

Spatial and temporal dynamics of the mesozooplankton (Crustacea: Cladocera, Copepoda and Decapoda) in a Pampean shallow hyposaline lake during drought conditions

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RESUMEN. La laguna Sauce Grande, un lago poco profundo, eutrófico e hiposalino, se estudió mediante muestreos mensuales entre diciembre de 2009 a noviembre de 2010. La sequía que afectó a la región desde 2009 y durante todo el período de estudio interrumpió la entrada regular del río y la salida al Océano Atlántico. La laguna presentó un aumento de los valores de salinidad y condiciones altamente turbias como resultado de las condiciones de sequía y de la resuspensión de sedimento por efecto del viento. Los cladóceros pequeños como *Moina micrura* y el copépodo *Boeckella poopoensis* dominaron la comunidad del mesozooplankton. La salinidad determinó la composición del mesozooplankton; mientras tanto, la dinámica de la abundancia estuvo determinada por la temperatura junto con las condiciones eutróficas durante el período de estudio. En un contexto global de cambio climático, y en una región donde la sequía y los ciclos húmedos son frecuentes, estos resultados contribuyen a comprender aún más los procesos que afectan la estructura y dinámica de la comunidad de zooplankton durante eventos climáticos extremos.

Palabras clave: Laguna Sauce Grande, mesozooplankton, salinidad, sequía.

ABSTRACT. The Sauce Grande Lake, a shallow, eutrophic, and hyposaline lake, was studied through monthly samplings during a year (December 2009- November 2010). The drought that affected the region since 2009 and during the entire study period interrupted the regular inflow from the river and outflow to the Atlantic Ocean. The lake presented an increase of salinity values and highly turbid conditions as a result of the drought conditions and wind resuspension. Small cladocerans such as *Moina micrura* and the copepod *Boeckella poopoensis* dominated the mesozooplankton community. The salinity determined the mesozooplankton composition; meanwhile, the abundance dynamic was ruled by temperature in conjunction with the eutrophic conditions during the study period. In a global context of climate change, and in a region where drought and wet cycles are frequent, these results further contribute to understanding the processes affecting the zooplankton community structure and dynamics during extreme climate events.

Keywords: Drought, mesozooplankton, salinity, Sauce Grande Lake.

INTRODUCTION

Shallow lakes are the most abundant lake types in the global landscape (Downing *et al.*, 2006). Lakes in the Pampas, a broad and fertile plain in Argentina, are mostly polymictic and present high nutrient levels, ranging from eutrophic to highly hypertrophic (Quirós & Drago, 1999). The Pampa Plain is the most highly developed agricultural region in Argentina, which contributes even more to the eutrophication process of the area (Quirós *et al.*, 2002). The occurrence of long periods of droughts and floods characterizes the region, and affects water availability, the productivity of agricultural systems, and other human activities (Aliaga *et al.*, 2017).

Plankton is an essential indicator of the structure and function of lake ecosystems and their ecological status (Jeppesen *et al.*, 2011). The copepods (cyclopoids and calanoids) and cladocerans dominate the mesozooplankton fraction (200-2000 μm) in the Pampas shallow lakes (Chaparro *et al.*, 2011; Diovisalvi *et al.*, 2015). The cyclopoid *Acanthocyclops robustus* (Sars, 1863) and the calanoid *Notodiaptomus incompositus* Brian, 1925 have significant occurrence (Menu Marque, 2000). Cladocera is represented by genera such as *Bosmina*, *Ceriodaphnia*, *Daphnia*, *Diaphanosoma*, *Moina* and members of Chydoridae. Cladocerans are particularly abundant at places or periods with low planktivore fish abundance (Diovisalvi *et al.*, 2015; Sosnovsky *et al.*, 2010), as well as in lakes densely colonized by submerged macrophytes (Ardohain, 2008). The predation by fish and invertebrates in conjunction with physicochemical variables can interactively affect the dynamic and structure of the mesozooplankton. Mainly, salinity changes the composition of plankton community (Jeppesen *et al.*, 2015). The species richness of zooplankton decreases with increasing salinity (Bruce *et al.*, 2009) and thereby, the trophic interactions in lakes is modified (Alfonso *et al.*, 2017; Bruce *et al.*, 2009; Jeppesen *et al.*, 2007a). In hyposaline waters, the predominant taxa are halotolerant freshwater forms, and species richness and composition are highly correlated with salinity (Jensen *et al.*, 2010). At

high salinities, the zooplankton communities are often dominated by small-bodied such as small cladocerans (e.g., *Bosmina* and *Ceriodaphnia*) and rotifers, which are less efficient phytoplankton controllers (Bruce *et al.*, 2009; Jeppesen *et al.*, 2007b). Meanwhile, salt intolerant large-bodied cladocerans such as *Daphnia* are restricted (Frey, 1993), except for some species such as *D. spinulata* Birabén, 1917 which tolerate changes in salt concentration (Echaniz *et al.*, 2009) and can be found in oligohaline and mesohaline environments (Hoffmeyer, 2004). Despite the well-known impact of salinity determining community structure, studies have indicated that other physicochemical variables of saline lakes could play a critical role controlling the zooplankton community (Williams, 1998). Other factors, such as habitat permanence, water management, incorporation of freshwater input (enriched by nutrients related to anthropogenic use) and trophic interactions alter the structure of aquatic communities in saline lakes (Alfonso *et al.*, 2017; Echaniz *et al.*, 2009; Larson & Belovsky, 2013; Stenger-Kovács *et al.*, 2014). Zooplankton species richness increases with nutrient enrichment in saline lakes, demonstrating the importance of nutrient supply (Larson & Belovsky, 2013). Furthermore, the depth of a shallow lake can be subject to extreme fluctuations resulting from climatic variability. Water-level variation emerges such as a decisive hydrology factor; mainly in shallow lakes located in wetlands particularly sensitive to a quick change in depth and water input (Leira & Cantonati, 2008). Therefore, the water level fluctuations may have a significant effect on the ecology, functioning, and management of shallow lakes. On the other hand, anthropogenic factors like water use may actively modify the amplitude of water level fluctuations with impact on the ecological status of the lake (Del Ponti *et al.*, 2015). Numerous investigations highlight the importance of the lake's depth for shifts between submerged macrophytes and turbid states in shallow lakes (Scheffer & van Nes, 2007). Nutrient concentrations (nitrogen and phosphorus) vary with water levels (Nöges *et al.*, 2003) and increase during drought periods (Tan & Beklioglu, 2005). The significant contact of water with sediments

related to low water level and prolonged water residence may enhance the nutrient internal release (Romo *et al.*, 2005). According to the IPCC (2007), climate change is likely to increase the risk of droughts and floods. For this reason, the knowledge about climate variability impact and the consequential flood and drought periods affecting water level, physicochemical parameters, and zooplankton community is crucial to assess the shift magnitude in the forthcoming environmental conditions.

We expect that the composition and the spatial and temporal dynamic of the mesozooplankton will reflect extreme conditions (water level diminution, salinity and eutrophication increase) during extraordinary drought events at Sauce Grande Lake. The results could be useful for establishing a baseline to future monitoring and water management decisions of the lake.

MATERIAL AND METHODS

Study site

The Sauce Grande shallow lake ($38^{\circ}57' S$, $61^{\circ}24'$

W) is located at SE of Buenos Aires Province, Argentina (Figure 1). It is a natural water body with a surface area of 21.55 km² and a maximum depth of 3 m (Fornerón *et al.*, 2010b). This lake is polymictic, rich in dissolved oxygen, turbid, and eutrophic (Ferrer *et al.*, 2012; Fornerón *et al.*, 2010a). The lake has an affluent, the Sauce Grande River, and a connection with the Atlantic Ocean. During the drought of 2008-2009 (Fornerón, 2010a), the high evaporation rate and the water use for irrigation generated the loss of both connections, and the lake evolved from a drainage lake to an isolated lake. It is a prolonged depression, with low shoreline and smooth slope, and colonized by reeds. The presence of the planktivorous fish *Odontesthes bonariensis* (Valenciennes, 1835) is frequent (Remes Lenicov & Colautti, 2003). The climate of the region is temperate, with mild winters and warm summers. The mean annual temperature ranges between 14 and 20 °C (Aliaga *et al.*, 2016). Wet and dry cycles characterize the region. Total annual precipitation ranges from 500 to 650 mm (Aliaga *et al.*, 2016).

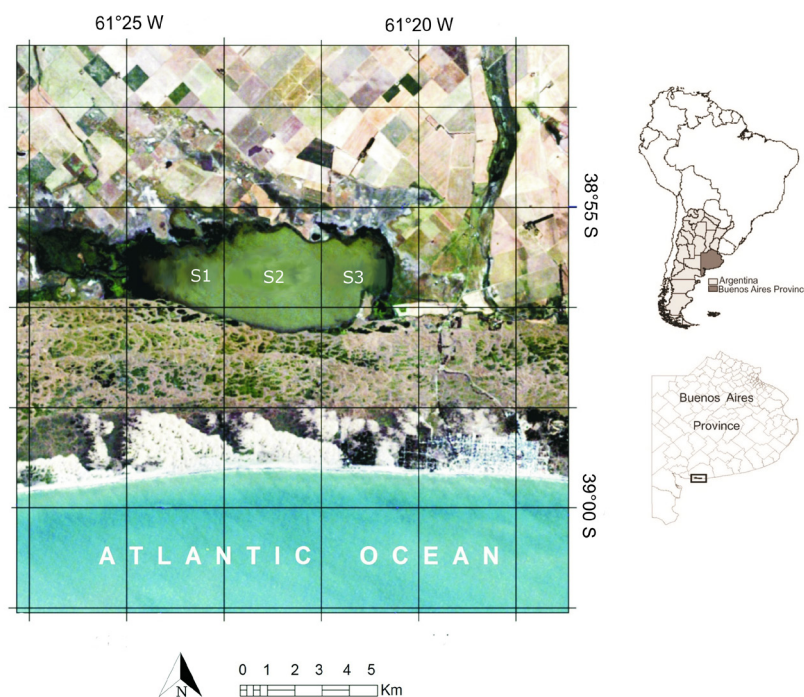


Figure 1. Location of the Sauce Grande Lake and of sampling stations (S1, S2, S3).

Figura 1. Ubicación geográfica de la laguna Sauce Grande y de las estaciones de muestreo (S1, S2, S3).

Environmental variables

Monthly samplings were carried out from December 2009 to November 2010, including the four seasons: summer (December 2009 to February 2010), autumn (March 2010 to May 2010), winter (June 2010 to August 2010), and spring (September 2010 to November 2010). Three sites were sampled across the central axis of the lake: (S1) near the inflow of the Sauce Grande River (S2) at the deepest zone of the lake and (S3) near the river outflow into the sea (Figura 1). Water temperature, conductivity, turbidity, dissolved oxygen (DO), and pH were measured in situ using a multi-sensor Horiba U-10. Also, the concentration of chlorophyll *a* (Chl *a*), suspended particulate matter (SPM), particulate organic matter (POM) and dissolved inorganic nutrients (soluble reactive phosphorus, nitrate, and nitrite) were obtained from surface water samples. The chlorophyll *a* was extracted with acetone 90% and measured spectrophotometrically according to the method described in APHA (2005). Soluble reactive phosphorus (SRP) and total dissolved phosphorus (TDP) were determined by the ascorbic acid method. The last fraction was digested with acidic persulphate (APHA, 2005). Nitrate and nitrite were measured by Cd reduction, followed by diazotization (APHA, 2005). SPM was determined from water samples filtrated through pre-combusted Whatman™ GF/F. POM was determined, according to Strickland & Parsons (1968). Water transparency was estimated with a Secchi disk (SDD). The trophic state indices were calculated considering Carlson equations (Carson, 1977) for Chl *a* concentration (µg/L) and SDD measurements in meters.

Plankton sampling and analysis

Mesozooplankton samples were collected at each site using a 200 µm net with a flow meter General Oceanics®. A previous study showed that this is a polymictic lake (Fornerón, 2016), so, as the entire column is mixed, the net was horizontally towed at the upper layer for 5 minutes at 2 m/s, considering it as representative of the entire water column. The

collected material was immediately preserved in a buffered solution of 4% formaldehyde. All samples were examined under a Nikon SMZ 1500 stereoscopic microscope and a Nikon Eclipse 80i microscope (100 x) for specimen identification (Bayly, 1992; Einsle, 1996, among others). The quantitative analysis was carried out in a 5 mL Bogorov chamber. The number of aliquots was estimated according to Cassie (1971). Copepod individuals were separately counted (nauplii, copepodites and adults).

Statistical analysis between limnological variables and mesozooplankton

The non-parametric analysis of variance (Kruskal-Wallis) was computed to test for significant differences in the limnological variables and mesozooplankton abundances between the sampling sites. Spearman's rank correlation coefficient (*r*) was used to estimate the relationship between limnological variables and mesozooplankton abundance. A detrended correspondence analysis (DCA) showed a linear response to the biological data; then, an RDA was performed to analyze which of the estimated environmental variables were responsible for the variation in the plankton community. Collinear variables, as defined by an inflation factor >4 (TerBraak, 1988), were removed from the analysis. Zooplankton data were not transformed so as not to down-weight abundant species. The significance of canonical axes was determined using Monte Carlo randomization with 9999 permutations under the reduced model. P values < 0.05 were considered statistically significant. Variables that did not contribute to the model at this significance level were removed. The analysis was performed with InfoStat® free version for students (Balzarini *et al.*, 2016) and CANOCO software version 4.53 (Licence number 5741).

RESULTS

Environmental variables

During the entire study period, the lake was under severe drought. Both the water flow from the river through the lake and the connection with the Atlantic Ocean were interrupted.

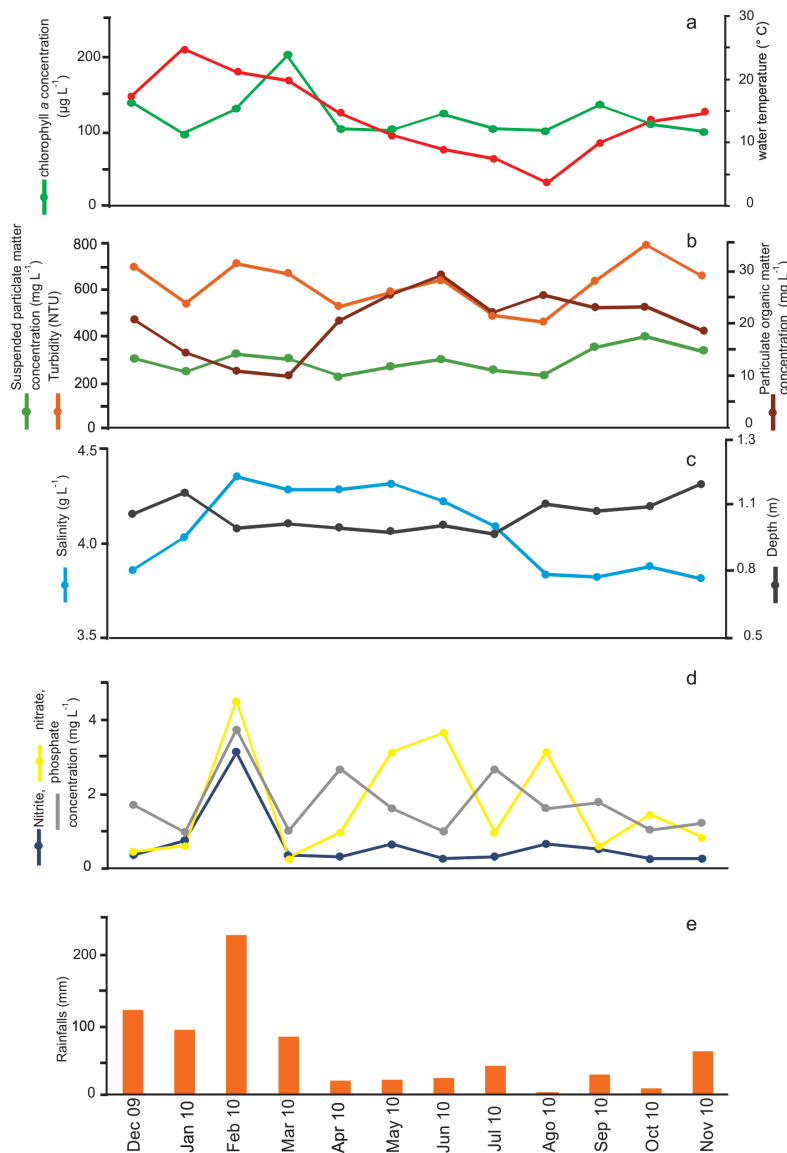


Figure 2. Temporal variation of the monthly mean values of: **a.** Chl *a* and water temperature, **b.** suspended particulate matter (SPM), particulate organic matter (POM) and turbidity, **c.** depth and salinity, **d.** nitrates, nitrites and phosphates and **e.** precipitation in the Sauce Grande Lake during the study period.

Figura 2. Variación temporal de: **a.** Clorofila *a* y temperatura del agua, **b.** materia particulada en suspensión (SPM), materia orgánica particulada (POM) y turbidez, **c.** profundidad y salinidad, **d.** nitratos, nitritos, fosfatos y **e.** precipitaciones en la laguna Sauce Grande durante el período de estudio.

Historically, it has a maximum depth of near 3 m; nevertheless, the lake did not exceed the 1.2 m depth during the study period. Physicochemical variables did not show significant differences between sampling sites except for depth ($p < 0.001$) and POM ($p < 0.05$). The annual mean water temperature was 14.4°C

and presented a clear seasonal pattern, ranging from 4.1°C (August) to 25.3°C (January) (Figure 2a). Mean, minimum, and maximum values and standard deviation of the limnological variables are given in Table 1. DO concentrations were high during the entire study period, with a mean value of 9.8 mg/L (Table 1). Chl *a* values

Table 1. Mean values with standard deviation (SD) and minimum (min) and maximum (max) values of limnological variables recorded at Sauce Grande Lake during the study period.**Tabla 1.** Valores medios con desviación estándar (SD) y valores mínimos y máximos de variables limnológicas registradas en la laguna Sauce Grande durante el período de estudio.

	mean	SD	min	max
Water temperature (°C)	14.45	6.14	4.13	25.33
pH	8.98	0.14	8.75	9.14
Depth (m)	1.07	0.07	0.98	1.21
Salinity (g/L)	4.06	0.21	3.81	4.34
Chl <i>a</i> (µg/L)	120.79	29.45	97.37	201.50
Dissolved oxygen (mg/L)	9.84	1.67	7.37	12.38
Turbidity	621.22	100.20	461.80	796.80
Secchi disk (m)	0.25	0.03	0.17	0.30
Suspended particulate matter (mg/L)	294.0	53.4	226.0	400.0
Particulate organic matter (mg/L)	20.18	5.90	9.81	29.06
Nitrites (µmol/L)	0.63	0.80	0.24	3.11
Nitrates (µmol/L)	1.69	1.47	0.27	4.50
Phosphates (µmol/L)	1.74	0.86	0.95	3.72
Trophic state indices (chlorophyll <i>a</i>)	86.41	2.07	84.52	91.65
Trophic state indices (secchi disk)	79.93	2.18	77.48	85.75

were also high, with a mean value of 120.8 µg/L, with the maximum concentration in March and the lowest in January (Table 1, Figure 2a). The pH was always alkaline. Transparency was low, with a mean SDD value of 25 cm related to high SPM and POM values (Table 1). The SPM presented the highest value in spring and the lowest one in autumn (Table 1, Figure 2b). Mean POM was 20.2 mg C/L, with maximum values in winter and minimum in autumn (Table 1, Figure 2b). Depth was low and oscillated between 1 and 1.2 m (Figure 2c). During February, March, and May in S3, the lake presented minimum depths and maximum in November in S2.

Salinity mean value was 4 g/L, classifying this lake as hyposaline according to Hammer (1986). Nutrient concentrations were high (Table 1) during all the study period but did not present a clear temporal pattern (Figure 2d). Precipitation was minimum in August (3 mm) and maximum in February (225 mm). Wind speed's minimum values were registered in summer (5 km/h) and maximum in spring (24 km/h). According to Carlson's TSI indexes, the lake is eutrophic (Table 1). TSIchl varied between 84.5 (January 2010) and 91.65 (March 2010). TSI_{sd} varied between 77.5 (January 2010) and 85.75 (March 2010). The Spearman's correlation analysis

showed that water temperature was positively correlated with precipitation ($p < 0.01$) and negatively with DO ($p < 0.001$), pH ($p < 0.05$), POM ($p < 0.001$) and phosphate concentration ($p < 0.05$). Also, turbidity was positively correlated with wind speed ($p < 0.01$). SDD also showed a significant negative correlation with Chl *a* ($p < 0.001$). Salinity was negatively correlated with depth ($p < 0.01$).

Mesozooplankton composition and spatiotemporal dynamics

Eight taxa distributed in four orders: Anomopoda, Calanoida, Cyclopoida, and Decapoda represent the mesozooplankton community. Mesozooplankton abundances showed significant differences between months but not significant between sampling points ($p > 0.7$).

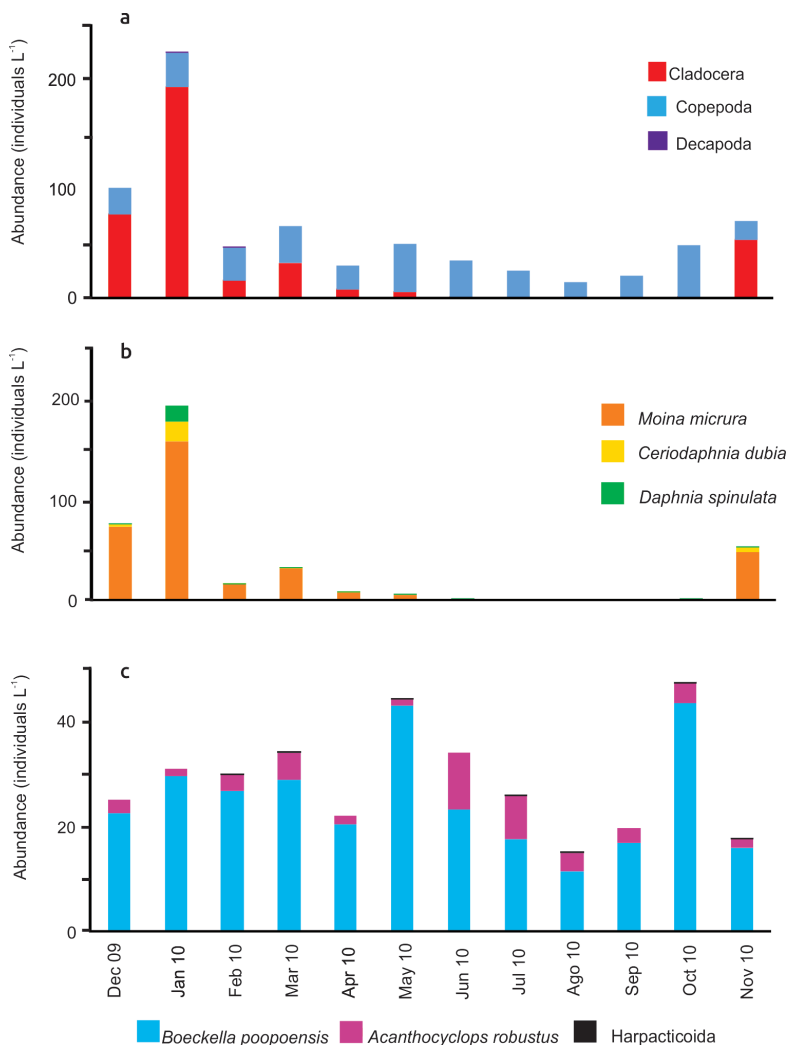


Figure 3. Mean mesozooplankton abundance recorded in Sauce Grande lake during the study period: **a.** Copepoda, Cladocera, and Decapoda monthly abundance, **b.** Cladocera species monthly abundance and **c.** Copepoda species monthly abundance.

Figura 3. Abundancia media del mesozooplankton registrada en la laguna Sauce Grande durante el período de estudio: **a.** Abundancia mensual de Copepoda, Cladocera y Decapoda, **b.** Abundancia mensual de las especies de Cladocera y **c.** Abundancia mensual de las especies de Copepoda.

Cladocerans predominate in the warmer period (December 2009, January 2010 and November 2010), while cyclopoids and calanoids were consistent all year, especially in cold months, when cladocerans were barely present (Figure 3a). Total species richness was similar during the study period, fluctuating between five species in January and April, and seven species in May, October, and November when low salinity values were also registered (Figure 4).

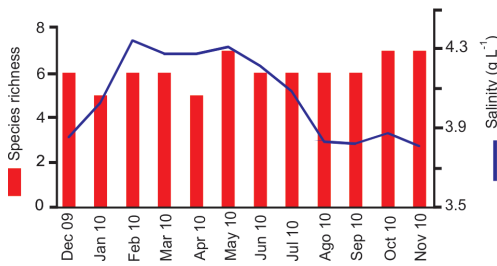


Figure 4. The temporal variation of total species richness and salinity concentration during the study period in the Sauce Grande Lake.

Figura 4. Variación temporal de la riqueza total de especies y de la salinidad durante el período de estudio en la laguna Sauce Grande.

In contrast, mesozooplankton abundance was slightly variable (15.5 – 225 ind/L). The lowest value was recorded in winter (August 2010), while the highest one in summer (January 2010) (Figure 3a). Four species of cladocerans were present, which represented 52.9% of the total mesozooplankton abundance. *Moina micrura* Kurz, 1874 was the most abundant taxon (Figure 3b), representing 46% of the total density. The highest abundance of this species was recorded in January (158.5 ind/L), whereas the minimum in September (< 1 ind/L). It is essential to mention that individuals of *M. micrura* with ephippia structures were observed during all the months the species was recorded. The cladoceran *Ceriodaphnia dubia* Richard, 1894 represented 4.7% of the total mesozooplankton abundance with values ranged from under 1 ind/L (July) to 20.2 ind/L (January). *Daphnia spinulata* represented only 2.2% of the total mesozooplankton abundance, and it was always

presented with low number (< 1 ind/L). *Leydigia louisii* Jenkin, 1934 represented only 0.1% of the total mesozooplankton abundance and its density ranged between 0 and 0.5 ind/L (Figure 3b).

Copepods (adults, copepodites, and nauplii) represented 47.1% of the total mesozooplankton abundance. *Boeckella poopensis* Marsh, 1906 (Figure 3c) was the most representative (40.6%), with densities ranging between 11.47 (August) and 43.4 ind/L (October) (Figure 3c). The cyclopoid *A. robustus* (Figure 3c) (6.4%) showed a maximum of 10.9 ind/L in June and a minimum of 1.33 ind/L in May (Figure 3c). Harpacticoids represented only 0.05% of total mesozooplankton abundance, with values minor than 1 ind/L. Their presence was intermittent during the study period (Figure 3c). Finally, Decapoda individuals were represented by Caridea postlarval individuals and were only observed in summer and with low number (January and February, < 1 ind/L).

Relationship between mesozooplankton and environmental variables

Cladocerans and carideans presented a strong seasonality. *Moina micrura*, *C. dubia*, *D. spinulata* and Caridea were positively correlated with temperature ($p < 0.01$, $p < 0.05$, $p < 0.05$, respectively) meanwhile *L. louisii* was negatively correlated ($p < 0.05$). Also, *M. micrura* was positively correlated with precipitation ($p < 0.01$) and negatively with POM ($p < 0.05$). *L. louisii* was negatively correlated with salinity ($p < 0.05$). Decapoda presented a negative correlation with pH ($p < 0.05$). Copepods did not present correlation with the evaluated environmental variables.

The first two axes of the RDA explained the 74.4% of total variance ($p = 0.025$). The ordination of the sampling dates along the first axis (45.2%; $p = 0.03$) was associated with temperature ($p = 0.05$) and pH ($p = 0.04$), and in the second axis (29.2%; $p = 0.048$) with salinity ($p = 0.05$), nitrate ($p = 0.05$), phosphate (0.04), turbidity ($p = 0.04$), and depth ($p = 0.03$) (Figure 5). Cladocerans were associated with high-temperature values; meanwhile, Harpacticoida and Decapoda were associated with low depth

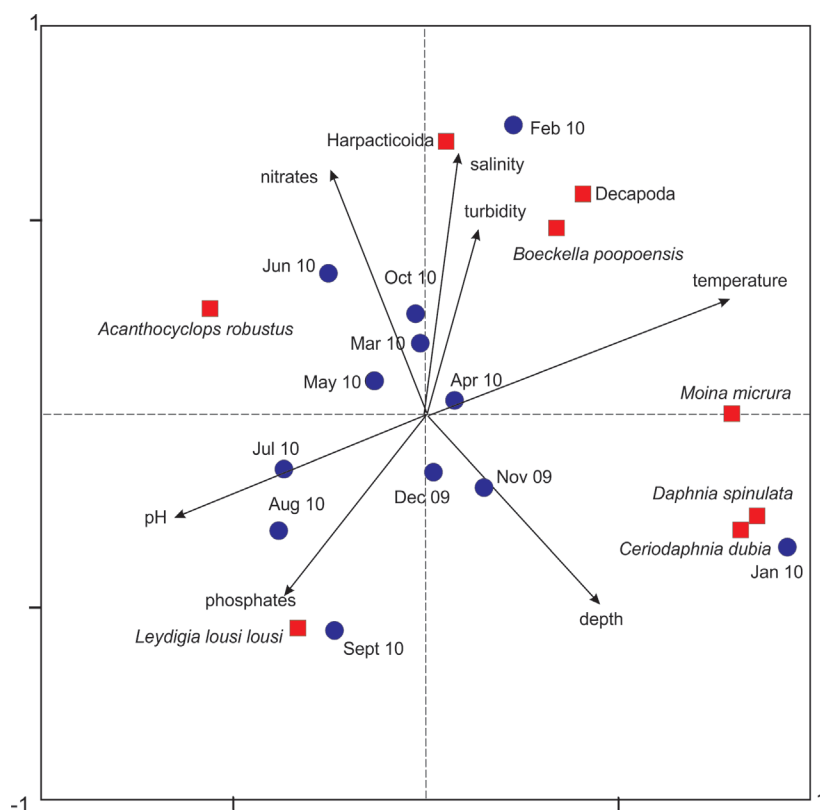


Figure 5. Result of Redundancy analysis (RDA) (first and second axis) based on mesozooplankton abundance and main environmental variables measured during the study period.

Figura 5. Resultado del análisis de Redundancia (RDA) (primer y segundo eje) basado en las abundancias del mesozooplankton y las principales variables ambientales registradas durante el período de estudio.

and high values of salinity, turbidity and nitrate concentration. *Acanthocyclops robustus* presented the abundance peaks in autumn and winter samples. Finally, spring samples were characterized by the presence of *L. lousi lousi*, with low salinity conditions, and high pH and phosphate values (Figure 5).

DISCUSSION

Shallow lakes are particularly vulnerable to drought conditions due to their large surface: volume ratio (Jeppesen *et al.*, 2009). Drought and wet cycles produce concentration and dilution processes in the pampean lakes because of the changes in precipitation and evaporation rates (Aliaga *et al.*, 2016). A salinity increase was observed in the lake respect to previous studies that reported the lake as a

subsaline system with 2 m of depth (Remes Lenicov y Colautti, 2003). It is well known that this kind of drastic reduction in water level produces a concentration of the substances in the lake, which has a high impact on the physicochemical conditions and consequently, in the plankton community (Beklioglu *et al.*, 2007; Jeppesen *et al.*, 2015). Also, like other lakes in the region, Sauce Grande presented highly turbid conditions (Diovisalvi *et al.*, 2010; Echaniz *et al.*, 2008, 2009). Because of its shallow depth, the wind action produces the resuspension of sediments in the water column (Margalef, 1983). The high Chl *a* values found during this study were coherent with the phytoplankton abundance values found in the lake (Ferrer *et al.*, 2012). This also evidences the high productivity and eutrophic conditions of the lake during the entire study period.

The mesozooplankton community of the Sauce Grande Lake presented a typical species association from hyposaline lakes of the Pampas (Echaniz *et al.*, 2008; Vignatti *et al.*, 2007). It was characterized by the presence of small cladocerans as *M. micrura* and *C. dubia* (Petrusek *et al.*, 2004), and the halophile copepod *B. poopoensis*. The large cladoceran *D. spinulata* considered typical of cold-mesohaline waters of Argentina (Olivier, 1962) and the small Chydoridae, *L. louisii* were also found. The latter was only cited for Hinojales and Nahuel Rucá Lakes in the Pampas (González Sagrario & Ferrero, 2013) and Patagonian region (Santa Cruz province) (Kotov, 2003). Studies in the Afro-tropical area (Kenya) and the Neotropical Region in Guatemala and Central Mexican highlands (Elías-Gutiérrez *et al.*, 2006, Kotov, 2003) also mention this species, evidencing a significant range of climatic conditions. Among copepods, the halotolerant *B. poopoensis* is a common species of saline lakes (5 - 90 g/L), and it is frequent in hyposaline lakes such as Sauce Grande but at higher abundances (Echaniz *et al.*, 2009; Vignatti *et al.*, 2012). The cyclopoid *A. robustus* is an omnivorous species characteristic of eutrophic systems (Caramujo & Boavida, 1999, Lacroix & Lescher-Moutoué, 1991) such as Sauce Grande Lake. Finally, Caridea postlarval individuals were also present but only at the highest salinities during January and February and at low number. Caridea is a diverse and significant ecological group that evolved in the sea and invaded brackish coastal, estuarine, and limnetic habitats (Augusto *et al.*, 2007; Freire *et al.*, 2003). Freshwater-inhabiting shows physiological characteristics that may indicate their recent evolutionary history in this habitat. In particular, tolerance to high salinities, dependence on saline water for larval development, and reproductive migrations towards the sea (Bauer & Delahoussaye, 2008), possibly explain their presence at maximum salinity values during the study period. In a previous study in Sauce Grande Lake, Remes Lenicov & Colautti (2003) described the zooplanktonic community with dominance of small cladocerans (*Bosmina* sp.). Also, the presence of *Alona* sp. and *C. dubia* were recorded. With respect to copepods, the study

also cited the presence of *A. robustus* but in conjunction with *Notodiaptomus incompositus* (Brian, 1925), a calanoid commonly cited in the Pampean Region for subsaline and permanent lakes (Pilati, 1997). The increases in salinity values observed during the present study could explain the replacement of *N. incompositus* by the halotolerant calanoid *B. poopoensis* and the modifications in cladoceran composition.

The mesozooplankton abundances registered here were lower than other saline lakes (Arora & Mehra, 2009; Del Ponti *et al.*, 2015; Echaniz *et al.*, 2009, 2012). Particularly, the abundances of *C. dubia* and *A. robustus* were lower compared with the results obtained by Remes Lenicov & Colautti (2003) in the same lake. The zooplankton richness was low and similar to that reported in other hyposaline lakes (Arora & Mehra, 2009, Del Ponti *et al.*, 2015, Echaniz *et al.*, 2012). The species richness decreased in the months with highest salinity values, as expected. Increased salinity causes osmotic stress accompanied by high mortality or lower reproduction and growth rates (Jeppesen *et al.*, 2007a), and may also promote Cyanobacteria blooms (Sellner *et al.*, 1988). These conditions can induce a state shift to turbid water period (Jeppesen *et al.*, 2007b) and a significant reduction of the resilience of the lake ecosystem. Salinity, in conjunction with high temperature and pH conditions and low dissolved nitrogen concentrations, can stimulate the appearance of cyanobacterial blooms, as it is frequently reported for lakes undergoing severe droughts (Paerl & Huisman, 2009; Unrein *et al.*, 2010). Ferrer *et al.* (2012) recorded the presence of potential toxic cyanobacteria bloom producers such as species of *Anabaena*, *Anabaenopsis*, *Aphanocapsa* and *Microcystis* in the lake for the same period.

Shallow lakes biota is usually highly diverse due to a more extensive littoral zone (Wetzel, 1999). Nevertheless, the reduction of the lake area by drought conditions could lead to a decrease of the different habitat choices and refuge for mesozooplankton, possibly promoting a detrimental decline in species richness (Rocha Sousa *et al.*, 2013). In the Sauce Grande Lake, the reduction in the basin size, water depth, and the salinity increase by the drought conditions are probably responsible

for the comparatively low species richness and abundance of mesozooplankton with respect to other pampean eutrophic lakes (Chaparro *et al.*, 2011). The individuals of *M. micrura* with ephippia structures recorded during the entire study period also indicate the adverse conditions that this lake presented during the drought period.

The predominance of small size taxa characterizes the zooplankton community when planktivores fishes such as *Odontesthes bonariensis* dominate the pelagic fish assemblages (Iglesias *et al.*, 2011). The grazing pressure of silverside populations is high because during the larval and juvenile stages the diet consists mainly of large planktonic cladocerans and secondarily of adult copepods (calanoids and cyclopoids) (Grosman & González Castelain 1996; Grosman *et al.*, 2002). Consequently, the predominance of median and small zooplankters with low filtration efficiency is related to a turbid state period (Echaniz & Vignatti, 2010; Jeppesen *et al.*, 2007a, b) frequently established in the lake. Although the fish community was not studied here, this is like the results found in this lake, for both 2003 and 2010, with a mesozooplankton community dominated by small size cladocerans and low transparency values during all the study period. *Daphnia spinulata* is the only large cladoceran recorded in this study but only with low density during spring and summer indicating an enhanced fish predation pressure (Jeppesen *et al.*, 1999). These results coincide with those reported for other shallow lakes of the region (e.g., Echaniz & Vignatti, 2010; Diovisalvi *et al.*, 2015).

In conclusion, the mesozooplankton composition in the Sauce Grande Lake during an extreme drought event was determined by salinity conditions; meanwhile, the abundance dynamic was ruled by temperature in conjunction with the prevailing eutrophic conditions during the study period. In a global scenario of climate change where an increase of extreme events is expected, and for a region where drought and wet cycles are frequent, these results contribute to the understanding of some processes affecting the zooplankton community during extreme drought events. Increased salinity

generated by extreme drought events could change the trophic structure of shallow lakes, reducing the lake ecosystem resilience.

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