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Biology of *Artemia persimilis* Piccinelli and Prosdocimi, 1968 in a hypersaline lake in a semiarid protected area (Parque Luro Reserve, La Pampa, Argentina)

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ABSTRACT

Biology of *Artemia persimilis* Piccinelli and Prosdocimi, 1968 in a hypersaline lake in a semiarid protected area (Parque Luro Reserve, La Pampa, Argentina)

Artemia persimilis is the only species of the genus that is native to South America. Its biology has been studied in lakes in the arid diagonal in Argentina, which are affected by agricultural and livestock activities. The aim was to study biological aspects and their relations with environmental variables in a protected lake under conditions similar to those that existed before the increase in human influence on this area. From October 2014 to September 2015, samples were taken monthly from Este Lake (64° 11' 04" W, 36° 55' 18" S), which is in the intangible zone of Parque Luro Provincial Reserve. *In situ* water temperature, dissolved oxygen, water transparency, and pH were determined, and two quantitative zooplankton samples were taken. The maximum depth varied between 0.9 and 0.33 m, the mean salinity was 262.17 g/L (± 43.87), and Na^+ and Cl^- predominated. The water transparency was 0.56 m (± 0.21), and the concentration of phytoplankton chlorophyll-*a* was 6.19 mg/m^3 (± 8.17). The mean density and biomass of *A. persimilis* were 209.31 ind./L (± 214.04) and 7535.10 µg/L (± 12 376.57), respectively, which exceeded those recorded in other lakes in the region. Nauplii and metanauplii were registered in every month except December and July, and they showed high percentages of total density. A correlation was found between density and temperature but not between density and salinity, which could indicate that the range in Este Lake is optimal for the species. Although it is difficult to prevent colonization by exotic anostracan species by zoochory, the existence of an abundant population of *A. persimilis* in a protected lake in the central Argentinean region is an optimal opportunity for the conservation of this species.

Key words: *Artemia persimilis*, *Artemia franciscana*, biological invasions, Argentinian Central Pampa, hypersaline lake

RESUMEN

Biología de* Artemia persimilis *Piccinelli y Prosdocimi, 1968 en un lago hipersalino de un área protegida del centro semiárido de Argentina

Artemia persimilis *es la única especie del género nativa de Sudamérica. Su biología se ha estudiado en lagos de la diagonal árida Argentina relativamente impactados por la explotación agrícola y ganadera. El objetivo fue estudiar aspectos biológicos y sus relaciones con parámetros ambientales en un lago protegido, en condiciones similares a las existentes antes del aumento de la influencia humana. Se tomaron muestras mensuales entre octubre de 2014 y septiembre de 2015 en el lago Este (64° 11' 04" W, 36° 55' 18" S), en la zona intangible de la Reserva Provincial Parque Luro.* In situ *se determinaron la temperatura del agua, oxígeno disuelto, transparencia, pH y se tomaron dos muestras cuantitativas de zooplancton. La profundidad varió entre 0.9 y 0.33 m, la salinidad media fue 262.17 g/L (± 43.87) y predominaron el* Na^+ *y* Cl^-*. La transparencia fue 0.56 m (± 0.21) y la concentración de clorofila-*a *fitoplanctónica fue 6.19 mg/m*^{3} *(± 8.17). La densidad y biomasa media de* A. persimilis *fueron 209.31 ind./L (± 214.04) y 7535.10 µg/L (± 12 376.57) y superaron las registradas en otros lagos de la región. Excepto en diciembre y julio, siempre se registraron nauplios y metanauplios, que representaron porcentajes elevados de la densidad total. Se encontró correlación entre la densidad y la temperatura pero no con la salinidad, lo que podría deberse a que el rango de ésta en el lago Este es óptimo para el desarrollo de la especie. Aunque es difícil prevenir la colonización mediante zoocoria* *por alguna especie de anostraco exótica, la existencia de la población de* A. persimilis *más abundante del centro de Argentina en un lago protegido representa una oportunidad óptima para la conservación de esta especie.*

Palabras clave: Artemia persimilis, Artemia franciscana*, invasiones biológicas, Pampa Central Argentina, lago hipersalino*

INTRODUCTION

Many saline lakes (salinity > 3 g/L) exist in the arid diagonal that crosses Argentina from north to south (D'Ambrosio *et al.*, 2016). These lakes, which range widely in salinity, are abundant in the central portion of the arid diagonal where the Dry Pampas region is located (Echaniz & Vignatti, 2017). Because the water in most of these lakes comes from rainfall or groundwater discharge, they can remain dry for variable periods from a few months to several years, which are strongly related to the short-term cycles of precipitation and drought cycles caused by El Niño and La Niña events (Viglizzo, 2010). The loss of water occurs mainly through evaporation, which causes marked changes in water levels during hydroperiods and produces wide fluctuations in salinity (Echaniz &Vignatti, 2017; Echaniz *et al.*, 2006; Vignatti *et al.*, 2012).

Hypersaline lakes have a salinity > 50 g/L (Hammer, 1986), which generates strong environmental stress (Herbst, 2001). These lakes have high biological productivity but low diversity (Amat *et al.*, 2007), which is restricted to organisms that have physiological mechanisms that are capable of withstanding osmotic stress (Gajardo & Beardmore, 2012). The most conspicuous of these organisms are the anostracans of the *Artemia* genus, which is dominant in the zooplankton community. These organisms are among the most exposed to the damaging effects of habitat loss and the entry of invasive species, which was previously recorded in hypersaline habitats in the Mediterranean basin (Amat *et al.*, 2007).

Two species have been recorded in Argentina: *Artemia franciscana* Kellogg, 1906 and *A. persimilis* Piccinelli and Prosdocimi, 1968 (Cohen, 1998; Vignatti *et al.*, 2017; Echaniz & Vignatti, 2017). *Artemia franciscana* is exotic, and it entered the country by cysts transported by migratory birds from the northern hemisphere (Muñoz *et al.*, 2013), which allowed its expansion to 31° S (Bucher, 2006; Pilati *et al.*, 2016). *Artemia persimilis* is autochthonous and restricted to Chile and Argentina (Clegg & Gajardo, 2009). It is the only species registered in the province of La Pampa (Vignatti *et al.*, 2014; Echaniz *et al.*, 2015; Echaniz & Vignatti, 2017; Vignatti *et al.*, 2017).

Artemia franciscana exhibits attributes that characterize an invasive species, such as a large native range, a short generation time, single female colonization, a high dispersal rate, among others (Speer & Weider, 2018). Previous research indicated that this species could be in evolutionary expansion because of its ability to colonize (Clegg & Gajardo, 2009). These characteristics have enabled this species to monopolize many aquatic ecosystems around the world (Muñoz *et al.*, 2014), thus displacing native species (Green *et al.*, 2005). In Argentina, *A. franciscana*'s lower tolerance of low temperatures could limit its spread toward the south of the country (Amat *et al.*, 2004; Vignatti *et al.*, 2014). Hence, the present study's focus on the saline lakes located between 33° and 37° S, in the transition zone between the distributions of *A. franciscana* and *A. persimilis*, is relevant to aquatic saline ecosystems both in this area and worldwide.

The *Artemia* species is important economically because it is grown as a live food in aquaculture (Sorgeloos *et al.*, 1986; Dhont & Sorgeloos, 2002; Rodríguez-Canché *et al.*, 2006; Ben Naceur *et al.*, 2008). Some aspects of the biology of *A. persimilis* have been studied in the laboratory (Pastorino *et al.*, 2002; Sato *et al.*, 2004; Medina *et al.*, 2007; Mechaly *et al.*, 2004, 2013). However, information about their biology under natural conditions is relatively scarce. Most data on this species were collected in studies conducted in hypersaline lakes in the central semiarid region of Argentina, which are affected by the agricultural and livestock exploitation carried out in their basins (Vignatti *et al.*, 2014; 2017; Echaniz *et al.*, 2015).

A hypersaline lake surrounded by natural vegetation in the intangible zone of the extensive protected area, the Parque Luro Provincial Reserve, offers an excellent opportunity to study the biological aspects of *A. persimilis* in conditions of low anthropogenic influence. The objective of this work is to analyze the population characteristics of the species (i.e., density, biomass, and size) and their relationships with the main limnological variables over an annual cycle in conditions similar to those that the hypersaline ecosystems of the region could have had before the increase in human influence by the deforestation of large areas for growing cereals and oilseeds and raising livestock. The results of the present study are compared with those obtained in other hypersaline environments previously studied in the region, such as the Utracán, La Amarga, and Guatraché Lakes, which are subject to much greater anthropogenic influence.

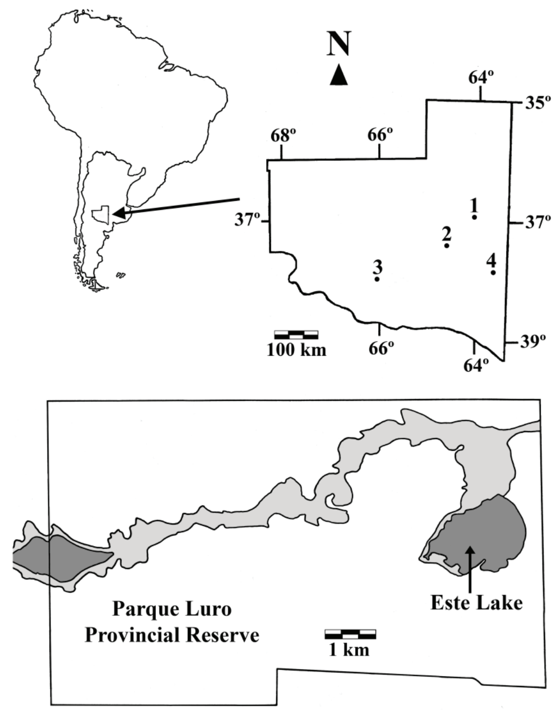

Figure 1. Above: Geographical location of the hypersaline lakes studied in the semiarid Argentinean Central Pampas. 1: Parque Luro Este Lake (64° 11' 04" W, 36° 55' 18" S). 2: Utracán Lake (64° 35' 56" W, 37° 16' 59" S). 3: La Amarga Lake (66° 06' 27" W, 38° 13' 20" S). 4: Guatraché Lake (63° 31' 28" W, 37° 44' 19" S). Below: Location of Este Lake in the Parque Luro Provincial Reserve. The external line indicates the limits of the Reserve. Dark gray: lakes. Light gray: areas of the basin that flood very occasionally. *Arriba: Ubicación geográfica de los lagos hipersalinos estudiados en la Pampa central semiárida de Argentina. 1: Lago Este de Parque Luro (64° 11' 04" W, 36° 55' 18" S). 2: Laguna Utracán (64° 35' 56" W, 37° 16' 59" S). 3: Laguna La Amarga (66° 06' 27" W, 38° 13' 20" S). 4: Laguna Guatraché (63° 31' 28" W, 37° 44' 19" S). Abajo: Ubicación del lago Este en la Reserva Provincial Parque Luro. El trazo externo indica los límites de la Reserva. Gris oscuro: lagunas. Gris claro: áreas de la cuenca que se inundan muy ocasionalmente.*

MATERIALS AND METHODS

Study area

The Parque Luro Provincial Reserve is located in the eastern-central area of the province of La Pampa (Fig. 1) in the phytogeographic region of the Thorny Forest (Oyarzábal *et al.*, 2018) where *caldén* (*Prosopis caldenia* Burkart) predominates. It has an area of 7607 ha, which is covered by natural vegetation, in which agricultural activities and deforestation have not occurred for more than 70 years (González-Roglich *et al.*, 2012).

The average annual rainfall (determined in Ataliva Roca, the town closest to the reserve) is around 700 mm/yr (APA, 2018). However, the rains are highly variable because they are influenced by El Niño and La Niña events (Viglizzo, 2010; Russián *et al.*, 2015). The distribution of rainfall throughout the year has shown higher peaks in October and March (Cano, 1980). In this area, evapotranspiration greatly exceeds the rainfall (an average of 800 mm/yr) (Roberto *et al.*, 1994).

The northern part of the reserve is crossed by one of the deep west-southwest to east-northeast transversal valleys that characterize the eastern-central region of La Pampa (Lorenzo *et al.*, 2013). Este Lake (64° 11' 04" W, 36° 55' 18" S) is located in this valley near the eastern limit of the Reserve in the zone of restricted access. This shallow temporary lake is fed by rainfall, surface runoff, and groundwater. It has no effluents, and the main water losses are through evaporation or infiltration during dry periods. During the study, Este Lake had a maximum length of 1708 m, a maximum width of 1056 m, and a maximum surface area of 132 ha (Fig. 1).

Field and laboratory work

From October 2014 to September 2015, samples were taken monthly at two sites in the lake. At each site, the water temperature, dissolved oxygen concentration (Lutron® OD 5510 oximeter), water transparency (22 cm diameter Secchi disk), and pH (Corning® PS 15 pH meter) were determined. Two quantitative zooplankton samples were taken. Because of the shallow depth, graduated pails were used to take samples by integrating the water column and then filtering through a net with a mesh size of 40 µm. A qualitative sample was also taken using a similar net. All samples were anesthetized with CO_2 and kept refrigerated until fixation. Subsequently, they were deposited in the collection at the Universidad Nacional de La Pampa. In addition, water samples were taken and kept refrigerated until laboratory analysis. The salinity was determinate by the gravimetric method by drying at 104 °C (APHA, 1992). The concentration of chlorophyll-*a* was determined through extraction with aqueous acetone and spectrophotometry (Arar, 1997). The concentrations of organic suspended solids (OSS), and inorganic suspended solids (ISS) were determined by weighing Microclar FFG047WPH filters after drying at 103 °C–105 °C to a constant weight and then calcining at 550 ºC (EPA, 1993). On two occasions (January and October), water samples were taken to determine the ionic composition according to standardized routines: Na^+ (selective ion electrode); K^+ (determination of the intensity of the turbidity by the combination of potassium with sodium tetraphenylborate); Ca^{2+} (EDTA digital titulometric method or spectrophotometric method for very low calcium levels); Mg^{2+} (digital titrometric method or spectrophotometric method for very low magnesium levels); Cl^- (argentometric method [digital titration with silver nitrate solution in the presence of potassium chromate] or the spectrophotometric method for very low concentrations); SO_4^{2-} (spectrophotometric determination of the intensity of the turbidity formed during the reaction of the sulfate with barium); and HCO_3^- and CO_3^{2-} (alkalinity method of phenolphthalein and digital titration) (APHA, 1992).

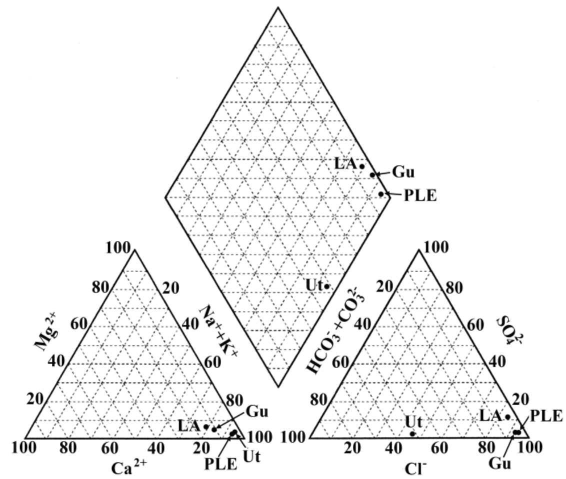

Figure 2. Comparison of the ionic composition of the water of the four-hypersaline lakes studied in the semiarid Argentinean Central Pampas. LA: La Amarga Lake. Gu: Guatraché Lake. PLE: Parque Luro Este Lake. Ut: Utracán Lake. *Comparación de la composición iónica del agua de los cuatro lagos hipersalinos estudiados en la en la Pampa central semiárida de Argentina. LA: La Amarga. Gu: Guatraché. PLE: Parque Luro Este. Ut: Utracán.*

The *Artemia* counts in the complete sample were performed under stereoscopic microscopy in Bogorov and Sedgwick–Rafter chambers. Density was expressed as ind./L.

The proportions of the different stages (Cohen *et al.*, 1999) were determined under an optical microscope in Sedgwick–Rafter chambers. To estimate the biomass, conventional measurements of 100 specimens per sample were taken using an optical microscope with a micrometric Arcano 10x eyepiece. The formulas that related the total length to the dry weight of *A. franciscana* (Wurtsbaugh, 1992) were used. Measurements were performed on all specimens present in the sample at a low density (< 100 specimens).

We used the classification of continental waters based on salinity, as proposed by Hammer (1986). When average values were presented, we used standard deviation (SD) as the error measure. To examine the relations between all environmental factors and zooplankton attributes, Spearman correlation coefficients (r_s) were calculated (Sokal & Rohlf, 1995; Zar, 1996). We used the Past (Hammer *et al.*, 2001) and Infostat (Di Rienzo *et* *al.*, 2010) software packages. All applicable international, national, and institutional guidelines for the care and use of animals were followed.

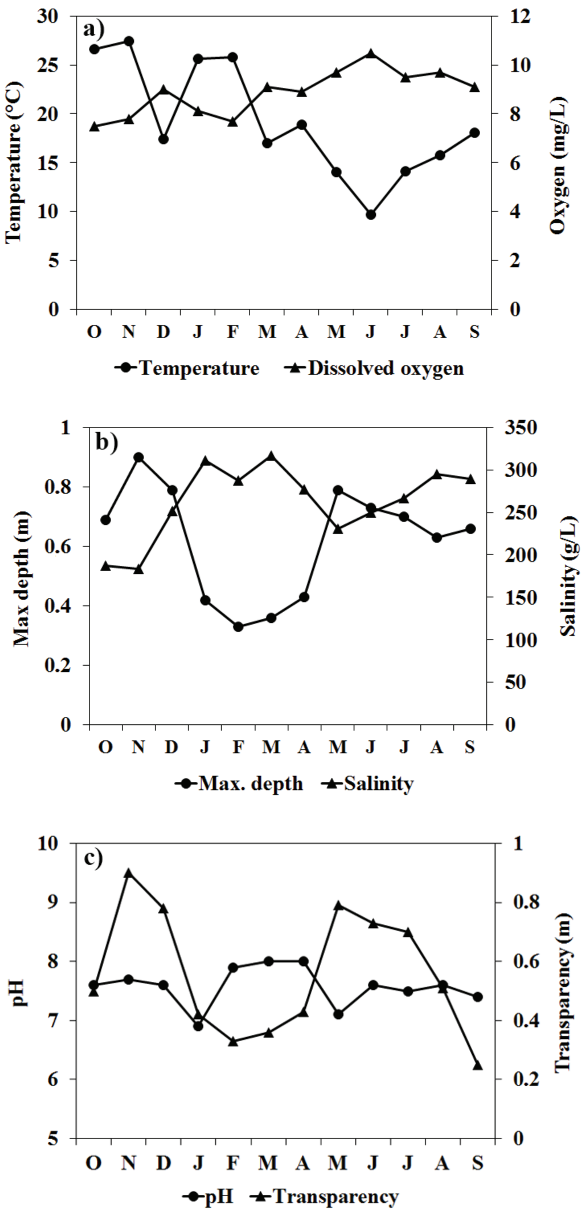

Figure 3. Monthly variations in (a) water temperature and dissolved oxygen, (b) maximum depth and salinity, and (c) pH and water transparency between October 2014 and September 2015 in Parque Luro Este Lake. *Variación mensual de (a) temperatura del agua y oxígeno disuelto, (b) profundidad máxima y salinidad y (c) pH y transparencia del agua del lago Este de Parque Luro entre octubre de 2014 y septiembre de 2015.*

RESULTS

The ionic composition showed the predominance of Cl^- (96.80 % of anions) and Na^+ (94.9 %, of cations) (Fig. 2). The water temperature followed a seasonal pattern with a minimum in June and a maximum in November. In December, the temperature dropped because of the entry of rainwater, but it then rose rapidly (Fig. 3a). The concentration of dissolved oxygen was relatively high and variable (Fig. 3a) in correlation with the water temperature (r_s = – 0.95, $p < 0.05$). The depth of the lake was low, and a great loss of water by evaporation was observed in summer. However, in March, the water level was increased by seasonal rainfall (Fig. 3b). The salinity was high during the entire study period in correlation with the depth of the lake (r_s = -0.81; $p < 0.05$) (Fig. 3b). The pH was relatively stable, ranging between 6.9 and 8.0 (Fig. 3c). The water transparency ranged between 0.25 m in September and 0.9 m in November (Fig. 3c). No significant correlations were found between transparency and the other environmental variables. With the exception of two peaks in August and September, the phytoplankton chlorophyll-*a* concentration did not exceed 3 mg/m^3 (Fig. 4). During the study, ISS represented the highest proportion of suspended solids (81 % of the total) (Fig. 4), and a significant correlation was found between the OSS concentration and that of chlorophyll-*a* (r_s = 0.8; $p < 0.05$).

The mean density of the *A. persimilis* population throughout the study was 209.31 ind./L (± 214.04); minimum density occurred in July, and maximum density occurred in April (Fig. 5). The mean density showed a significant correlation with water temperature only (r_s = 0.57; $p < 0.05$). The total mean biomass was 7535.10 µg/L (± 12 376.57), with a minimum in March and a maximum in November (Fig. 5). No correlations were found between the *Artemia* biomass and any environmental variable.

The first stages (nauplii and metanauplii) were verified in every month except December and July when only post-metanauplii, post-larvae, and adults were observed. Nauplii represented high percentages of population density in February and March (Fig. 6a), but their abundance was relative-

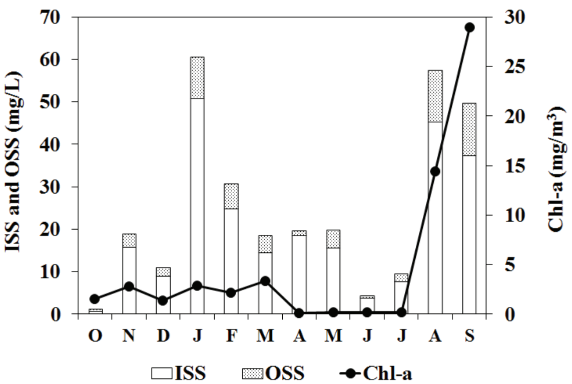

Figure 4. Monthly variations in ISS, OSS, and chlorophyll-*a* concentrations between October 2014 and September 2015 in Parque Luro Este Lake. *Variación mensual de la concentración de ISS, OSS y clorofila-*a *en el lago Este de Parque Luro entre octubre de 2014 y septiembre de 2015.*

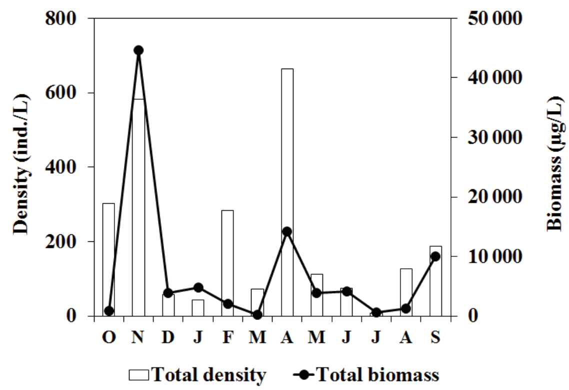

Figure 5. Monthly variations in *Artemia persimilis* density and biomass between October 2014 and September 2015 in Parque Luro Este Lake. *Variación mensual de la densidad y biomasa totales de* Artemia persimilis *del lago Este de Parque Luro entre octubre de 2014 y septiembre de 2015.*

ly low in the remaining samples. Metanauplii were the dominant stage on five occasions, when they exceeded 40 % of the population density (Fig. 6a). Positive significant correlations were obtained between the density of nauplii and metanauplii and water temperature ($r_S = 0.61$; $p < 0.05$ and $r_S = 0.57$; $p < 0.05$, respectively).

With the exception of February, the most frequent stage was post-metanauplii, which showed in high percentages of the population in most samples. A peak occurred in April when 78 % of the population was comprised of post-metanauplii (Fig. 6a). The most advanced stages (post-larvae and adults) were not recorded in October and March, and in the remaining months, they showed relatively low densities. Post-larvae dominated only in September (32 % of the total population density), and the adult stage was never dominant (Fig. 6a). The group composed of post-larvae and adults comprised the highest biomass percentage of the population on nine occasions (Fig. 6b) because of their larger size (some adults reached 10.12 mm). This contribution was highest in November when they reached 13 % and 82 % of the population biomass. When post-larvae and adults were not registered, the less developed stages reflected the highest biomass, such as in October, when metanauplii reached 48 % of the total, or in March, when the nauplii represented the 70 % of the population biomass. In contrast, in August, all stages were found, and post-metanauplii contributed the highest biomass, reaching 592.05 µg/L (45 % of the population biomass) (Fig. 6b).

DISCUSSION

The results showed that the salinity of Parque Luro Este Lake was similar to that of other hypersaline lakes in the semiarid Central Pampas where *A. persimilis* was detected (Table 1), such as La Amarga Lake (Echaniz *et al.*, 2015; Echaniz & Vignatti, 2017), Utracán Lake (Vignatti *et al.*, 2017), and Guatraché Lake, where *A. persimilis* was recorded when the salinity reached 418.5 g/L, which is the maximum salinity in which this species has been found in natural waters (Vignatti *et al.*, 2014).

Similar to most lakes in the semiarid Central Pampas, Este Lake depends on seasonal rains (Cano, 1980) that highly fluctuate interannually (Viglizzo, 2010; Russián *et al.*, 2015). This explains the changes in certain lake variables, such as the depth, which reached the maximum in November and then fell sharply, or salinity, which showed variations higher than 130 g/L during the study period. This result is similar to that recorded in the aforementioned hypersaline

Table 1. Main limnological variables, total density, and biomass of *Artemia persimilis* and stage densities (mean values) in saline lakes in the semiarid Central Pampas where the species was recorded. *Valores de las principales variables limnológicas, densidad y biomasa totales de* A. persimilis *y densidad de los diferentes estadios (valores medios) en los lagos de la Pampa central semiárida en los que la especie fue registrada.*

	La Amarga (2007)	Utracán (2009–2010)	Guatraché (2011–2012)	Parque Luro Este
Water temperature (°C)	14.58 ±7.99	16.53 ±7.61	23.78 ±10.87	19.20 ±5.81
Salinity (g/L)	115.51 ±19.02	238.05 ±92.34	345.40 ±48.25	262.17 ±43.87
pH	7.82 ±0.53	9.21 ±0.09	7.73 ±0.23	7.58 ±0.33
Transparency (m)	1.54 ±0.15	0.11 ±0.06	> 0.2	0.56 ±0.21
Chlorophyll-*a* (mg/m)	1.65 ±1.16	39.16 ±22.69	8.39 ±6.97	4.84 ±8.53
Dissolved oxygen (mg/L)	6.83 ±1.23	8.11 ±3.07	N/D	8.88 ±0.93
Total density (ind./L)	1.56 ±2.17	56.98 ±106.64	9.60 ±16.12	209.31±214.04
Nauplii density (ind./L)	0.46 ±0.63	11.59 ±33.68	2.15 ±1.12	39.50 ±54.49
Metanauplii density (ind./L)	0.82 ±1.35	16.10 ±38.54	1.22 ±1.50	63.31 ±77.51
Post-metanauplii density (ind./ L)	0.08 ±0.08	22.87 ±43.04	5.77 ±11.80	74.22 ±142.80
Post-larvae density (ind./L)	0.14 ±0.16	3.78 ±6.48	1.08 ±1.57	24.93 ±20.07
Adults density (ind./L)	0.05 ±0.06	2.73 ±3.95	1.30 ±2.05	15.30 ±26.03
Total biomass (µg/L)	122.43 ±99.33	1230.10 ±1353.69	346.11	7535.10 ±12 376.57

lakes: in La Amarga, salinity varied in a range of 46 g/L; in Guatraché, it was almost 140 g/L; and in Utracán, it was 325 g/L (Echaniz *et al.*, 2015; Vignatti *et al.*, 2014, 2017).

The predominance of Na^+ and Cl^- in Este Lake is similar to most shallow lakes previously studied in the semiarid Central Pampas (Echaniz & Vignatti, 2017). This ionic composition indicates that the mechanisms that control the water chemistry of Este Lake involve evaporation and crystallization, which are typical processes in arid or semiarid regions where the evapotranspiration rates are higher than the precipitation rates (Gibbs, 1970; Wetzel, 2001; Kalff, 2002). The pH of Este Lake was slightly alkaline and similar to that of La Amarga and Guatraché Lake (Echaniz *et al.*, 2015; Vignatti *et al.*, 2014), but it was considerably lower than that of Utracán Lake. This could have been due to the latter's relatively high amounts of $CO_3{}^{2-}$ and $HCO_3{}^-$ (Fig. 2) from the discharge of groundwater enriched with these ions, and which are stored in the sediments of the *Cerro Azul* geological formation (Malán, 2007).

The findings of this study showed that the transparency of the water was always high, reaching the bottom in most of the study period, which could be attributed to the reduced concentrations of chlorophyll-*a* and TSS.

A feature that distinguishes the protected Este Lake *A. persimilis* population is the high mean density, which in this study greatly exceeded the densities previously recorded in other lakes. The minimum salinity of Guatraché Lake coincided with the maximum value measured in Este Lake. The greater salinity of the latter could be a limiting environmental factor for *A. persimilis* in that lake (Vignatti *et al.*, 2014) because high environmental stress could cause more energy to be allocated to osmoregulation than to reproduction (Gajardo & Beardmore, 2012). The mean salinity of Utracán Lake was relatively similar to that of Este Lake, but salinities higher than 300 g/L were recorded on occasions when *A. persimilis* was not registered (Vignatti *et al.*, 2017).

The lack of correlation between *A. persimilis* density and salinity in Este Lake, where the greatest number of individuals was found, could indicate that the salinity range of Este Lake is the best for the development of the species (Vignatti *et al.*, 2014).

As in other Central Pampas lakes, in Este Lake the total density was positively influenced by temperature. The abundance of nauplii and metanauplii was higher in the months of higher temperatures, which would indicate a high reproductive rate by the production of subitaneous eggs. Although post-metanauplii, post-larvae, and adults predominated, nauplii were also recorded during the winter months, which coincided with the results found in Utracán Lake, where a high proportion of juvenile stages with temperatures barely above 3 °C were recorded. This finding could indicate that *A. persimilis* reproduction continued despite the low temperature, which could be an effective defense against possible invasions by its congeneric, *A. franciscana*.

The mean biomass of *A. persimilis* in Este Lake was considerably higher than that in La Amarga, Guatraché and Utracán Lakes, and it was related to the size of the organisms. The group composed of post-larvae and adults were the greatest proportion of the total population biomass on most occasions. Exceptions were in October and March, when the most advanced stages were not recorded, and metanauplii and nauplii represented the highest biomass.

Many saline lakes in the central region of Argentina are influenced by anthropogenic activity, especially agriculture and livestock. This activity has resulted in increased nutrient concentrations in water, sediment, which has changed

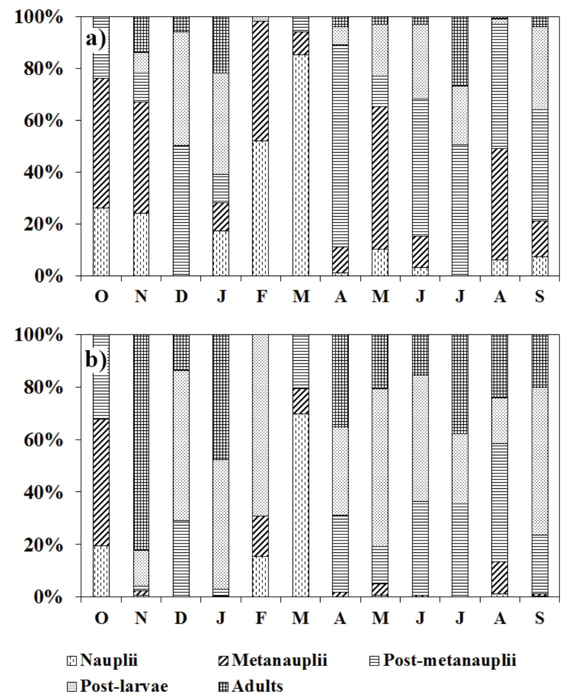

Figure 6. Monthly variations in contributions of the different stages to the total (a) density and (b) biomass of *A. persimilis* population. *Variación mensual de la contribución relativa de los diferentes estadios a (a) la densidad y (b) la biomasa total de la población de* A. persimilis*.*

the original characteristics of the lakes (Echaniz & Vignatti, 2017). The loss of environments suitable for the development of autochthonous species is a factor that damages global biodiversity and may lead to the loss of *Artemia* species (Amat *et al.*, 2007).

The existence of a hypersaline lake in the intangible sector of a protected area where the most abundant *A. persimilis* population of the central region of Argentina has been recorded offers an opportunity for the conservation of this species. The restrictions to access and human activities in the Este Lake basin can prevent environmental deterioration and minimize the risk of the anthropogenic introduction of non-native zooplankton species. The latter is a phenomenon that has already occurred in central Argentina, where the introduction and rapid dispersion of the Old World cladoceran *Moina macrocopa* (Straus, 1820) (Paggi, 1997; Vignatti *et al.*, 2013) has been recorded. However, the presence in Este Lake of waterfowl, such as the flamingo *Phoenicopterus chilensis* Molina, 1782 (per. obs.), represents a potential risk for the introduction of *A. franciscana*. This invasion is difficult to avoid because zooplankton is included in the diet of these birds, which are widely distributed in South America and have long migratory routes (De los Ríos Escalante, 2015; Polla *et al.*, 2018). Thus, it is currently difficult to anticipate any measure to prevent or eradicate the exotic brine shrimp species because the arrival of waterfowl cannot be prevented, and the oviparism mode of reproduction in *Artemia* ensures its persistence in any colonized ecosystem (Amat *et al.*, 2007).

Although a possible limitation of the advance of *A. franciscana* to the south is its lower tolerance of low temperatures (Amat *et al.*, 2004; Vignatti *et al.*, 2014), the phenomenon of global warming, which has been verified in Argentina (Barros *et al.*, 2015), could change this situation drastically. A small increase in the average water temperature of the saline lakes in the Central Pampas would allow *A. franciscana* to colonize ecosystems located farther south than its current distribution, which could result in the local extinction of the native species *A. persimilis* (Vignatti *et al.*, 2017).

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