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# Do temporary lakes vary from year to year? A comparison of limnological parameters and zooplankton from two consecutive annual cycles in an Argentine temporary saline lake

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**Abstract:** Temporary wetlands alternate dry phases with hydroperiods of varying duration. When their salinity is high it becomes one of the abiotic factors more influencing on wetland ecology. Due to the temporary nature of the ecosystem, the physico-chemical and biological parameters exhibit relatively large variation in short time periods; therefore studies limited to short periods cannot record long-term dynamics. Temporary aquatic ecosystems in other latitudes have been well studied; however those in Argentina have received little attention, despite their high frequency; particularly in the semi-arid central-west belt. Given that in La Pampa province (central region of Argentina) data previously collected from different hydroperiods of several temporary saline lakes are available, the aim of this study was to compare and establish relationships between physico-chemical parameters, and zooplankton taxonomic composition, diversity and biomass, recorded in two consecutive annual cycles in a saline lake in the northern of the province. Seasonal water and zooplankton samples were obtained during 2006 and 2007. Salinity differed, and increased from a mean of 23.98 g.L$^{-1}$ (2006) to 36.71 g.L$^{-1}$ (2007). Transparency, total phosphorus, chlorophyll-*a*, and total suspended solid concentrations did not differed. Total species richness was reduced (six and three species in 2006 and 2007, respectively), and was negatively correlated with salinity. Halophilic species, including *Boeckella poopoensis*, *Brachionus plicatilis*, and *Moina eugeniae* were registered during both years. Total zooplankton density and biomass were not significantly distinct, neither those of copepods and rotifers; however cladocerans were negatively affected by salinity, resulting in decreased density and biomass in 2007. The zooplankton species inhabiting this saline lake are halophilic, which can explain the few differences observed in biological parameters between the two annual cycles.

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**Key words:** Temporary lakes, zooplankton, *Moina eugeniae, Boeckella poopoensis*

## Introduction

Temporary lake ecosystems typically develop in shallow depressions, and may occupy a few square meters to hundreds of hectares (Williams, 1987 and 2002; Schwartz and Jenkins, 2000). They are characterized by containing water from a few months to a few years (Schwartz and Jenkins, 2000). Due to the temporary nature of these lakes, relatively large changes can occur in the physical, chemical, and biological attributes over short time periods, so that studies limited to short periods generally reflect relatively punctual situations and do not explain their long-term dynamics.

The ecology of temporary environments in other parts of the world, *e.g.* Australia (Williams *et al*., 1998; Bayly, 2001; Roshier *et al*., 2001), North America (Smith *et al*., 2003; Wallace *et al*., 2005), and Europe (Mura and Brecciaroli, 2003; Frisch *et al*., 2006) have been widely studied. However in Argentina, although these ecosystems are particularly abundant in the center - west of the country's semiarid belt, they have not been adequately studied. In addition, while many conclusions on the ecological features of temporary lakes worldwide are applicable to Argentinean ones, the species assemblages reported differ from those on other continents, showing some elements of the endemic neotropical fauna, particularly among crustaceans (Battistoni, 1998; Paggi, 1998; Adamowicz *et al*., 2004; Echaniz, 2010; Echaniz *et al.*, 2005 and 2006; Vignatti *et al*., 2007) and about which there is little ecological knowledge.

In La Pampa province, in the central region of Argentina, temporary wetlands are the most common aquatic ecosystem (Echaniz and Vignatti, 2011). They are shallow and fed principally by precipitation and to a lesser extent by phreatic inputs. As most are restricted to arheic basins and potential evapotranspiration exceeds rainfall (Roberto *et al*., 1994; Casagrande *et al*., 2006), the largest outputs are produced by evaporation. Dissolved solids concentration is typically high, with marked variability consistent with water level. Therefore, salinity is an abiotic factor exhibiting substantial influence on taxonomic composition and diversity of the biota, and so on the zooplankton (Hammer, 1986; Herbst, 2001; Hobæk *et al.*, 2002; Ivanova and Kazantseva, 2006). Pampean temporary lakes are eutrophic or hypertrophic environments, with high biological productivity due to high nutrient concentrations recorded in water and sediments (Echaniz, 2010, Echaniz *et al*., 2009, Echaniz and Vignatti, 2011, Vignatti, 2011).

In La Pampa, limnological and biological parameter data are available, particularly for the zooplankton community, collected in some temporary lakes during the last 17 years (Echaniz *et al*., 2005; 2006; 2009; 2011; 2012; Echaniz and Vignatti, 1996; 2011; Vignatti *et al*., 2007; 2012a). Due to the availability of these data, the aim of this study was to compare and establish relationships between physical, chemical, and biological parameters (zooplankton taxonomic composition, species richness, diversity, and biomass) determined seasonally (summer, autumn, winter, and spring) in a shallow, saline lake in the northern La Pampa province in two consecutive annual cycles, and test the following hypotheses: i) 2006 was drier than 2007, consequently lake depth was reduced, increasing the salinity due to evaporation; ii) due to the increased salinity, zooplankton taxonomic composition and species richness in 2007 differed from 2006; and iii) total zooplankton richness, density, and biomass, and those of taxonomic groups that comprise the community were lower in 2007 due to increased environmental stress induced by increased salinity.

## Materials and methods

### Study area

Estancia Pey-Ma Lake is located in north of La Pampa province (64º 15´ W, 35º 26´ S) (Fig. 1), in the ecotone between the phytogeographical provinces of the Pampean Plains and the Thorny Forest (Cabrera, 1976). The lake is in a plain region, with soft hills covered with a sand layer of variable thickness (Calmels and Casadío, 2005). The basin region is used for agriculture, and extensive cattle grazing.

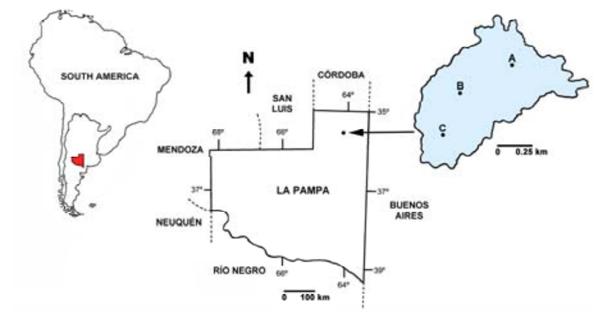


**Fig. 1: Location of the Estancia Pey-Ma shallow lake in the North of La Pampa province (Argentina). A, B and C: Sampling sites. Córdoba, Buenos Aires, Río Negro, Neuquén and Mendoza: neighboring provinces.**

The mean annual regional precipitation is 700 mm (Casagrande *et al*., 2006); with a maximum in summer, and the potential evapotranspiration is approximately 800 mm year$^{-1}$ (Roberto *et al*., 1994). The lake is fed by rainfall and to a lesser extent by a phreatic system. It is in an arheic basin, which loses water by evaporation or infiltration, and suffers large level fluctuations. The lake has a regular shape; its bottom sediments consist primarily of sands, and lack macrophytes, even during dry periods due to the salts layer that is deposited on the bed. It also lacks ichthyic fauna. During the study, the lake measured a maximum length and width of 1326 m and 683 m respectively, an area of 62.8 ha, and a maximum depth of 2.61 m.

### Field and laboratory work

Samples were collected seasonally (January, April, July and October) during 2006 and 2007, at three stations located along the longest lake axis (Fig. 1). Water temperature, dissolved oxygen concentration (oximeter Lutron® OD 5510), water transparency (measured with a 22 cm diameter Secchi disc), and pH (digital pH meter Corning® PS 15) were determined at each station. Maximal depth was determined by a graduated stick. Water samples were collected and kept refrigerated until their analyses in the laboratory.

Two quantitative zooplankton samples were obtained from each site using a 0.04 mm mesh size 10-L Schindler-Patalas trap, and one qualitative sample using a 22 cm diameter net with a similar mesh size. All the samples were anesthetized with $CO_2$, and refrigerated until fixation; this methodology served to avoid contractions that may deform the collected individuals.

Salinity was determined applying the gravimetric method with drying at 104°C. Chlorophyll-*a* concentration was measured by extraction with aqueous acetone, and spectro-photometry (spectrophotometer Metro-lab 1700) (APHA, 1992; Arar, 1997); total nitrogen following the Kjeldahl method; and total phosphorus by potassium peroxodisulfate digestion in acid medium, and subsequent UV-visible spectrophotometry (APHA, 1992). Total, inorganic and organic suspended solids concentration were determined with fiberglass filters (Microclar FFG047WPH), dried at 103-105°C until reaching a constant weight, and calcined at 550 ºC (EPA, 1993).

Macro and microzooplankton (Kalff, 2002) were counted under a stereoscopic and conventional optical microscope in Bogorov and Sedgwick - Rafter chambers, respectively. Conventional measurements of individuals representing each species sampled were obtained with a Carl Zeiss ocular micrometer, and length-dry weight formulae were used to calculate zooplankton biomass (Dumont *et al.,* 1975; Ruttner-Kolisko, 1977; Rosen, 1981; McCauley, 1984; Culver *et al*., 1985; Kobayashi, 1997).

### Data analyses

A nonparametric Kruskal-Wallis test was applied to determine significant differences between annual cycles among physical, chemical, and biological parameters measured in the temporary lake ecosystem. In addition, we calculated Spearman correlation coefficients (Sokal and Rohlf, 1995; Zar, 1996, Pereyra *et al*., 2004) to examine relationships between environmental factors and zooplankton attributes. Infostat (Di Rienzo *et al*., 2010) and Past (Hammer *et al*., 2001) software were used for all analyses.

## Results

### Environmental parameters

Lake mean depth differed significantly between annual cycles (H = 5.33, p = 0.0209); the lake exceeded 2.4 m in 2006, and was close to 2 m in 2007 (Tab. 1). During 2006, the lake decreased from about 2.6 m (summer) to near 2.2 m (spring). However, in 2007 water level increased from 1.9 m (summer), to near to 2.1 m (spring) (Fig. 2).

Mean dissolved solids concentration significantly differed between years (H = 5.21, p = 0.0212). In 2006, the lake salinity was near to 24 $g.L^{-1}$ (Tab. 1), which increased from a minimum close to 19.5 $g.L^{-1}$ in summer, when the study was initiated, to more than 30 $g.L^{-1}$ in spring (Fig. 2). Mean salinity was higher in 2007, close to 37 $g.L^{-1}$ (Tab. 1), and exhibited different changes, with a decrease from more than 48 $g.L^{-1}$ detected in summer to almost 31 $g.L^{-1}$ in spring (Fig. 2).

Mean water temperature showed no significant difference between 2006 and 2007 (H = 0, p = 1). It was around 17°C (Tab. 1), with a minimum just above of 8°C in winter (July), and a maximum higher than 24°C in summer (January) (Fig. 3). The concentration of dissolved oxygen did not significantly differ between the two years (H = 0, p = 1). The lowest concentration was less than 2.5 $mg.L^{-1}$ (Tab. 1), and a seasonal pattern was not detected (Fig. 3).

Results detected high and variable nutrient concentrations in Pey-Ma Lake, with increased variability in 2007 (Fig. 4). Total phosphorus means were not significantly different (H = 0, p = 1) between the two years, and values close to 18 $mg.L^{-1}$ (2006) and 15 $mg.L^{-1}$ (2007) were found (Tab. 1). Total nitrogen concentrations significantly differed between years (H = 5.33, p = 0.0209), and were close to 27 $mg.L^{-1}$ in 2006 and 34 $mg.L^{-1}$ in 2007 (Tab. 1). Seasonal fluctuations were not observed, and no correlation was found between both nutrient concentrations (R = 0.23, p = 0.5878).

Mean water transparency was low, and did not significantly differ between the two years (H = 0.75, p = 0.3865) (Tab. 1). Minimum values were recorded in spring 2006 and winter 2007, and the maximum were detected in summer of both years (Fig. 5).

Inorganic suspended solids concentrations did not significantly differ between years (H = 0.33, p = 0.5637). The means were close to 35 $mg.L^{-1}$ (2006) and 52 $mg.L^{-1}$ (2007) (Tab. 1). Maximum concentrations were registered in winter-spring of both years (Fig. 5) and we found significant correlation between inorganic suspended solids concentrations and water transparency (R = -0.95, p = 0.0003).

Although in 2006 the mean concentration of chlorophyll-*a* exceeded 30 $mg.m^{-3}$ and in 2007 was lower, closer to 14 $mg.m^{-3}$ (Tab. 1), the difference was not significant (H = 2.08, p = 0.1489). No seasonal pattern was detected,

**Tab. 1: Mean (bold), minimum and maximum (italics) values of the limnological parameters estimated in Estancia Pey-Ma shallow lake.**

| | 2006 | 2007 |
|---|---|---|
| Max. depth (m) | **2.43** | **2.02** |
| | *2.22 -2.61* | *1.90–2.11* |
| Salinity (g.L$^{-1}$) | **23.98** | **36.71** |
| | *19.47-30.42* | *31.21-48.32* |
| Water temperature (°C) | **17.45** | **17.01** |
| | *8.1-24.7* | *8.2-24.4* |
| Dissolved oxygen (mg.L$^{-1}$) | **5.73** | **5.88** |
| | *1.3-8.3* | *2.4-9.7* |
| TP (mg.L$^{-1}$) | **17.78** | **14.82** |
| | *15-20.3* | *0.54-22.5* |
| TN (mg.L$^{-1}$) | **26.76** | **34.69** |
| | *26.25-27.3* | *28.13 - 43.13* |
| Transparency (m) | **0.20** | **0.16** |
| | *0.12-0.31* | *0.08-0.32* |
| Inorganic suspended solids (mg.L$^{-1}$) | **35.28** | **52.38** |
| | *13-59.3* | *4.14-103.8* |
| Organic suspended solids (mg.L$^{-1}$) | **38.53** | **33.15** |
| | *16-78.7* | *10.56-63.1* |
| Chorophyll-*a* (mg.m$^{-3}$) | **30.58** | **14.05** |
| | *15.26-73.23* | *7.37-24.72* |
| pH | **9.02** | **9.44** |
| | *8.9 -9.24* | *9.3-9.59* |

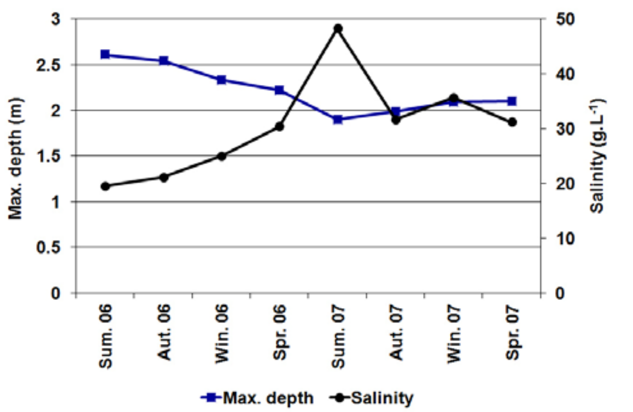


**Fig. 2: Seasonal variation of the maximal depth and salinity of the Estancia Pey-Ma shallow lake during the study period.**

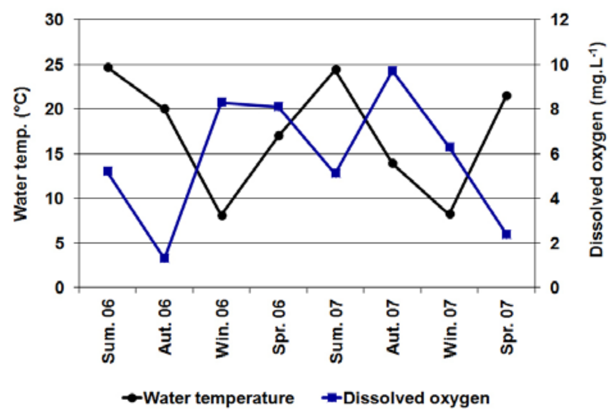


**Fig. 3: Seasonal variation of water temperature and dissolved oxygen concentration in the Estancia Pey-Ma shallow lake during the study period.**

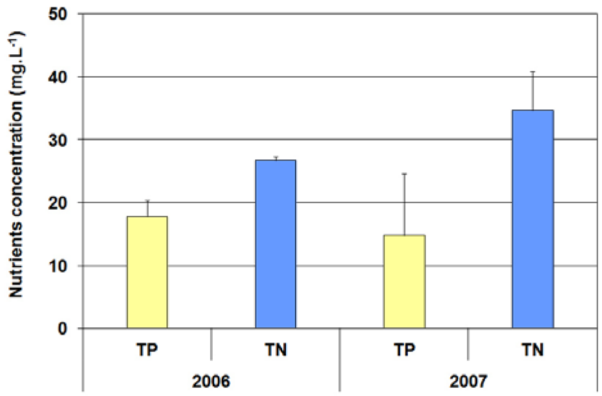


Fig. 4: Comparison of mean nutrients concentrations in the Estancia Pey-Ma shallow lake during the study period.

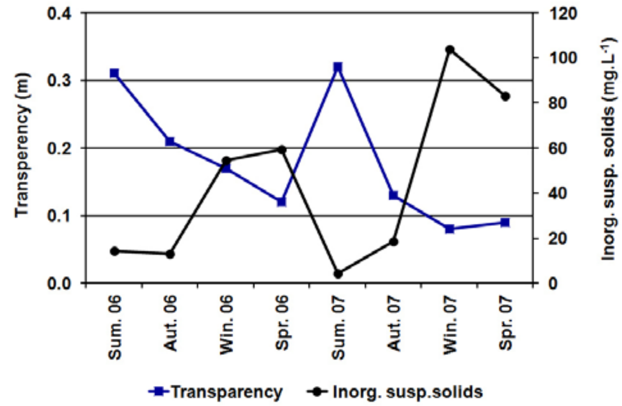


Fig. 5: Seasonal variation of water transparency and inorganic suspended solids concentration in the Estancia Pey-Ma shallow lake during the study period.

since in 2006 the minimum was recorded in spring and the maximum in summer, while in 2007 the minimum was observed in summer and the maximum in autumn (Fig. 6). Significant negative correlations were found between chlorophyll-*a* concentration and dissolved solid concentrations (R = -0.76, p = 0.0280) and between chlorophyll-*a* and total nitrogen (R = -0.78, p = 0.0229).

Organic suspended solids concentration did not differ between years (H = 0.08, p = 0.7728) (Tab. 1), and a seasonal pattern was not observed (Fig. 6). A non-significant negative correlation with water transparency was detected (R = -0.48, p = 0.2329). In addition, organic suspended solids concentration and chlorophyll-*a* concentration were not significantly correlated (R = 0.19, p = 0.6514).

The pH was high, exceeding 9 both years (Tab. 1). The fluctuation in each year was reduced and no seasonality in its variations was found.

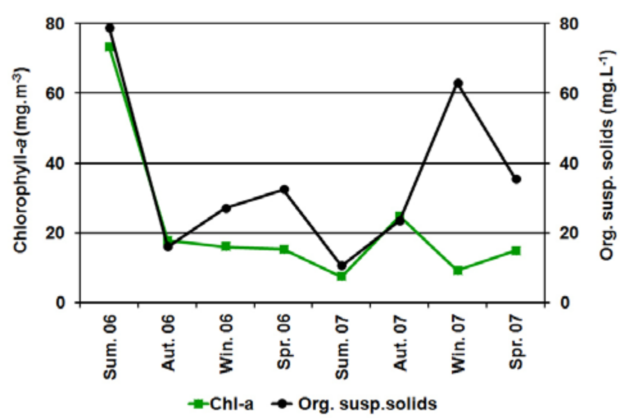


Fig. 6: Seasonal variation of the chlorophyll-*a* and organic suspended solids in the Estancia Pey-Ma shallow lake during the study period.

**Biological parameters**

Six zooplankton species were collected during the two annual cycles (Fig. 7), and a significant negative correlation between species number and salinity was found (R = -0.71, p = 0.0488). All species were recorded in 2006, but in 2007 the richness was reduced to half (Fig. 7). The crustaceans with the highest frequency were *Moina eugeniae* and *Boeckella poopoensis*, while *Moina macrocopa* and *Cletocamptus deitersi* were present only in 2006. Among the rotifers, *Brachionus plicatilis* was observed during both years, however *B. dimidiatus* was only registered in 2006 (Fig. 7).

The mean density of the zooplankton community during 2006 was 4251 ind.$L^{-1}$ (± 6547.6). The 2007 mean density was lower and less variable, 2154.2 ind.$L^{-1}$ (± 1946.4). Although the 2006 mean value was greater than 2007, density values between years were not significantly different (H = 0.08, p = 0.7728). Seasonal changes in both annual cycles differed. Minimum densities were recorded in spring 2006 (406.3 ind.$L^{-1}$) and winter 2007 (878.5 ind.$L^{-1}$) and the maximum in summer 2006 (14018 ind.$L^{-1}$) and spring 2007 (5051.3 ind.$L^{-1}$) (Fig. 8). During both years, rotifers exhibited the highest density, which represented 81.4% (2006) and 66% (2007) of the total (Fig. 9).

Mean total biomass values between 2006 and 2007 were not significantly different (H = 0.33, p = 0.5637). Results showed a biomass of 7543.2 µg.$L^{-1}$ (± 4632.2) in 2006, and 11577.1 µg.$L^{-1}$ (± 8910.49) in 2007. Its variation was different in both annual cycles. Minimum values were recorded in spring 2006 (2533.4 µg.$L^{-1}$) and summer 2007 (3259.8 µg.$L^{-1}$), and maximum ones in autumn 2006 (12803.4 µg.$L^{-1}$) and spring 2007 (24182.7 µg.$L^{-1}$) (Fig. 10). The cladoceran and copepod community contribution in 2006 was relatively equal (45% and 51%, respectively), but in 2007 the latter largely dominated the community biomass, accounting for 88% of the total (Fig. 9).

Cladoceran density and biomass determined during the two years differed (H = 5.33, p = 0.0209 in both cases). Significantly negative correlations between density and salinity (R = -0.81, p = 0.0149), and biomass and salinity (R = -0.78, p = 0.0208) were found; since they were registered under all 2006 seasons, when mean density and biomass exceeded 460 ind.$L^{-1}$ and 3300 µg.$L^{-1}$, respectively (Tab. 2). In 2007, the results indicated density and mean biomass were markedly lower close to 6 ind.$L^{-1}$ and 34.7 µg.$L^{-1}$, respectively (Tab. 2). Among cladocerans, *M. eugeniae* exhibited the highest density, and contributed to increased biomass, although both parameters differed between years (Tab. 3). Its seasonal pattern was different since maximum density and biomass were observed in autumn 2006, and spring 2007. The lower density and biomass values were found during the summer 2006 and in summer and autumn 2007, and it is remarkable its absence during

**Tab. 2: Mean (bold), minimum and maximum (italics) zooplankton density and biomass by taxonomic group registered in Estancia Pey-Ma saline lake during the study period.**

| | Density (Ind.L$^{-1}$) | | Biomass (µg.L$^{-1}$) | |
|---|---|---|---|---|
| | 2006 | 2007 | 2006 | 2007 |
| Cladocerans | **465.8** | **6.6** | **3335.8** | **34.7** |
| | *179-1235.33* | *0-24* | *826.9-8190.24* | *0-125.52* |
| Copepods | **276.3** | **617.1** | **3800.7** | **9939.7** |
| | *83-465.33* | *221.6-1099.3* | *516.1-7788.4* | *2853.8-19293.3* |
| Rotifers | **3261.8** | **1206.2** | **247.4** | **1333.2** |
| | *0-12970* | *1.2-3807.3* | *0-919.3* | *0.73-4683* |

**Tab. 3: Mean (bold), minimum and maximum (italics) density and biomass of the species registered in the zooplankton of Estancia Pey-Ma saline lake during the study period.**

| | Density (Ind.L$^{-1}$) | | Biomass (µg.L$^{-1}$) | |
|---|---|---|---|---|
| | 2006 | 2007 | 2006 | 2007 |
| *Moina eugeniae* | **465.0** | **6.6** | **3332.4** | **34.7** |
| | *176.0-1235.3* | *0.0-24.0* | *813.1-8190.2* | *0.0-125.5* |
| *Moina macrocopa* | **0.8** | **0.0** | **3.5** | **0.0** |
| | *0.0-3.0* | *0.0* | *0.0-13.8* | *0.0* |
| *Boeckella* | **270.1** | **617.1** | **3794.3** | **9939.7** |
| *poopoensis* | *72.7-465.3* | *221.6-1099.3* | *515.2-7771.1* | *2853.8-19293.3* |
| *Cletocamptus* | **6.2** | **0.0** | **6.4** | **0.0** |
| *deitersi* | *0.0-11.3* | *0.0* | *0.0-17.2* | *0.0* |
| *Brachionus* | **645.0** | **1206.2** | **142.8** | **1333.2** |
| *plicatilis* | *0.0-2503.0* | *1.2-3807.3* | *0.0-500.6* | *0.7-1333.2* |
| *Brachionus* | **2616.8** | **0.0** | **104.7** | **0.0** |
| *dimidiatus* | *0.0-10467.0* | *0.0* | *0.0-418.7* | *0.0* |

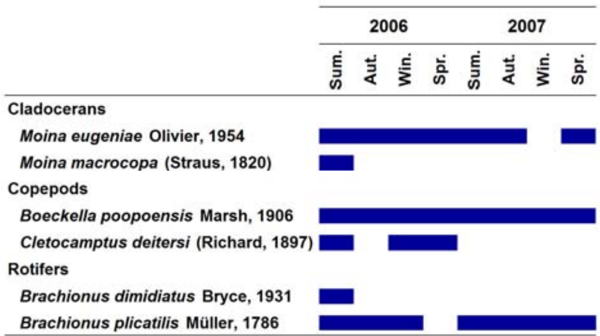


**Fig. 7: Species recorded in the Estancia Pey-Ma shallow lake and seasons in which they were recorded.**

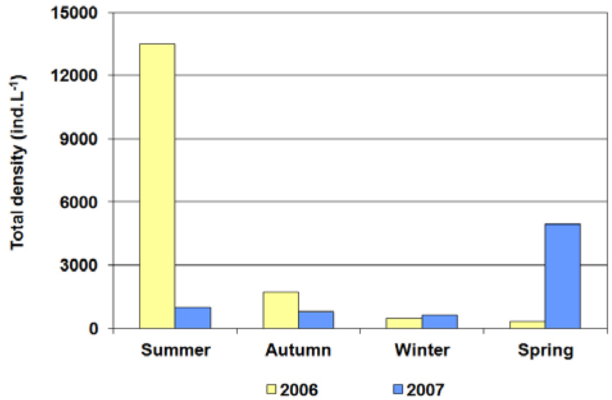


**Fig. 8: Seasonal variation of the zooplankton total density in Estancia Pey-Ma shallow lake during the study period.**

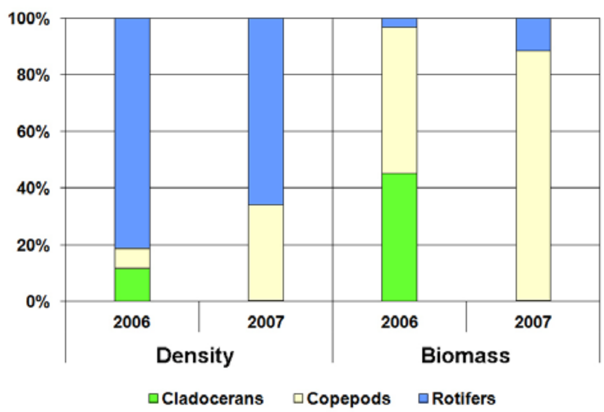


**Fig. 9: Percentage composition of the total zooplankton density and biomass registered in Estancia Pey-Ma lake during the study period.**

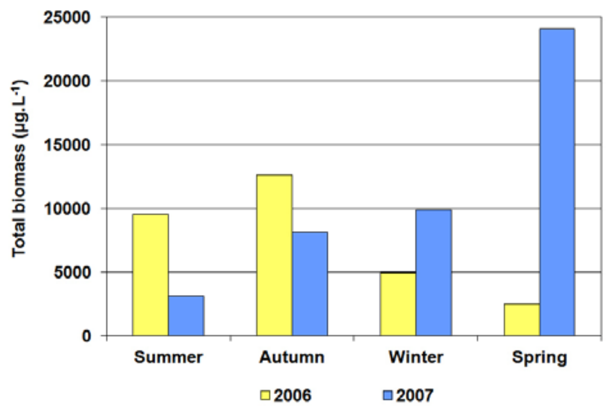


**Fig. 10: Seasonal variation of the zooplankton total biomass in Estancia Pey-Ma shallow lake during the study period.**

the winter of the second year. *M. macrocopa* was found only during the summer 2006, when reached a density and biomass close to 3 ind.L$^{-1}$ and 13 µg.L$^{-1}$, respectively (Tab. 3).

Copepod mean density and biomass for 2006 were slightly above 275 ind.L$^{-1}$ and 3800 µg.L$^{-1}$, while in 2007 exceeded 617 ind.L$^{-1}$ and 9939 µg.L$^{-1}$ (Tab. 2). However, no significant differences were observed (density: $H = 3.00$, $p = 0.0833$, and biomass: $H = 2.083$, $p = 0.1489$). Significant correlations between copepod density and biomass, and any of the environmental factors evaluated were not detected. *B. poopoensis*, which was registered in all the samples, was the copepod species that exhibited the highest density and biomass; and these parameters did not significantly differ between the two years ($H = 3.00$, $p = 0.0833$ and $H = 2.08$, $p = 0.1489$) (Tab. 3). However, their variation was different during the two years. The lower density and biomass values were recorded in spring 2006 and in summer 2007 (Tab. 3), while the maximum density and biomass of 2006 were found in autumn and summer, but in 2007 they coincided in spring (Tab. 3). *Cletocamptus deitersi* was recorded only three times in 2006, when it reached a mean diversity just above 6 ind.$L^{-1}$, with its peak during the summer with density and biomass values close to 11 ind.$L^{-1}$ and 17 µg.$L^{-1}$ respectively (Tab. 3).

Significant differences were not found between rotifer mean density and biomass of the two annual cycles ($H = 0.33$, $p = 0.5637$ and $H = 0.75$, $p = 0.3865$). Rotifer mean density and biomass in 2006 were above 3200 ind.$L^{-1}$ and 247 µg.$L^{-1}$; and in 2007 were close to 1200 ind.$L^{-1}$ and 1330 µg.$L^{-1}$ respectively (Tab. 2). In 2006, *B. plicatilis* mean density and biomass values were near to 640 ind.$L^{-1}$ and 140 µg.$L^{-1}$ respectively, and in 2007 values were higher; both exceeded 1200 ind.$L^{-1}$ and 1300 µg.$L^{-1}$ respectively (Tab. 3). Nevertheless, the differences between variables and annual cycles were not significant ($H = 0.72$, $P = 0.3896$ in both cases). The seasonal variation of this species was different. In 2006 it reached its maximum density and biomass in summer, but in 2007 it was in spring (Tab. 3). *B. dimidiatus* was recorded only during the summer of 2006, and its density and biomass values were close to 10000 ind.$L^{-1}$ and 420 µg.$L^{-1}$ respectively (Tab. 3).

## Discussion

The results of our study showed Estancia Pey-Ma Lake possesses several characteristics typical of shallow lakes in La Pampa province, particularly high dissolved solids concentration, and relatively wide fluctuations in water levels, which resulted in salinity changes (Echaniz and Vignatti, 2011). This happens as a result of being located in arheic basins unconnected to fluvial systems, so they are especially fed by rainfall (Echaniz *et al*., 2006; Vignatti *et al*., 2007; Echaniz, 2010; Vignatti, 2011). The Pampean lakes are located in a region where evapotranspiration exceeds precipitation (Roberto *et al*., 1994), which facilitates lake level fluctuations. This characteristic was reflected by the decreased water levels in Pey-Ma between summer 2006 and 2007 due to a short-lived drought, which continued until the end of January 2007. Water loss resulted in a 0.7 m lake depth, which produced a marked increase in dissolved solids concentration. In summer 2007, salinity value duplicated that observed when the study was initiated. During late summer; when the highest rainfall typically occurs in the province (Cano, 1980); water input resulted in increased lake levels. However, the temporary lake nature was evident in mid-2010, during an intense drought period, when Estancia Pey-Ma Lake dried completely (Vignatti and Echaniz, pers. obs.).

Water level fluctuations were reflected in notable dissolved solids concentration changes. The lake was mesosaline (Hammer, 1986) almost exclusively, however salinity levels were so broadly variable that in summer 2006, a salinity below 20 $g.L^{-1}$ behaved as hyposaline, and in summer 2007, when the lake reached its highest salinity, was very close to pass to hypersaline interval (Hammer, 1986).

Transparency, which is related to water turbidity and euphotic depth, was similar and very low in both years. The values were similar with other La Pampa lakes previously studied. However phytoplanktonic chlorophyll-*a* concentrations were much lower in Pey-Ma Lake (Vignatti *et al*., 2007; Echaniz, 2010; Echaniz *et al*., 2008 and 2009). One characteristic of this lake is that the reduced transparency is produced by a high concentration of inorganic suspended solids, which leads the lake to be considered a turbid, inorganic one (Quirós *et al*., 2002). Inorganic suspended solids were more abundant during winter and spring, the seasons with the highest recorded wind speeds in the province (Cano, 1980). Winds can cause resuspension of bottom sediments, a phenomenon enhanced by reduced lake depth, a relatively flat bottom and no rooted vegetation to mitigate wave effects (Echaniz, 2010; Vignatti, 2011; Echaniz and Vignatti, 2011).

During the two annual cycles, nutrient concentrations were so high that based on OECD (1982) criteria, the lake was hypertrophic, and consistent with other La Pampa lake environments free from urbanization impacts (Echaniz *et al*., 2008, Echaniz, 2010; Vignatti, 2011; Echaniz and Vignatti, 2011). Most notably, Pey-Ma Lake exhibited higher total P concentrations than levels identified in shallow lakes of the Upper Salado River basin in Buenos Aires province, which have been cited as some of the highest recorded in the world (Quirós *et al*., 2002; Sosnovsky and Quirós, 2006). The increased concentration of these nutrients may be due to livestock and agricultural activities developed in the basin, and/or to internal eutrophication (Smolders *et al*., 2006) due to nutrient resolubilization from lake bottom deposition. This effect was confirmed in the present study, where higher P concentrations were measured during the winter and spring of the two years, when more intense winds were recorded (Cano, 1980), and the highest concentrations of inorganic suspended solids were determined. A high trophic state is also favored by the arheic basin location of Pey-Ma Lake, *i.e*. evaporation water outputs lead to nutrient accumulation (Echaniz, 2010; Echaniz and Vignatti, 2011).

Despite increased nutrient concentration, phytoplanktonic chlorophyll-*a* (similar during both annual cycles) was not too high. A plausible explanation could be, on one hand; the absence of fish, which facilitated the development of relatively large-sized cladocerans, that maintained a relatively low phytoplankton biomass due to their grazing pressure (Scheffer, 1998; Quirós *et al*., 2002; Scheffer and Jeppesen, 2007). On the other hand, the high inorganic turbidity can limit the entry of light, which would become a limiting factor for algal growth (Torremorell *et al*., 2007; Cáceres *et al*., 2008; Llames *et al*., 2009; Diovisalvi *et al*., 2010).

The zooplankton richness was reduced, which is a common characteristic in saline ecosystems (Hammer, 1986; Ivanova and Kazantseva, 2006), and also previously cited in La Pampa (Echaniz *et al*., 2006; Vignatti *et al*., 2007; Echaniz, 2010; Vignatti, 2011); because only organisms with the physiological adaptations to withstand the environmental stress produced by halophylic conditions can inhabit these ecosystems (Herbst, 2001; Vignatti, 2011). An additional characteristic that differentiates Pey-Ma Lake from other lakes in La Pampa province was the lowest species number here verified since in other lakes with similar salinity, the richness was close to 15 taxa (Echaniz *et al*., 2006, Vignatti *et al*., 2007; Vignatti, 2011).

We recorded the typical species association of La Pampa temporary lakes ecosystems, which were characterized by autochthonous halophilic crustaceans, including *Moina eugeniae*, a species restricted to saline waters in central Argentina (Paggi, 1998; Echaniz *et al*., 2006; Echaniz, 2010; Echaniz and Vignatti, 2011; Vignatti *et al*., 2012a and b), and *Boeckella poopoensis*, a species that exhibits a wide geographical distribution from North of the Patagonian plateau to southern Perú (Locascio de Mitrovich *et al*., 2005; De los Ríos-Escalante, 2010, 2011; De los Ríos *et al*., 2010; Echaniz *et al*., 2012). The two rotifer species have cosmopolitan distribution (Pejler, 1995) and are salt tolerant, especially *Brachionus plicatilis* (Fontaneto *et al*., 2006; Echaniz, 2010). Remarkable is the presence of *Moina macrocopa*, since it is an exotic species, whose record in Argentina is relatively recent, so it has been proposed the possibility of a recent introduction in South America (Paggi, 1997; Echaniz and Vignatti, 2011).

Zooplankton richness was negatively influenced by dissolved solids concentration, and species number in 2007 was half that of 2006. The lower *M. eugeniae* density (and hence biomass) during 2007 indicated that salinity (had) has a substantial (affect) effect on this cladoceran species. *B. poopoensis* exhibited different responses, since no differences in density or biomass values were detected. This species is tolerant to a broad range of saline conditions, as waters of approximately 100 $g.L^{-1}$

have been reported in La Pampa (Echaniz, 2010). Therefore, the variation in Pey-Ma Lake salinity did not affect the species.

Total zooplankton density was similar throughout this study, and therefore it was not affected by increased salinity. Furthermore, total density did not exhibit a seasonal pattern; in 2006 the maximum was determined in summer, and in 2007 at spring. In both annual cycles, the peaks of density were given by rotifers, which reached densities several times higher than crustaceans.

An important difference between this lake and other La Pampa saline lakes was the increased zooplankton density of Pey-Ma, which was a total of four to six times higher (Echaniz, 2010; Echaniz *et al*., 2006, Vignatti *et al*., 2007; Vignatti, 2011), and the rotifer numerical dominance, whose peak of density was nearly four and 10 times more numerous than copepods and cladocerans, respectively.

The total zooplankton community biomass was not affected by increased dissolved solids concentration. As the biomass was provided especially by crustaceans (between 89% and 97% of the total) because they are larger than rotifers, it did not show the same seasonal variation than total density. An important characteristic of Estancia Pey-Ma Lake despite its temporary nature is its productivity, since zooplankton biomass was three to 10 times higher than in nine Pampean shallow lakes of a broad salinity spectrum (Echaniz, 2010), but with similar nutrient concentrations. Furthermore, the macrozooplankton biomass from Pey-Ma Lake exceeded six times the maximum biomass derived from 23 organic turbid shallow lakes in Buenos Aires, with salinities between 0.3 and 27 $g.L^{-1}$, and chlorophyll-*a* concentrations reaching 405 mg $m^{-3}$ (Quirós *et al*. 2002) .

During 2006, the biomass was relatively equally distributed between *Moina eugeniae* and *Boeckella poopoensis*. However, since *M. eugeniae* showed a lower tolerance than *B. poopoensis* to increased salinity, the largest contribution to biomass in 2007 (*i.e.* 86%) was done by *B. poopoensis*. The halophylic species was previously reported as dominant and geographically widespread in other high salinity shallow Pampean lakes, where it represents the greatest zooplankton biomass (Echaniz, 2010; Echaniz *et al*., 2006, Echaniz and Vignatti, 2011; Vignatti *et al*., 2007; Vignatti, 2011; Vignatti *et al*., 2012a).

With the exception of the changes exhibited by *M. eugeniae*, few differences were observed in the biological parameters evaluated at Estancia Pey-Ma shallow lake during the two annual cycles, despite the notable changes in salinity. This might be explained by the presence of halophylic and euryhaline zooplankton species. Estancia Pey-Ma's range of environmental variability was within the tolerance range of species that occupy the temporary lake ecosystem. Consequently, each species population parameters were not significantly affected by the extent of environmental changes recorded. Although this study provides information to growing body of research on Argentine temporary lakes, this situation would require the further studies in different ecological conditions.

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