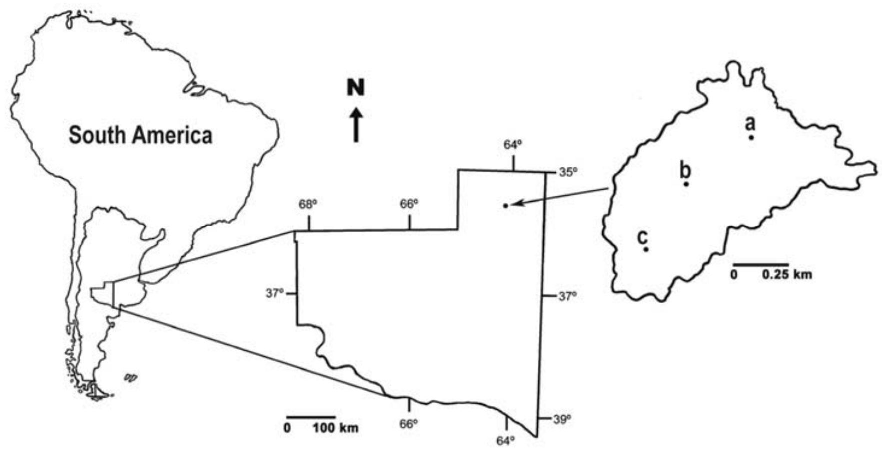

Figure 1. Location of the Prato shallow lake in the north of La Pampa province, Argentina. a, b and c: sampling sites.

Figura 1. Localización de la laguna de Prato en el norte de la provincia de La Pampa, Argentina. a, b y c: sitios de muestreo.

et al., 1975; Rosen, 1981; McCauley, 1984; Culver *et al*., 1985; Kobayashi, 1997).

Non parametric ANOVA Kruskal Wallis test, Spearman's correlations and principal component analysis (PCA) (Zar, 1996; Mangeaud, 2004; Pérez, 2004) were carried out by means of the PAST software version 1.94b (Hammer *et al*., 2001).

RESULTS

Physical and chemical parameters

Spatial variations of this parameters were not significant, so we used mean values. The mean concentration of total dissolved solids in the water was 25.3 g L^{-1}, but increased as the level of water decreased (Fig. 2 and Table 1), and was characterized by the predominance of Cl^- and Na^+, which were higher than 49% and 92% of the anions and cations respectively. The pH was high (9.02 ± 0.16) and relatively stable (Table 1).

The water temperature varied seasonally, with a maximum of 26.8°C in December 2005 and a minimum of 8.1°C in July 2006 (Fig. 3). The concentration of dissolved oxygen was also variable, oscillating between 9.8 mg L^{-1} in December 2005 and 1.3 mg L^{-1} in April 2006 (Fig. 3). The concentration of nutrients was high and variable (Table 1). Chlorophyll-*a* concentration correlated with water temperature (R = 0.73; P = 0.0065) and presented a maximum in February 2006, but was relatively low and stable during the rest of the period studied (Fig. 4).

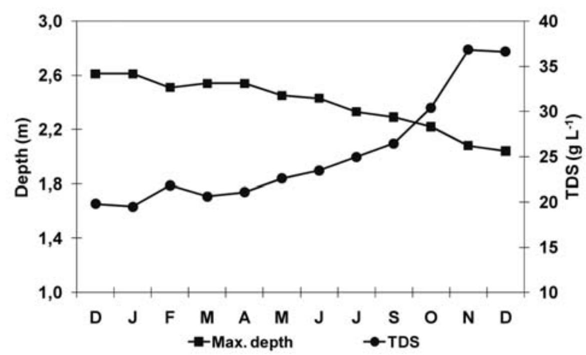

Figure 2. Monthly variation of maximum depth and concentration of total dissolved solids (TDS) in Prato shallow lake.

Figura 2. Variación mensual de la profundidad máxima y de la concentración de sólidos disueltos totales (TDS) en la laguna de Prato.

The concentration of organic suspended solids was higher during the first four months and was significantly correlated with chlorophyll-*a* concentration (R = 0.65; P = 0.022), whereas that of inorganic suspended solids was more abundant during the last six months (Fig. 4). We found a significant correlation between the concentration of inorganic suspended solids and that of total phosphorus (R = 0.75; P = 0.005).

Water transparency was reduced (0.17 m ± 0.06) and variable along the year (Fig. 5, Table 1), and was significantly correlated with the concentration of inorganic suspended solids (R = -0.89; P = 0.0001), but not significantly correlated with that of organic suspended solids (R = 0.02; P = 0.940) or chlorophyll-*a* concentration (R = 0.40; P = 0.194) (Fig. 8).

Table 1. Main physical and chemical parameters registered in Prato shallow lake during the studied period. TP: total phosforus, TN: total nitrogen.

Tabla 1. Principales parámetros físico químicos registrados en la laguna de Prato durante el período estudiado. TP: fósforo total, TN: nitrógeno total.

	Mean	Min.	Max.
Transparency (m)	0.17	0.08	0.31
Salinity (g L^{-1})	25.34	19.47	36.84
pH	9.02	8.9	9.32
TP (mg L^{-1})	18.1	11.25	25
TN (mg L^{-1})	28.62	20.63	35.63
TN:TP	1.58	1.3	2.5
Chlorophill-*a* (mg m^{-3})	30.79	9.35	94.79
Dissolved oxigen (mg L^{-1})	6.3	1.3	9.8
Inorganic suspended solids (mg L^{-1})	38.03	10	63.2
Organic suspended solids (mg L^{-1})	37.52	16	78.7

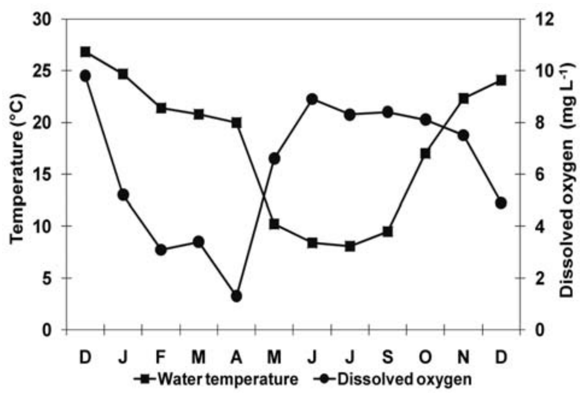

Figure 3. Monthly variation of water temperature and dissolved oxygen concentration in Prato shallow lake.

Figura 3. Variación mensual de la temperatura del agua y de la concentración de oxígeno disuelto en la laguna de Prato.

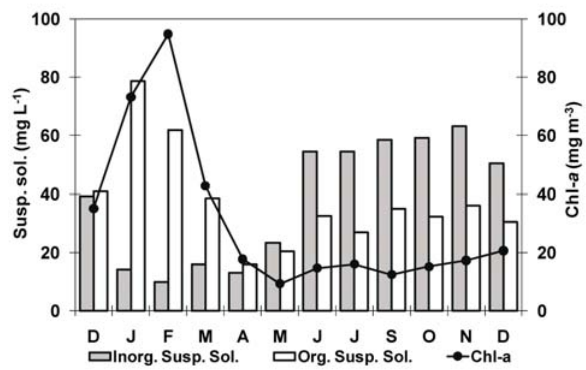

Figure 4. Monthly variation of the concentration of inorganic and organic suspended solids and chlorophyll-*a* in Prato shallow lake.

Figura 4. Variación mensual de la concentración de sólidos suspendidos inorgánicos y orgánicos y de clorofila-*a* en la laguna de Prato.

Zooplankton

We recorded a total of six species (Table 2). Among crustaceans, *Moina eugeniae* and the calanoid *Boeckella poopoensis* were constantly present, whereas *M. macrocopa* and the harpacticoid *Cletocamptus deitersi* were recorded along four and nine months respectively. Among rotifers, *Brachionus plicatilis* was present along 10 months, whereas *B. dimidiatus* along only 2 months (Table 2). Variations of micro- and macrozooplankton abundance between sampling sites were not significant.

The spatial variations of the zooplankton abundance and biomass were not significant, so we used mean values.

The density of the community presented two peaks during the warmer months (Fig. 6), produced mainly by rotifers (*B. dimidiatus* in January 2006 and *B. plicatilis* in December 2006). Although their abundance was very variable and there were months during which they were not recorded, they presented the highest annual mean abundance (Fig. 7, Table 2). The PCA, whose first two components allowed explaining more than 60% of the variance, showed positive correlations between their abundance, the concentrations of organic suspended solids, chlorophyll-*a* and water temperature, but negative correlations between their abundance and salinity and inorganic suspended solids concentrations (Fig. 8).

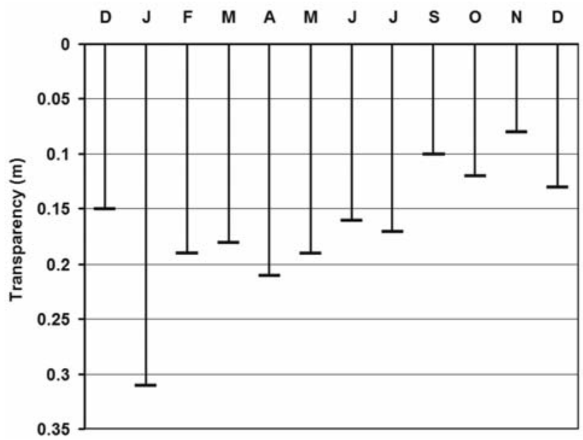

Figure 5. Monthly variation of water transparency in Prato shallow lake.

Figura 5. Variación mensual de la transparencia del agua en la laguna de Prato.

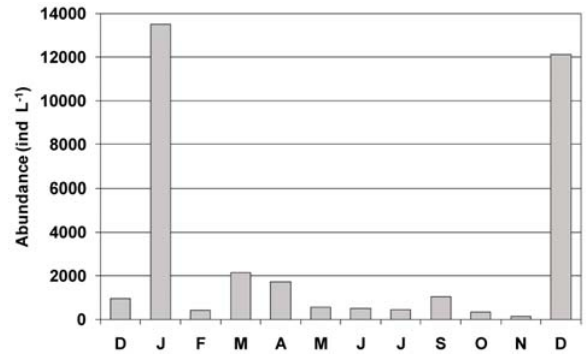

Figure 6. Monthly variation in the total zooplanktonic abundance in Prato shallow lake. The values are the mean of the three sampling stations.

Figura 6. Variación mensual de la abundancia total zooplanctónica en la laguna de Prato. Los valores corresponden al promedio de las tres estaciones de muestreo.

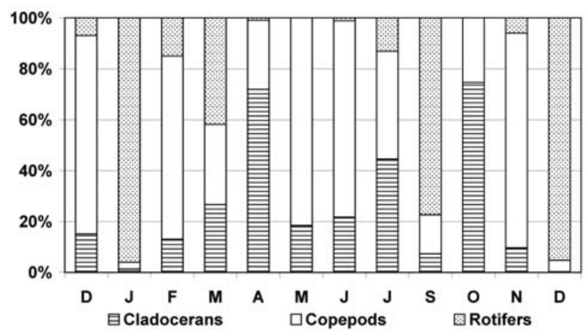

Figure 7. Monthly variation in the percent composition of the zooplanktonic abundance during the studied period. The values are the mean of the three sampling stations.

Figura 7. Variación mensual de la composición porcentual de la abundancia zooplanctónica durante el período estudiado. Los valores corresponden al promedio de las tres estaciones de muestreo.

Among crustaceans, the most abundant species was *B. poopoensis* followed by *M. eugeniae* (Table 2). *B. poopoensis* presented its maximum abundances at the beginning of the summer, whereas *M. eugeniae* and *M. macrocopa* did so during fall. The PCA showed positive correlations between crustacean abundance, chlorophyll-*a* concentration and water transparency, but negative ones between crustacean abundance**,** salinity and inorganic suspended solids (Fig. 8).

The mean biomass of the zooplankton community (6614.1 µg L^{-1} ± 4336.9) presented a peak during fall and a minimum in spring (Fig. 9). In all cases, the highest contribution was that of crustaceans (Fig. 10), among which *B. poopoensis* represented more than their biomass and salinity and organic suspended solid concentrations. The contribution of rotifers was important only in December 2006, when it represented 29.5% of the total (Fig. 10) and the PCA also showed a positive correlation with abundance and water temperature (Fig. 8).

DISCUSSION

The Prato lake is located in the western boundary of the Pampean plain (Cabrera, 1976), and although it shares characteristics with typical Pampean lakes of the province of Buenos Aires (Ringuelet, 1968 and 1972; Torremorell *et al*., 2007), such as the reduced depth and the polymixis, it differs from them because of its seasonality and great variations in water level and salinity.

These fluctuations are typical of most shallow lakes of La Pampa province, which are mainly fed by precipitations and lose water by evaporation (Echaniz *et al*., 2005, 2006; Vignatti *et al*., 2007). This phenomenon is particularly important because these lakes are located in a region where the evapo-transpiration overpasses precipitations (Roberto *et al*., 1994). This characteristic was reflected in this lake by the decrease of almost 0.6 m in the water level and an increase in the concentration of dissolved solids, which, at the end of the study, was almost twice of the initial value, although it was within the mesosaline range (Hammer, 1986).

The absence of variations in the spatial distribution of physical and chemical parameters and zooplank-tonic abundance and biomass of this lake was

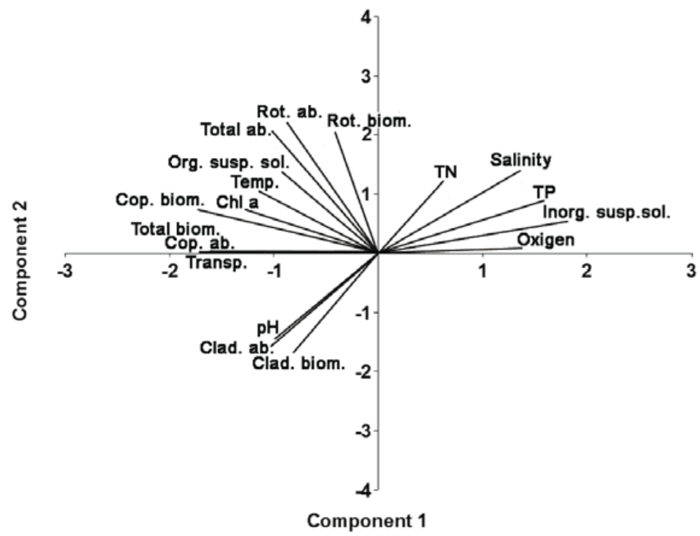

Figure 8. Results of the Principal Component Analysis (PCA). Rot.: rotifers, Clad.: cladocerans, Cop.: copepods, Ab.: abundance, Biom.: biomass, TN and TP: total nitrogen and phosphorus concentrations, Inorg. susp. sol.: inorganic supended solids, Org. susp. sol.: organic suspended solids, Transp.: water transparency, Temp.: water temperature, Chl a: chlorophyll concentration.

Figura 8. Resultados del Análisis de Componentes Principales (ACP). Rot.: rotíferos, Clad.: cladóceros, Cop.: copépodos, Ab.: abundancia, Biom.: biomasa, TN y TP: concentraciones de nitrógeno y fósforo totales, Inorg. susp. sol.: sólidos suspendidos inorgánicos, Org. susp. sol.: sólidos suspendidos orgánicos, Transp.: transparencia del agua, Temp.: temperatura del agua. Chl a: concentración de clorofila.

Table 2. List of species recorded, mean, minimum and maximum abundance and biomass and relative frequency of their appearance in the samples.

Tabla 2. Lista de las especies registradas, abundancia y biomasa medias, mínimas y máximas y frecuencia relativa de aparición en las muestras.

	Frequency (%)	Abundance (ind L^{-1})			Biomass (μg L^{-1})		
		Mean	Min.	Max.	Mean	Min.	Max.
Cladocerans							
Moina eugeniae Olivier, 195	100	219.1	14	1235.3	1611.4	153	8190.2
Moina macrocopa (Straus, 1820)	33.3	28	0	312.7	185.54	0	2101.1
Copepods							
Boeckella poopoensis Marsh, 1906	100	369.7	72.7	737.3	4236.3	512.2	9436
Cletocamptus deitersi (Richard, 1897)	66.7	4.2	0	13.5	4.28	0	17.2
Rotifers							
Brachionus plicatilis Müller, 1786	83.3	1330.4	0	11546.7	412	0	3002.1
Brachionus dimidiatus Bryce, 1931	16.7	872.5	0	10467	34.9	0	418.7

probably related to their shallow depth, the shape of their basin (flat and free from obstacles) and to wind action, all of which determine their polymictic condition and the permanent mixture of water.

Another feature shared by most lakes of La Pampa is the predominance of Cl^- and Na^+, with proportionally low bivalent cations concentrations (Ca^{++} and Mg^{++}) (Echaniz *et al.*, 2006).

The lake studied presented some characteristics that differentiate it from other environments of La Pampa with similar salinity, in particular, among the physical factors, its reduced transparency, which was

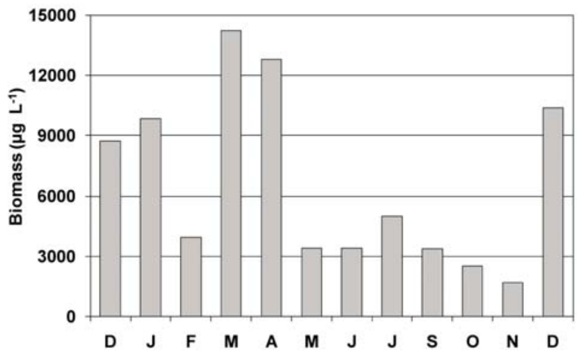

Figure 9. Monthly variation in total zooplankton biomass during the studied period. The values are the mean of the three sampling stations.

Figura 9. Variación mensual de la biomasa total del zooplancton durante el período estudiado. Los valores corresponden al promedio de las tres estaciones de muestreo.

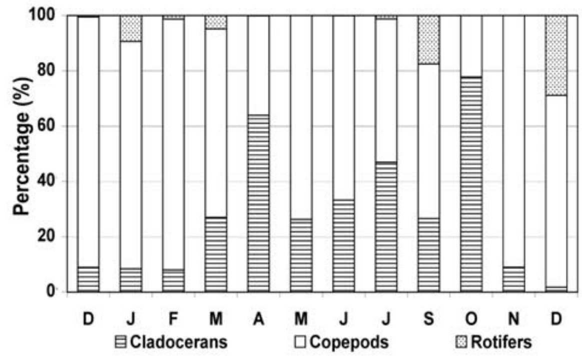

Figure 10. Monthly variation in the percent composition of zooplankton biomass. The values are the mean of the three sampling stations.

Figura 10. Variación mensual de la composición porcentual de la biomasa del zooplancton. Los valores corresponden al promedio de las tres estaciones de muestreo.

almost 10 times lower than that recorded in previous studies (Echaniz *et al*., 2006; Vignatti *et al*., 2007). This high turbidity was due to the differential predominance of the two fractions of suspended solids along the year. Those of organic origin were higher during the summer, when the concentration of chlorophyll-*a* was also high, whereas those of inorganic origin were higher during winter and spring, when more intense winds are present (Cano, 1980). Due to the scarce depth of the lake, these winds cause the removal and resuspension of bottom sediments (Scheffer, 1998; Borell Lövstedt & Bengtsson, 2008). In addition, unlike that found in similar lakes of the province, this situation was favored by the total absence of macrophytes, which make resuspension more difficult.

The high concentrations of nutrients, which allowed us to characterize the lake as hypereutrophic (OECD, 1982), were similar to those of other environments of La Pampa (Echaniz *et al*., 2008; Echaniz & Vignatti, unpublished data), but, in particular, total phosphorus was several times higher than those reported by Quirós *et al*. (2002) and Sosnovsky & Quirós (2006) for shallow lakes of Buenos Aires province. This could be due, on one hand, to the high impact caused by the dragging of the feces of animals that feed on its basin, especially during storms (Carpenter *et al*., 1998; Bennett *et al*., 1999; Bremigan *et al*., 2008), since cattle can excrete between 9 and 16 kg of phosphorus.ind.year^{-1} (Russell *et al*., 2008). On the other hand, the resuspension of sediments by the wind is particularly important in shallow lakes (Markensten & Pierson, 2003; De Vicente *et al*., 2006; Borell-Lövstedt & Bengtsson, 2008), since removal favors the resolubilization of the nutrients of the internal load (Havens *et al*., 2007), which, in turn, favors the internal eutrophication of the lake (Smolders *et al*., 2006). This was probably the case in the lake studied in this work, since the highest concentrations of phosphorus were found during the second half of the year, during which stronger winds are present (Cano, 1980) and the concentrations of inorganic suspended solids were highest. In addition, the reduced capacity of phosphorus and nitrogen absorption of the sediments due to the relatively large size of the predominant particles (Kapanen, 2008) and to the fact that water is lost only by evaporation because the lake is an arheic environment leads to accumulation processes.

Zooplankton diversity was reduced, a common situation in environments with high salinity (Hammer, 1986; Herbst, 2001; Ivanova & Kazantseva, 2006), but another feature that differentiates this lake from others of La Pampa is the lower species richness found, since the species richness in other lakes with similar concentrations of dissolved solids but much higher transparency is close to 15 (Echaniz *et al*., 2006, Vignatti *et al*., 2007).

As regards the zooplankton found, the species recorded were typical of these ecosystems and were characterized by the presence of autochthonous halophilic crustaceans, such as *Moina eugeniae*, a species restricted to saline waters of the central region of Argentina (Paggi, 1998; Echaniz *et al*., 2006), and

Boeckella poopoensis, a species that has a very wide geographical distribution, from the north of Patagonia to the south of Perú (Menu-Marque *et al*., 2000; De los Ríos, 2005; Locascio de Mitrovich *et al*., 2005). The two rotifer species found have a wide distribution and are tolerant to salinity (Fontaneto *et al*., 2006).

Other important differences found with other saline lakes of La Pampa were the high total mean abundance, which was between four and six times higher (Echaniz *et al*., 2006; Vignatti *et al*., 2007), and the numeric predominance of rotifers, which were almost four and ten times more abundant than copepods and cladocerans respectively, in spite of which their biomass was only about 7% of the total.

Among rotifers, *B. plicatilis* showed a more constant presence, since it was recorded during most of the year and its maximum density was several times higher than the maximum recorded in other lakes of the province (Echaniz *et al.*, 2006).

The abundance and biomass of rotifers were affected by water temperature and chlorophyll-*a* concentration, but not by salinity or the concentration of inorganic suspended solids. In contrast, the abundance and biomass of both cladocerans and copepods were negatively affected by the concentration of inorganic suspended solids and salinity, but positively affected by water temperature, since both parameters were higher during summer and fall.

The zooplankton biomass of Prato shallow lake was two-fold higher than that recorded in the same period in Don Tomás and Bajo de Giuliani, two shallow lakes of La Pampa, which showed a similar concentration of nutrients, but salinities of 0.8 and 9.82 g L^{-1} and concentrations of chlorophyll-*a* of 154.6 and 173.7 mg m^{-3} respectively (Echaniz *et al.*, 2008; Echaniz *et al.*, 2009).

Besides, the macrozooplankton biomass of Prato lake was six times higher than the maximum determined by Quirós *et al*. (2002) in a group of 23 organic turbid shallow lakes of Buenos Aires, which presented salinities between 0.3 and 27 g L^{-1} and concentrations of chlorophyll-*a* of up to 405 mg m^{-3}. This supports the hypothesis that although saline lakes have low concentrations of chlorophyll-*a*, lower algal biomass, and thus low primary productivity, they are able to support high zooplankton biomasses (Evans *et al*., 1996).

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