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Dynamics of the Limnological Parameters and Zooplankton of La Brava, a Shallow Lake of the Atuel-Salado-Chadileuvú-Curacó Rivers System (La Pampa, Argentina)

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Abstract La Brava is a shallow lake that is different from others of La Pampa, as it is part of the fluvial system of Desaguadero-Atuel-Salado-Chadileuvú-Curacó rivers. However, dams built upstream disrupt runoff, so water only enters when excessive snowfall in the Andes mountains forces the reservoirs to be opened. Once water enters, it is slowly lost through evaporation, which can lead to drying of the lake. As the ecology of La Brava is unknown, the objective of this study was to determine the limnological parameters, density and taxonomic composition of zooplankton during a period that contained water and salinity increased by evaporation. Samples between January 2009 and November 2010 were taken. The maximum depth (2.1 m) was recorded in October 2009 but declined and in November 2010 was 0.66 m. Na^+ and Cl^- predominated in ionic composition and the salinity rose from 15.83 to 49.89 $g.L^{-1}$. The mean transparency was 0.65 m (±0.12) and despite the high concentration of nutrients (TP: 6.02 ±2.87; TKN: 11.17 ±5.92 $mg.L^{-1}$) the phytoplankton chlorophyll-*a* concentration was reduced (1.29 ±1.27 $mg.m^{-3}$). One cladoceran, four copepods and eight rotifers were registered. The greatest diversity was observed during the first month, specially provided by rotifers, when the group reached its greatest density (385.8 $ind.L^{-1}$), especially given by *Brachionus plicatilis* Müller, 1786. Increasing salinity affects the diversity, so in June and August 2009 the copepod *Boeckella gracilis* (Daday, 1902) was recorded, later replaced by the halotolerant *Boeckella poopoensis* Marsh, 1906. October 2009 was the only occasion when the cladoceran *Daphnia menucoensis* Paggi, 1996 was registered, in low density (5.7 $ind.L^{-1}$). Despite their differences with other Pampean environments, in La Brava the typical zooplankton association of the center of the country and northern Patagonia was found, but it differs from another lake of Curacó system where only the halophilic anostracan *Artemia persimilis* Piccinelli & Prosdocimi, 1968 was registered.

Keywords: *Saline lakes, shallow lakes, Chadileuvú-Curacó River system, Boeckella poopoensis, Daphnia menucoensis, Odontesthes bonariensis*

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1. Introduction

The river basin of Desaguadero River (Figure 1) is the largest that exists entirely in Argentinean territory [1]. It includes rivers originating in the Andes Mountains, in the provinces of La Rioja, San Juan and Mendoza (Vinchina, Bermejo, Jáchal, San Juan, Mendoza, Tunuyán, Diamante, Atuel and Desaguadero rivers), so that their regime is totally nival. Near of their entry in the province of La Pampa, the Atuel and the el Desaguadero (Salado) rivers converge and give rise to the Chadileuvú. This river fed numerous wetlands and a group of large shallow lakes located in the central region of the province (Lagunas de Curacó) and surplus flow was directed by the Curacó River to join the Colorado River and from there to its mouth in the Atlantic Ocean (Figure 1).

However, the construction of large dams in all the tributaries, especially in the San Juan and Mendoza provinces, has altered the natural hydrology and landscape, with the total loss of the wetlands and making the Curacó Lakes receive water only sporadically, during the years when snowfall in the Andes Mountains is abundant and the floodgates of the reservoirs must be opened [2].

This has changed the natural dynamics of these shallow lakes, and while information indicating they were relatively stable and had reduced salinity exists, to the point of sustaining commercial fisheries [3,4,5], actually they have become temporary lakes and salinity has risen [6], to the point that one of them, La Amarga, has become a large hypersaline lake [7,8].

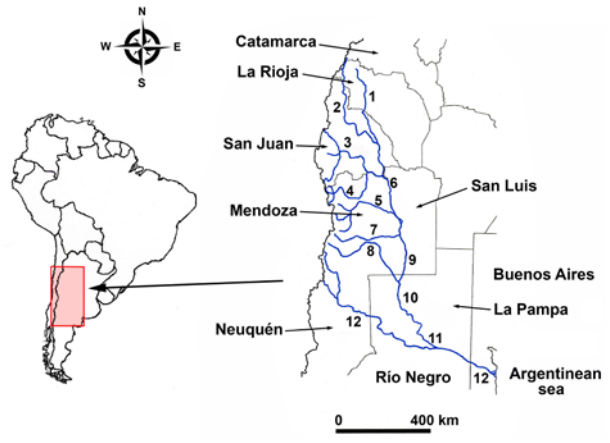

Figure 1. Left: Geographic location of Desaguadero river basin. Right: Rivers that integrate the basin. 1: Vinchina. 2: Jachal. 3: San Juan. 4: Mendoza. 5: Tunuyán. 6: Desaguadero. 7: Diamante. 8: Atuel. 9: Salado. 10: Chadileuvú. 11: Curacó. 12: Colorado

Information on the Curacó lakes is relatively scarce and refers mainly to hydrological aspects, with scattered biological data. Only recently have researchers begun to study the ecology of some of them, so there is only information on the dynamics of zooplankton of the La Amarga Lake, dominated by *Artemia persimilis* [7,8].

Given the particular dynamics acquired by these water bodies by human action, which distinguishes them strongly from the rest of shallow lakes in the central region of Argentina, the aim of this study was to determine the main limnological parameters, the taxonomic composition and density of zooplankton and their relationships, in La Brava, another important lake of the Curacó group, during a period when water flowed in and test the hypothesis that environmental instability, due to the temporary isolation of the lake, produces changes in the hydrochemical conditions that determine modifications both in the richness and abundance of zooplankton.

2. Materials and Methods

2.1. Study Area

La Brava Lake (37º 55'S, 65º 55'W) (Figure 2) is a shallow lake that differs from others of the La Pampa province, because their supply depends on the very sporadic contributions of water from the Chadileuvú river. Given the low mean annual precipitation, of around 300 mm, and being a region with sandy soils, the contributions of rainfall and runoff are of little significance. Furthermore, potential evapotranspiration is around 750 mm [9], so each time that water enters from the river system, it evaporates slowly and the lake can completely dry out.

During the study, La Brava had a maximum length of 3257 m, a maximum width of 2495 m, an area of 524.5 hectares and a maximum depth of 2.10 m.

It is located in the phytogeographic province of the Monte [10], where low and scattered scrub of jarillas (*Larrea* sp.) predominates. The arid landscape means the little human activity in the region is restricted to raising goats. During the study period there was a lack of rooted vegetation but fish fauna was present with a predominance of "bonaerense" silverside (*Odontesthes bonariensis* Cuvier & Valenciennes, 1835).

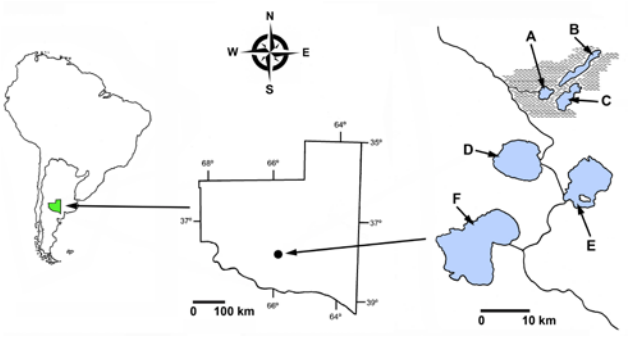

Figure 2. Geographic location of La Brava lake in Curacó system. A: La Brava. B: La Tigra. C: La Leona. D: La Dulce. E: Urre Lauquen. F: La Amarga

2.2. Field and Laboratory Work

Ten sampling surveys were conducted during the period January 2009 to November 2010.

Five sampling sites were determined on a transect located between the river entrance and output of the lake. At two sites, the nearest to the entrance and the nearest to the output, water temperature and pH were determined with Hanna Hi 98129 equipment and the water transparency with a Secchi disk of 20 cm diameter. At the five survey sites, twenty liters subsurface samples of zooplankton were taken, filtered by a net of 40 microns mesh size and fixed with 7% formalin [11]. Furthermore, water samples were taken for physical and chemical determinations and stored refrigerated in the dark until analysis in the laboratory.

The dissolved solids concentration (salinity) was determined by the gravimetric method with drying at 104°C of 50 ml of previously filtered water. The ionic composition of the water was determined by a commercial certified laboratory with standard methods [12].

The concentration of chlorophyll-*a* was determined by extraction with aqueous acetone to 90% and subsequent reading in a spectrophotometer [12,13], total Kjeldahl nitrogen by the Kjeldahl method and total phosphorus using the method of ascorbic acid, previous digestion with potassium persulfate.

The trophic state and typology of the lake was determined as a function of water transparency, Z_{mean}/Z_{photic} ratio, TP, TKN and chlorophyll-*a* concentrations, according to Quirós *et al*., [14] for pampasic shallow lakes.

Counts of micro and macrozooplankton [15] were conducted in Sedgwick-Rafter and Bogorov chambers under optical and stereoscopic microscopes respectively. The density was expressed in individuals per liter.

Levene's test was performed to determine the variances homocedasticity and Q-Q plots were used to determine the data normality. To search differences between environmental or biological parameters the Kruskal-Wallis test (H) was performed [16]. Furthermore, in order to find relationships between environmental variables and zooplankton density Spearman's rank correlation coefficient (r_s) was used.

No differences in limnological parameters and total density of zooplankton were recorded among the three sampling sites, not even when we considered separately the density of rotifers, copepods or cladocerans.

All analyzes were performed with InfoStat [17] and Past [18] software.

3. Results

3.1. Limnological Parameters

Because during the study period there were times when water from the river entered the lake, depth varies greatly (Figure 3). The maximum (2.1 m) was registered in October 2009, but as from this month water ingress was stopped, depth dropped and in November 2010 it reached 0.66 m. The mean salinity was 25.9 $g.L^{-1}$. The value determined during January 2009 was 15.83 $g.L^{-1}$, which fell to a minimum of just 12.15 $g.L^{-1}$ in October 2009, coinciding with the largest maximum depth, but subsequently rising to reach 49.89 $g.L^{-1}$ in November 2010 (Figure 3), therefore the concentration of dissolved solids showed a high negative correlation with depth (r_s= -0.99; p= 0.0000).

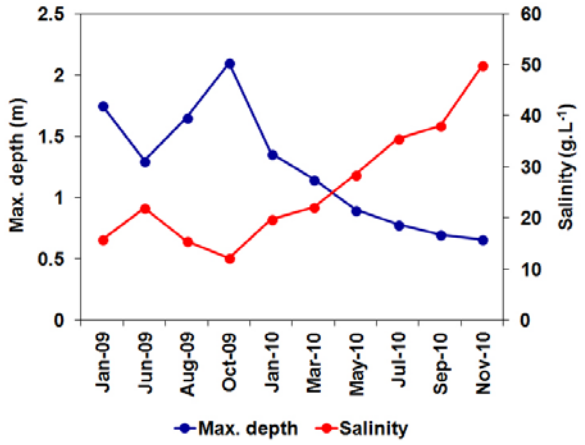

Figure 3. Variation of the maximal depth and salinity of La Brava Lake between January 2009 and November 2010

The ionic composition of the water showed the strong predominance of Cl^-, which represented 74% of anions and Na^+ which was the 70% of cations (Figure 4). The mean pH was 8.04 (±0.43) and ranged from a low of 7.3 (January 2010) to a maximum of 9 (November 2010). A negative correlation between the pH of the water and the maximum depth was found (r_s = -0.68; p = 0.0363).

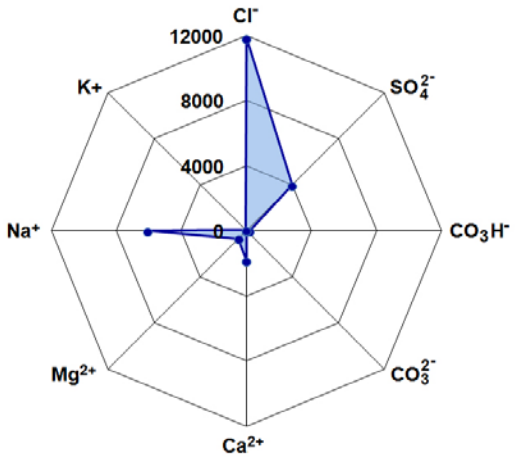

Figure 4. Ionic composition of the water of La Brava Lake

The water temperature follows a seasonal pattern, with a minimum of 5.9°C in July 2010 and a maximum close to 27°C in January 2009 and November 2010 (Figure 5).

The mean transparency throughout the study was 0.65 (± 0.12) m. It fluctuated during the two years; the maximum, close to 0.8 m, was recorded in autumn while the minimum, fluctuating between 0.4 and 0.5 m, was recorded during the spring (Figure 5). The mean ratio Z_{mean}/Z_{photic} was 0.57.

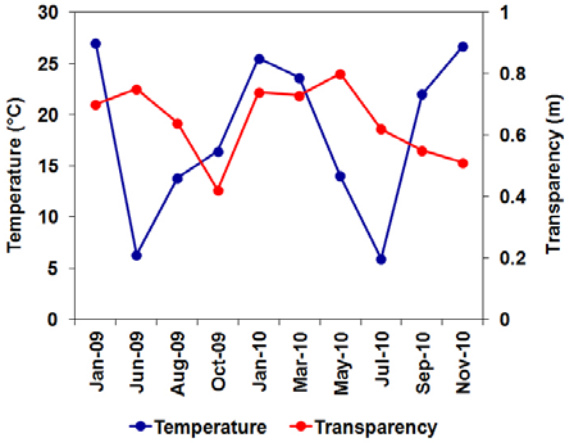

Figure 5. Variation of the water temperature and transparency of La Brava Lake between January 2009 and November 2010

Despite the fact that the mean nutrient concentration was relatively high (TP: 6.02 ± 2.87 $mg.L^{-1}$; TKN: 11.17 ± 5.92 $mg.L^{-1}$) the mean concentration of phytoplankton chlorophyll-*a* was relatively low (1.29 ± 1.27 mg. m^{-3}). The latter did not show a seasonal pattern because during 2009 the maximum (1.06 mg m^{-3}) was recorded in late autumn (June) while during 2010 the peak was higher (3.9 mg m^{-3}) and occurred in late spring (November) (Figure 6). No correlation between the concentration of chlorophyll-*a* and water transparency was found.

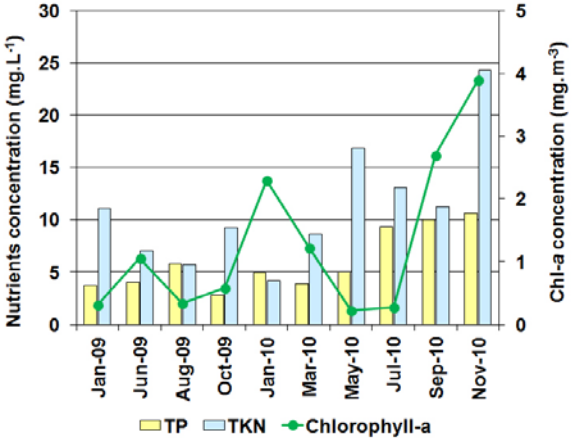

Figure 6. Variation of the nutrients and phytoplankton chlorophyll-*a* concentrations of La Brava Lake between January 2009 and November 2010

3.2. Zooplankton

Thirteen *taxa* were registered: one cladoceran, four copepods and eight rotifers (Table 1). In 2009, the richness was higher because 13 *taxa* were recorded against only seven in 2010.

Among crustaceans, copepods were recorded in all sampling and the calanoids *Boeckella gracilis* (Daday, 1902) and *B. poopoensis* Marsh, 1906 were the most frequent (Table 1). Only one cladoceran, *Daphnia menucoensis*

Paggi, 1996, was recorded on a single occasion (October 2009) and rotifers, which were the most diverse group, were recorded in all sampling occasions. Among them, *Brachionus plicatilis* Müller, 1786 and *Hexarthra fennica* (Levander, 1892) were of almost constant presence during the two annual cycles studied and conversely *Brachionus dimidiatus* Bryce, 1931 and *Keratella tropica* (Apstein, 1907) were registered on a single occasion in the summer (January) 2009 (Table 1).

Table 1. *Taxa* registered in La Brava Lake during 2009 and 2010 and sampling occasions in that were found

	Jan-09	Jun-09	Aug-09	Oct-09	Jan-10	Mar-10	May-10	Jul-10	Sep-10	Nov-10
Cladocerans										
Daphnia menucoensis Paggi, 1996				×						
Copepods										
Boeckella gracilis (Daday, 1902)		×	×							
Boeckella poopoensis Marsh,1906				×		×		×	×	×
Metacyclops mendocinus (Wierzejski, 1892)	×	×								
Cletocamptus deitersii (Richard, 1897)				×					×	×
Rotifers										
Brachionus plicatilis Müller, 1786	×	×	×	×	×	×	×	×	×	×
Brachionus angularis Gosse, 1851	×				×					
Brachionus dimidiatus Bryce, 1931	×									
Hexarthra fennica (Levander, 1892)	×	×	×	×	×	×	×	×	×	
Keratella tropica (Apstein, 1907)	×									
Keratella cochlearis (Gosse, 1851)	×				×					
Collurella sp.	×						×			
Synchaeta sp.	×		×							

No significant differences were found when comparing total mean densities of each annual cycle studied ($H = 0.18$; $p = 0.6698$).

The mean total density along the study was 262.11 ind.L^{-1} (± 433.2), and fluctuated from a maximum of 1459.5 ind.L^{-1} in March 2010 and a minimum of 36.2 ind.L^{-1} in November 2010 (Figure 7). There were no correlations between density and depth or salinity or other environmental parameters.

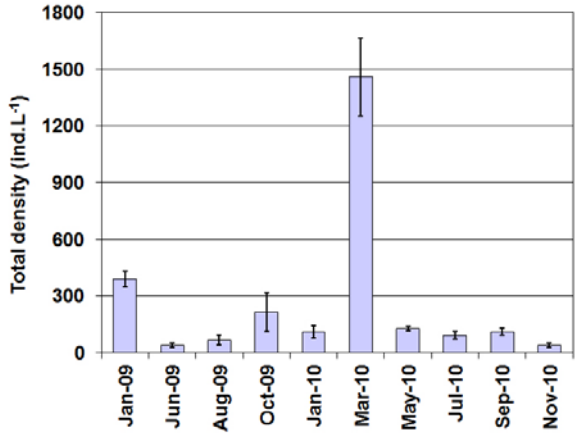

Figure 7. Variation of zooplankton total density of La Brava Lake between January 2009 and November 2010

The total mean density strongly correlated with that of rotifers ($r_s = 0.94$, $p = 0.0001$), as in most of the samples they were the dominant taxonomic group and reached a mean density of 229.6 ind.L^{-1} along the study. On some occasions (January 2009 and March 2010) the rotifers reached densities 500 or 600 times higher than in the other groups and in others (January and May 2010) they accounted for 100% of the density of the zooplankton community (Figure 8). The density of rotifers varies over a wide range, from a maximum 1444.6 ind.L^{-1} (March 2010) to a minimum of 1.5 ind.L^{-1} (November 2010). Like as happened to the total density of zooplankton, the density of this group showed no correlation with the determined environmental parameters. Although the mean density of 2009 was lower (146.8 ± 161.8 ind.L^{-1}) than in 2010 (284.7 ± 570.5 ind.L^{-1}), the differences between the two annual cycles were not significant.

Copepods, absent in January and May 2010, had a mean density of 16.8 ind.L^{-1} (± 23.6), with a peak of 70.83 ind.L^{-1} in October 2009 (Figure 8). No correlation between the density of this group and environmental parameters was found. On the other hand, no differences were found when considering mean densities corresponding to each annual cycle.

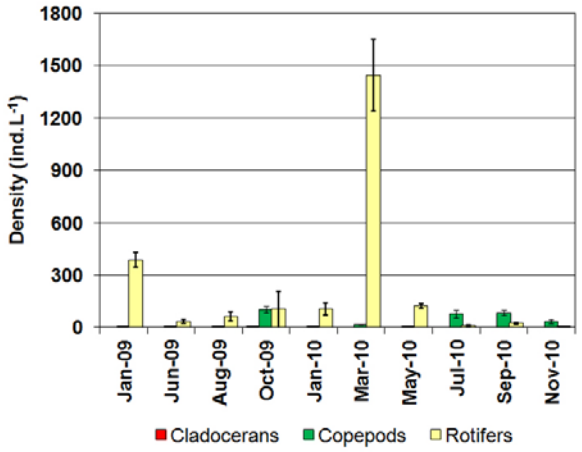

Figure 8. Variation of zooplankton taxonomic groups density of La Brava Lake between January 2009 and November 2010

Among rotifers, *Brachionus plicatilis* was recorded in all samples and was the most abundant species, as it represented 71.2% of the total density of the group, followed by *Hexarthra fennica*, absent only in November 2010, representing 24.6%. The remaining *taxa* were

reported on rare occasions and the densities were always very low (Figure 9).

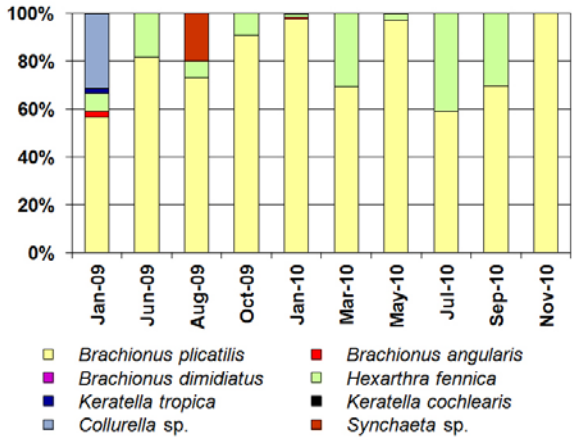

Figure 9. Percentage composition of the diversity of rotifers of La Brava Lake between January 2009 and November 2010

Boeckella poopoensis was the copepod that showed greater mean density (31.5 ± 24.6 ind.L^{-1}), representing 87.5% of the density of the group throughout the study. It was recorded five times with a density peak in October 2009 (70.8 ind.L^{-1}), followed by *Cletocampthus deitersi* (Richard, 1897), and although it was registered only in the last two sampling times, it reached a density of 5 ind.L^{-1} during November 2010. Among cladocerans, *Daphnia menucoensis* was recorded only during October 2009, and reached a density of 5.7 ind.L^{-1} (Figure 10).

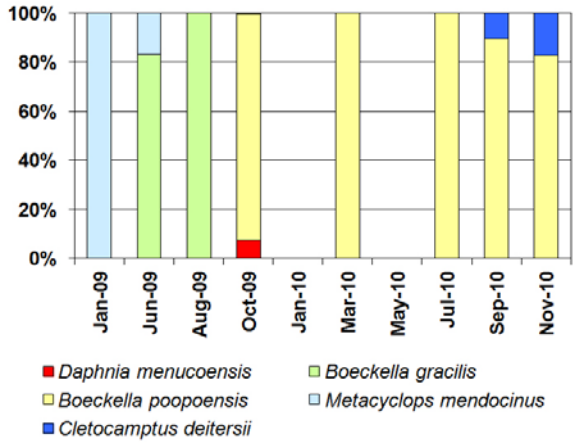

Figure 10. Percentage composition of the diversity of crustaceans of La Brava Lake between January 2009 and November 2010

4. Discussion

The vast majority of the shallow lakes of La Pampa province is temporary and fed by rainfall and groundwater contributions. This makes the events of filling and drying, with the consequent increase in salinity, part of the normal dynamics [19-24].

The succession that occurs in zooplankton, both during filling and during the salt concentration by evaporation of water accompanying the drying, is relatively well known for a variety of Pampean lakes in a wide range of salinities [23,24,25].

Unlike them, filling of the La Brava Lake is provided mainly by the contribution of the River Chadileuvú. Formerly, this river had an important flow that exceeded 200 $m^3.s^{-1}$ [26] and it made La Brava a permanent lake. As mentioned, this allows the development of commercial fishing in it, principally based on the presence of silversides *Odonthestes bonariensis* and *O. hatcheri* [3,4,5]. The presence of these species suggests that salinity was lower in the past, as its tolerance, though wide, does not allow it to thrive with salinities near the sea [27,28].

Today, water enters La Brava during the few years that excessive snowfall in the mountains forces the opening of the floodgates of the reservoirs, which means the incoming water has relatively low concentrations of salts. On such occasions ictiofauna usually develops in the lake with a predominance of *O. bonariensis*. However, after stopping the flow from the river, the water level of the lake drops and the evaporation causes the salinity to increase slowly.

This phenomenon was verified in this study, since the maximum depth was recorded in October 2009, the moment from which water ingress stopped. This meant that, in late 2010, the depth was more than three times lower and, after completion of this study, became totally dried (Del Ponti, pers. obs.), giving La Brava a temporary character.

By the high nutrient concentrations recorded in the water it can be categorized as hypertrophic. However, high concentrations of TP and TKN is a characteristic that La Brava shares with most of the lakes of La Pampa. It is proposed that this could be due primarily to the shallow depth of the environments and the important action of the wind, which produces the removal of bottom sediments with subsequent resolubilization of nutrients into the water column [29,30]. Furthermore, the sediments have little capacity to retain nutrients because the sands predominate in them, and these particles, by their large size, are characterized by their low adsorption capacity, which favors internal eutrophication [29,30].

In this sense the importance of wind became apparent and during the two annual cycles, water transparency was lower during the spring, despite the low concentrations of phytoplankton chlorophyll-*a*. At that time the strongest winds are registered in the region [31] which leads to sediment resuspension and therefore, produces turbidity of inorganic origin.

A very particular characteristic of La Brava is that the mean value of the Z_{mean}/Z_{photic} ratio [14] allows it to be classified as a clear lake, despite the high concentrations of nutrients, absence of macrophytes and cladocerans of large size and presence of fishes that are predominantly planktivorous. Under these conditions it was expected that La Brava had high phytoplankton biomass, which would confer high turbidity, situation that was not found in this study.

In relation to this, *Daphnia menucoensis*, a cladoceran that is characterized by its high impact on the ecology of the water bodies in the region [32], was recorded. However, their low densities in the only time that it was found, would not be enough to explain the clear state maintained by La Brava throughout the study. The fact that *D. menucoensis* was registered once, despite being within range of salinity tolerance, could be due to predation exerted by the fish. It has been determined in other Pampean saline lakes that have fish fauna, especially with *O. bonariensis*, that often hatch some specimens of *D.*

menucoensis from the egg bank, but fail to establish a stable population [32].

Despite their differences with other Pampean aquatic ecosysytems, in the zooplankton of La Brava the typical species association of saline lakes in the center of the country and northern Patagonia was found [7,22,33,34,35,36,37,38] given the predominance of *B. poopoensis* a calanoid of Neotropical distribution and by the rotifers *Brachionus plicatilis* and *Hexarthra fennica*, both halotolerant and cosmopolitan species [39,40], which numerically dominate the zooplankton community. This is different from most of the Pampean saline lakes, where the prevalence is usually of crustaceans, especially *B. poopoensis*, which usually reach high densities and biomasses [7,22,33,34,35,36,37,38].

On the other hand, among the common species in Pampean lakes there is the copepod harpacticoid *Cletocamptus deitersii*, a species of mainly benthic habits [41]. However, their presence in subsurface samples could be due to the action of winds, which, by turbulence, could lead specimens to the water column [7]. In support of this assertion this species was recorded in spring 2010 samples, the time of year, as mentioned, when the strongest winds are recorded [31].

The influence of increasing salinity was manifested in the decrease of the richness verified from the time of stopping ingress of water from the river. Thus, during the first month the greatest richness was recorded, especially given by rotifers, including some *taxa* that were not found again. In addition, during the first month species with low tolerance to salinity were recorded among the crustaceans, such as *M. mendocinus* and *B. gracilis*, then replaced by *B. poopoensis*, a much more halotolerant species, in the same way as recorded by Vignatti *et al*. [24] in El Carancho lake.

The increased salinity that accompanied the decline of the water level allowed verification that the succession that occurred in the zooplankton of La Brava was similar to that registered in shallow lakes of La Pampa, located in typically arheic basins [20,23,24].

However, a notable feature of La Brava, that is different from both other Pampean lakes and the most shallow lakes is that, despite the dominance of rotifers and the near absence of cladocerans, it is a clear water ecosystem, with concentrations of phytoplankton chlorophyll-*a* that are very low. This could be due to the high amount of salts, particularly a high concentration of chloride, since it has been found that this ion has high negative impact on the richness and density of algae [6,42].

5. Conclusion

La Brava is a shallow lake that is very different from the most of the Pampean lakes. It belongs to an almost inactive river system, so its water supply is sporadic. Sometimes freshwater enters from the Chadileuvú River that, when the inflow is cut, evaporates slowly increasing salinity.

Through a study of two years duration it was verified that there are some characteristics in common with other Pampean lakes, such as the dominance of Cl^- and Na^+, its high concentration of TP and TKN and the presence of the assemblage of halotolerant species typical of the region.

However, some particularities were found. Among them is the predominance of rotifers on crustaceans and, despite having zooplanktivorous fish and near absence of large size cladocerans, very low concentrations of phytoplankton chlorophyll-*a* that led to water transparency was very high.

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Competing Interests

The authors have no competing interests.

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