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Preliminary Zooplankton Study of Six "Mercedinas" Lakes (San Luis, Argentina)

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Abstract The south of the province of San Luis (Argentina) has more than 100 lakes located among dunes and grasslands, known as "mercedinas" due to their proximity to the city of Villa Mercedes. Although there are several reports on the ecology of zooplankton in other regions of the country, very little is known about the aquatic ecosystems of this extensive area. The aim of the study was to determine the taxonomic composition and the zooplankton density of six "mercedinas" lakes and analyze the relationship between this community and limnological parameters and fish fauna. The samplings were carried out in October 2007. The average depth of the six lakes ranged between 2.3 and 3.6 m. Salinity ranged between 1.3 and 3.3 $g.L^{-1}$, so they can be classified as subsaline to slightly hyposaline. Water transparency varied widely (0.3-2.3 m). Macrophytes were present in the six lakes and fish richness was represented by seven species, with predominance of *Jenynsia multidentata* and *Odontesthes bonariensis*. Zooplankton richness included 20 taxa: five cladocerans, six copepods and nine rotifers. The species common to the six lakes were *Bosmina huaronensis*, *Ceriodaphnia dubia* and *Filinia longiseta*. We found a situation that does not match that proposed by the model of alternative states of shallow lakes: the lakes where we did not find *O. bonariensis*, a main predator of zooplankton, showed the lowest water transparency, although a large filtering cladoceran such as *Daphnia spinulata* was present in one of them. These preliminary results make it necessary to carry out further research to see if this situation is maintained over time or if this was a specific situation.

Keywords Zooplankton, Bosmina Huaronensis, Shallow Lakes, "Lagunas Mercedinas"

1. Introduction

In aquatic ecosystems, zooplankton is a key component because of it grazes on phytoplankton, recycles nutrients through excretion, and serves as food to predators. Its taxonomic composition and density depend on abiotic factors such as salinity, temperature, environmental heterogeneity, or land use in the basin[1, 2, 3, 4, 5, 6] and biotic factors such as food availability, interspecific competition and predation by vertebrates and invertebrates[7, 8, 9, 10, 11]. The predation by fish has strong structuring effects on the diversity and size of the zooplankton community[12], which in turn cause marked changes in the ecology of water bodies by the effect of the trophic cascade[10, 11, 13, 14].

The distribution of zooplankton rotifers and crustaceans is relatively well known in various regions of Argentina. The taxonomic composition of the zooplankton has been studied both in lentic[15, 16, 17, 18, 19] and lotic environments[20, 21, 22] of the province of Buenos Aires. The zooplankton of the basin of the Paraná River[23, 24], as well as that of the saline lakes of the Northwest, both of the Puna[25, 26] and of the Yungas[27], are also relatively known. There is also information about the zooplankton of some aquatic ecosystems of Patagonia[28, 29, 30] and even of some lakes of Antarctica[31, 32]. Other publications have provided information on the distribution of rotifers[33, 34, 35], cladocerans[36, 37, 38] and copepods[39, 40, 41, 42, 43]. However, knowledge of the zooplankton of the water bodies of the central semiarid region of Argentina, which are usually temporary and shallow lakes, is more recent and referred primarily to environments of the provinces of La Pampa[44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57] and Córdoba[58]. Since the zooplankton diversity of many water bodies in other provinces of the same region still remains unknown, some authors have proposed that some species could have discontinuous distributions between the north of Argentina and Patagonia[59]. In some cases, this perceived discontinuity was the result of lack of information, such as was the case of *Daphnia menucoensis*, whose distribution was found to be relatively continuous between the two regions[54].

In central Argentina, there are numerous shallow lakes

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with a wide range of salinities and it is common that they are either eutrophic or hypertrophic[49, 55, 60, 61]. Many have suffered alterations due to the human activities developed in their watersheds, such as piping, animal husbandry, cultivation of grains and oilseeds, and urbanizations, or due to the introduction of fish, particularly the zooplanktivorous *Odontesthes bonariensis* Cuvier y Valenciennes, 1835 due to its sport and economic value[50, 62, 63, 64]. The aim of this work was to study the taxonomic composition of the zooplankton community, the total density and the density per species of shallow lakes of the province of San Luis, an area for which there are no previous reports on this issue, and to relate them to the composition of the fish assemblages and main limnological parameters.

2. Materials and Method

2.1. Study Area

The six lakes studied (lakes 1 to 6) are located in the General Pedernera Department (34°00´S, 65°24´W), province of San Luis, in the region known as "area of plains and lagoons", in the geomorphological system of the pampas of eolic sands[60] (Figure 1). From the phytogeographic point of view, the lakes are located in the province of Thorny Forest, characterized by the presence of deciduous forests with a predominance of the genus *Prosopis* and psammophilous pastures[65]. The average annual rainfall ranges from 500 to 600 mm and the average temperature from 7.3 to 22.9ºC for the months of January and July respectively.

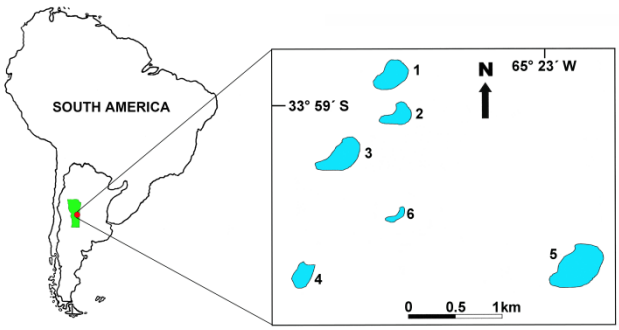

Figure 1. Geographical location of the studied "mercedinas" lakes

Table 1. Main morphometric parameters of the studied lakes

Lakes	1	2	3	4	5	6
Area (ha)	19.4	14.5	25.8	9.1	32.1	5.9
Depth (m)	2.85	3.46	3	2.36	3.65	s/d

The lakes studied are located in basins originated by wind deflation, are arheic, and are fed by rainfall and groundwater contributions[60]. Their depth varies between 2.36 and 3.65 m and its surface between 5.9 and 32.1 ha (Table 1). Rooted macrophytes, both submerged and emerging, were recorded in the six lakes.

2.2. Field Work and Laboratory

The samplings were carried out in October 2007. *In situ*, we determined transparency with a Secchi disk, the concentration of dissolved oxygen, and pH and water temperature with a Consort C535 digital Analyzer. Also, water samples from the center of each lake were taken to perform physicochemical analysis.

Quantitative subsurface zooplankton samples were collected at three sampling stations in the limnetic zone along the longitudinal axis of each lake. In each station, we filtered 36 L of water with a 90-µm-mesh plankton net. Samples were fixed with 4% formalin.

Fish were captured by trotlines, drag nets and drift nets, and species were identified according to Rosso, 2007[62], Haro and Bistoni, 2007[66] and López *et al*., 2003[67].

Hardness, alkalinity and concentration of total dissolved solids in the water[68] were determined in the laboratory.

Abundances of macro- and microzooplankton[14] were determined by the count of subsamples in Bogorov and Sedgwick Rafter chambers respectively. Aliquots were taken with 5-ml Russell subsamplers and 1-ml micropipettes. The taxonomic identification of zooplankton were according to Ringuelet, 1958[39], Olivier, 1962 and 1965[37, 69], Ruttner-Kolisko, 1974[70], Koste, 1978[71], Reid, 1985[72], Dusart and Frutos, 1986[73], Bayly, 1992[74] and Paggi, 1995[36].

The ratio between the mean depth and the depth of the photic area (Z_m/Z_{phot}) was calculated to classify the lakes according to their transparency[75]. To compare the diversity of water bodies, we calculated the Margalef and dominance indices, and to determine replacement of species between environments, we calculated Whittaker's beta diversity index[76, 77, 78, 79]. The similarity of the lakes was determined through cluster analysis based on the similarity of Bray-Curtis. Past software was used[80].

3. Results

Table 2. Values of the limnological parametes (Modified of Mancini *et al*., 2009)

Lake	1	2	3	4	5	6
Salinity ($g.L^{-1}$)	1.67	s/d	s/d	1.38	1.94	3.37
Transparency (m)	2.3	1	1.1	0.4	1.7	0.3
$Z_m/Z_{phot.}$ ratio	0.48	1.38	1.05	2.18	0.85	s/d
pH	8.85	8.94	9.04	9.68	8.76	9.52
Dis. oxygen ($mg.L^{-1}$)	8.45	10.33	10.35	11.67	9.1	11.23
Temperature (ºC)	16	17.3	17.2	16.2	16.3	16.4

The salinity determined in four of the lakes was reduced, ranging from 1.39 to 3.37 $g.L^{-1}$. Water transparency ranged from 0.3 to 2.3 m (Table 2) and the calculation of the Z_m/Z_{phot} ratio suggested that lakes 2 and 4 were turbid, and that lakes 1, 3 and 5 were clear. All the lakes were alkaline,

with pHs ranging from 8.76 to 9.68 (Table 2), and their dissolved oxygen concentration was relatively high, from 8.45 to 11.67 mg.L^{-1} (Table 2).

We recorded a total of 20 taxa: five cladocerans, six copepods and nine rotifers. The beta diversity index was 1.03. Lakes 2 and 4 presented the greatest richness and the highest values of Margalef's diversity index (2.17 and 2.35 respectively), whereas lake 3 showed the lowest value (1.25). Lakes 1, 3 and 4 were dominated by crustaceans, whose maximum richness was recorded in lake 4, since four cladocerans and three copepods were found (Table 3). Lake 5 presented the same number of taxa of crustaceans and rotifers, and lakes 2 and 6 were dominated by rotifers.

Among cladocerans, *Bosmina huaronensis* and *Ceriodaphnia dubia* were found in the six lakes. *Bosmina huaronensis* was the species which presented highest density in five of the lakes, whereas *C. dubia* was only more abundant in lake 4 (Table 3). Among copepods, the most frequent species was *Microcyclops anceps*, which was found in four of the lakes and was the one that reached the greatest densities of the group in all the lakes in which it was recorded (Table 3).

The only rotifer common to the six lakes was *Filinia longiseta*, although *Keratella tropica* and *Testudinella patina* were recorded in five lakes (Table 3). *F. longiseta* was the species with greatest density in four lakes although *Brachionus dimidiatus* showed high densities of over 200 ind.L^{-1} in lake 6 (Table 3).

Table 3. Zooplankton density (ind.L^{-1}) registered in each shallow lake

	1	2	3	4	5	6
Ceriodaphnia dubia Richard, 1895	6.48	1.39	1.04	56.25	3.5	1.56
Daphnia spinulata Birabén, 1917				1.39		
Bosmina huaronensis Delachaux, 1918	16.9	83.7	26.7	48.61	113.2	15.63
Chydoridae (Aloninae)	1.85	0.69			0.7	
Chydoridae (Chydorinae)				2.78		
Cladocerans	25.23	85.78	27.74	109.03	117.4	17.19
Notodiaptomus incompositus (Brian, 1925)	2.08	5.9			8.33	
Boeckella gracilis (Daday, 1902)				11.11		
B. poopoensis Marsh, 1906			3.47			
Microcyclops anceps (Richard, 1897)		58.3	9.72	22.92	56.25	
Metacyclops mendocinus (Wierzejski, 1892)						133.6
Cletocamptus deitersi (Richard, 1897)	0.23	0.35		2.08		
Copepods	2.31	64.55	13.19	36.11	64.58	133.6
Brachionus plicatilis Müller, 1786		27.1		3.47	0.69	2.34
B. dimidiatus Bryce, 1931						218.0
B. calyciflorus Rousselet, 1913		6.25			6.25	
B. caudatus Barrois & Daday, 1894		9.03		1.39		
Testudinella patina (Hermann, 1783)	0.93	3.13		0.7	2.78	0.78
Filinia longiseta (Ehrenberg, 1834)	3.7	49.3	4.86	11.81	15.28	2.34
Keratella tropica (Apstein, 1907)		4.5	9.38	2.78	4.86	7.81
Asplanchna sp.	0.12			0.7		0.78
Lecane sp.		0.35				
Rotifers	4.75	99.66	14.24	20.85	29.86	232.05
Total density	32.29	249.99	55.17	165.99	211.84	382.84
Total richness	8	13	6	13	10	9
Margalef´s diversity index	2.02	2.17	1.25	2.35	1.68	1.35

Table 4. Fish fauna recorded in the "mercedinas" lakes and number of captured specimens

	1	2	3	4	5	6
Odontesthes bonariensis (Cuvier y Valenciennes, 1835)	92	14	116	0	46	0
Jenynsia multidentata (Jenyns, 1842)	52	205	51	5	57	2
Cnesterodon decemmaculatus (Jenyns, 1842)	25	25	0	0	0	0
Corydoras paleatus (Jenyns, 1842)	5	4	3	0	0	0
Astyanax eigenmanniorum (Cope, 1984)	0	13	4	0	0	0
Cheirodon interruptus (Jenyns, 1842)	0	3	1	3	0	1
Oligosarcus jenynsii (Günter, 1864)	0	0	10	0	0	0
Total fishes captured	174	264	185	8	103	3

The highest total density (over 380 ind.L^{-1}) was recorded in lake 6, whereas the lowest (barely higher than 30 ind.L^{-1}) was found in lake 1 (Table 3). Cladocerans dominated in most of the lakes (lakes 1, 3, 4 and 5), followed by rotifers, which were most abundant only in two of them (lakes 2 and 6) (Table 3). The highest dominance index (0.45) was calculated for lake 6, given that 61% of the density was contributed by the rotifer *Brachionus dimidiatus* (Table 3). The dominance index was also high in lakes 5 (0.37) and 1 (0.34), although in this case the predominant species was the cladoceran *B. huaronensis*, which contributed between 53 and 54% of total density (Table 3).

The cluster analysis showed that lakes 2 and 5 were the most similar (Figure 2), since they shared the same species, with very similar densities, with the exception of *Cletocamptus deitersi*, *Brachionus caudatus* and *Lecane* sp., which were present only in lake 2. The analysis also grouped lakes 1 and 3 (Figure 2), although lake 1 had cladocerans of the family Chydoridae (subfamily Aloninae), *Cletocamptus deitersi*, *Testudinella patina* and *Asplanchna* sp., absent in lake 3, and lake 3 had the copepod *Boeckella poopoensis*. Lake 6 showed less similarity with the rest (Figure 2), due to the exclusive presence of the rotifer *Brachionus dimidiatus* and the cyclopoid *Metacyclops mendocinus*, which presented a relatively high density.

The fish fauna was represented by seven species, of which *Jenynsia multidentata* was the most widespread, as it was recorded in all the lakes, followed by *O. bonariensis* and *Cheirodon interruptus* (Table 4).

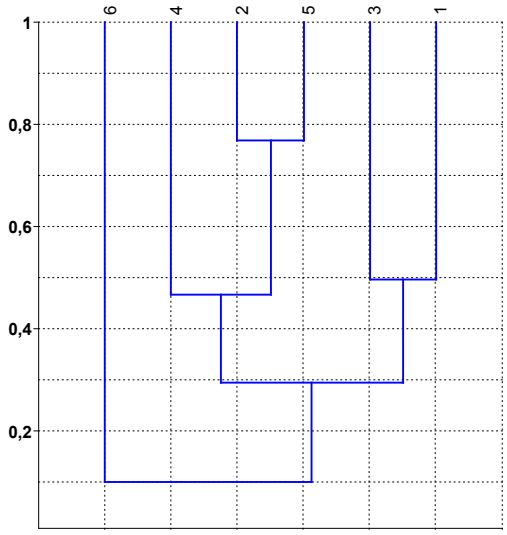

Figure 2. Clustering of lakes based on zooplankton species

4. Discussion

The lakes studied were shallow and had a relatively reduced extension. Although the concentration of dissolved solids was not determined in all cases, four of them can be characterized as subsaline to slightly hyposaline[81]. The latter is common in aquatic environments located in dune landscapes, in watersheds caused by wind deflation, fed mainly by rainfall and phreatic contributions.

Water transparency covered a wide range, from very turbid to very clear lakes, such as the case of lake 1. The values of the ratio between the depths of the lake and the photic zone were also different and allowed categorizing lakes 1, 3 and 5 as clear, a state that would be favored by the presence of macrophytes in the littoral zone and the lower impact of agricultural activities developed in its surroundings[60]. In contrast, lakes 2 and 4 can be categorized as turbid. In this case, the dominance of cyanophytes and the agricultural activity developed in its basins would contribute to the maintenance of the turbid state of its waters[60].

Total zooplankton richness was relatively high and the beta diversity index showed a relatively low species replacement between lakes, which is natural because these lakes are located in a region with little expansion and have relatively similar characteristics.

Most of the species found are typical of the zooplankton association of lakes with intermediate salinity in the central region of the country and the presence of the cladocerans *Ceriodaphnia dubia* and *Bosmina huaronensis* makes the "mercedinas" lakes similar to the relatively eutrophic reservoirs of the Northwest Center of Argentina[38]. However, a discordant trait was the presence in lake 3 of *Boeckella poopoensis*, a widely extended halotolerant calanoid, typical of saline lakes, between 5 and 90 g.L^{-1}, whose distribution is considered to be linked with the migratory route of the southern flamingo *Phoenicopterus chilensis* Molina, 1782[82], since it includes *B. poopoensis* in its feeding and has a wide distribution in Argentina[83]. The presence of *B. poopoensis* in only one lake and its very low density could be due to an occasional event, related to the passing of flamingos during their migration, since, in the same lake, we recorded *B. huaronensis* and *C. dubia*, zooplankton species typical of low salinity lakes, with which the coexistence of *B. poopoensis* has not been reported.

Lake 4, which had very low transparency, showed the presence of *Daphnia spinulata*, a cladoceran of considerable size, which is relatively common when there are no predators[64, 84]. This was the case of this lake because *O. bonariensis*, the main zooplanktivorous fish, was absent. Most of the remaining lakes showed higher water transparency and presence of *O. bonariensis*, and the crustaceans recorded were of small size. The latter raises a particular situation regarding the "mercedinas" lakes, because it does not coincide with that proposed by the model of the alternative states of shallow lakes (lakes less than 3 m deep). This theory, which takes into account changes in the characteristics of the lakes caused by changes in the zooplankton grazing pressure, considers that the lakes can alternate between two states. In the absence of predation, zooplankton dominated by species of large size and high efficiency of filtration of phytoplankton (especially cladocerans of the genus *Daphnia*) frequently develop,

which leads to a clear state, with high water transparency[14, 47, 85, 86, 87, 88]. On the other hand, in the presence of zooplanktivorous fish,

the zooplankton community is reflected in the dominance of taxa of reduced size and hence of low filtration efficiency, which results in the establishment of the turbid state[14, 64, 85, 86, 87, 88]. However, in the lakes studied, we verified that the lowest water transparencies were found in lakes where *O. bonariensis* was absent, despite the presence of *D. spinulata* in one of them.

Although the results here presented are preliminary, they allow characterizing the diversity and density of the zooplankton of six "mercedinas" lakes, located in a region of Argentina where there was no information. Future systemized and long-term studies will help determine the seasonal dynamics of zooplankton and its relationship with the fish fauna and verify whether there is alternation between the clear and turbid states that characterize shallow lakes, or if (as in some lakes of Central Argentina) one state or another dominates[48, 51, , 56, 57, 64, 89].

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