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Benthic invertebrates of some saline lakes of the Sud Lipez region, Bolivia

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Abstract

The benthic invertebrates fauna of most of the saline lakes of the Sud Lipez region (Bolivia, Altiplano) has been until now quite unstudied. Samples collected during an extensive survey of 12 lakes and two small inflow rivers allow a first list of the main macroinvertebrates living in these biotopes.

The heterogeneous nature of these saline lakes with their freshwater springs and phreatic inflows offers a variety of habitats to macroinvertebrates. The benthic fauna in lakes with salinities $> 10\ g\ l^{-1}$ is not so low in density but includes few species and is dominated by Orthocladiinae and Podonominae larvae. In contrast, the freshwater springs and inflows are colonized by a diverse fauna, with a mixture of both freshwater and saline taxa, but dominated by Elmidae and Amphipoda. The lakes are quite isolated and, apart from some cosmopolitan organisms, their fauna can be quite distinctive.

Extending into the southern part of Bolivia and close to the Chilean border, the Sud Lipez region is a volcanic area of the Bolivian Altiplano located at a mean altitude of 4000 m. Numerous small lakes can be encountered there. They are in general shallow, saline, temporary or permanent, but always subject to wide variations in area.

Since the works of Risacher (1978), Ballivian & Risacher (1981), Hurlbert & Chang (1984, 1988), the physicochemical characteristics of these lakes are quite well known.

Their biota are less well studied and only the algae has been described (Servant-Vildary, 1978, 1983, 1984; Iltis *et al.*, 1984) as well as the aquatic avifauna (Pena, 1961; Hurlbert & Keith, 1979; Hurlbert, 1978, 1981, 1982; Hurlbert & Chang, 1983).

Apart from some nematodes and *Artemia salina* (Iltis *et al.*, 1984; Hurlbert, 1982) no other macroinvertebrates from this desertic region have been recorded. We report here the benthic invertebrates encountered during a survey of these saline lakes carried out in November 1987.

Area studied and methods

Qualitative samples of invertebrates were collected from 10 lakes and 2 small rivers in the region (Fig. 1). Sampling was done using techniques such as brushing and sieving (250 μm screens) of submerged substrates (stones, gravel, plants, sediments) or collecting with fine mesh nets. All samples were preserved in the field with formalin and sorted in the laboratory under a binocular microscope. We tried to sample a variety of biotopes in each lake, including muddy sediments from the most saline areas as well as substrates from the freshwater springs or small brooks running into the lakes. Each type of

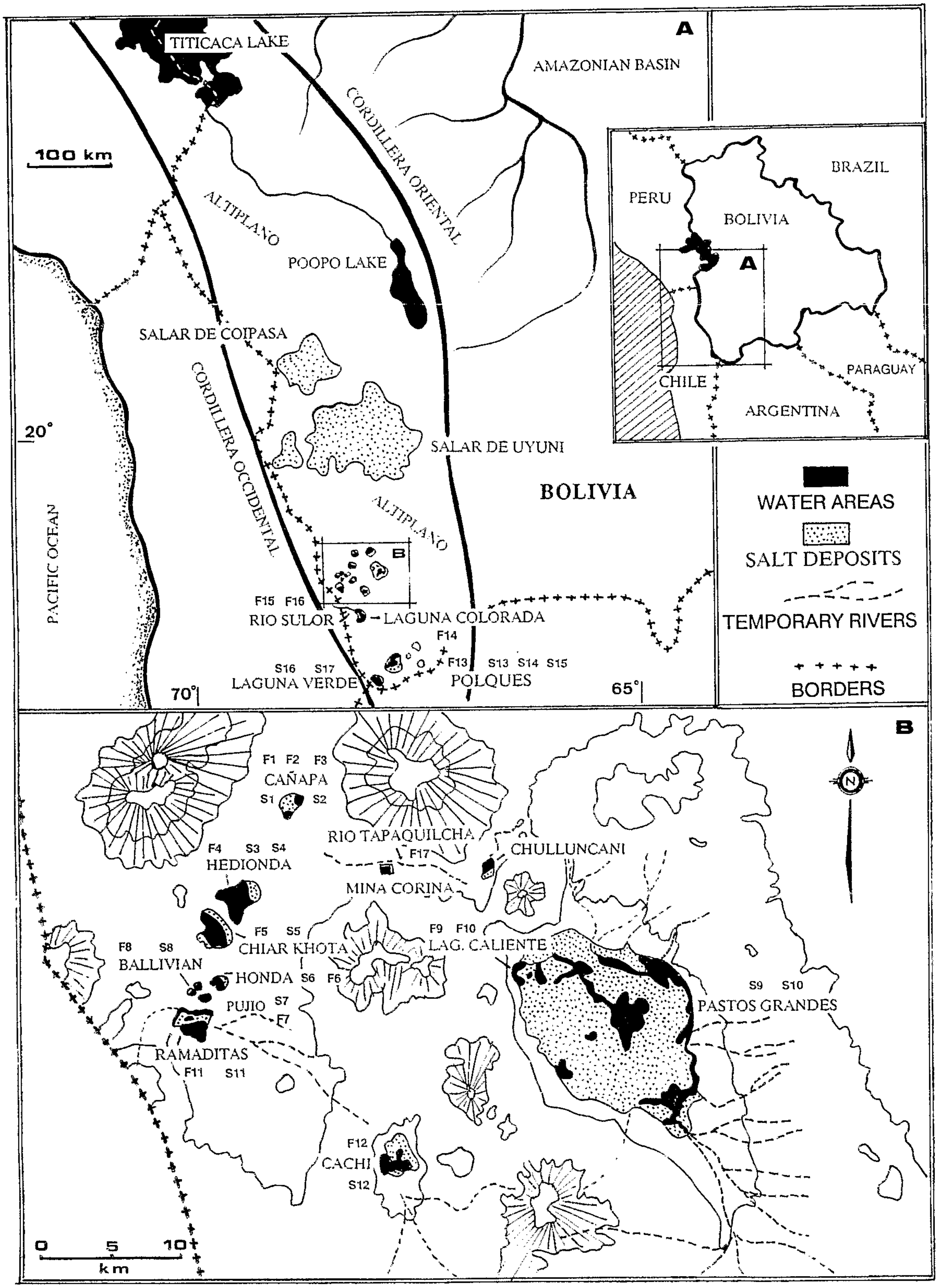

Fig. 1. Map of the studied region and location of studied sites in and around saline lakes of the Sud Lipez.

biotope identified in a lake was considered as a 'site'. Sites are numbered S1 to S17 for the saline habitats (<3 g l^{-1}). In each site we collected 2 to 6 subsamples, according to the density of organisms present, and these subsamples were combined into a single composite sample. The results (Tables 3 and 4) refer to the composition of these composite samples. Water samples were collected for chemical analysis and some variables (pH, temperature and conductivity) were measured *in situ* at each site. Temperature was measured with a digital K/T BIOBLOCK thermometer, pH with a LED IP/65 BIOBLOCK apparatus and conductivity with a JP BIOBLOCK scientific conductimeter, the value being corrected for a temperature of 20 °C. Total salinity was measured at least at one site for each lake, using a field optical salinometer (Manual refractometer ATAGO, France). For the sites where the total salinity was not measured, an evaluation was made from the conductivily value (C), using the empirical formula:

$$\text{Salinity (mg l}^{-1}) = C\,(\mu\text{S cm}^{-1}) \times 0.76$$

when the conductivity is less than 10 000 μS cm^{-1}. This formula changes for conductivities over 10 000 μS cm^{-1} and becomes

$$\text{Salinity (mg l}^{-1}) = C\,(\mu\text{S cm}^{-1}) \times 0.85$$

The greatest difficulty encountered in this study were the taxonomic determinations. Taxa that we could not identify to species were coded with the letter L (= Lipez) and a number. The same code was always applied to specimens nominally identified as the same species and added to the tentative generic or familial name.

Most of the material sent to specialists for identification has not been yet returned and the taxonomy was worked out using the following works: Haas, 1955; Viets, 1955; Roback *et al.*, 1980; Roback & Coffman, 1983.

Oligochaetes were identified by Dr B. Lafont from CEMAGREF Institut (France) and beetles by Dr P. J. Sprangler from the Smithsonian Institution (Washington).

All the material collected remains in the reference collections of the author and is available for taxonomical works.

As our samples are only qualitative, we have only used the following semi-quantitative scale to indicate the relative abundance of each collected taxon: + = only one individual collected,

Table 1. Some physico-chemical parameters from water samples collected in different lakes from Sud Lipez.

Sampling sites*	Temp. (°C)	pH	Cond. in laboratory (μS cm^{-1})	Total salinity (g l^{-1})	Ca (mg l^{-1})	Mg (mg l^{-1})	Na (mg l^{-1})	K (mg l^{-1})	SiO_2 (mg l^{-1})
Lag. Colorado	9.0	8.2	96285	81.4	–	1056	82500	6405	30.4
Lag. Verde	17.0	8.6	23820	20.2	164	300	4647	340	65.8
Lag. Hedionda	23.1	8.4	48920	41.6	–	634	17252	1488	47.5
Lag. Cachi (spring)	16.8	8.3	262	0.2	1.8	1.0	128	35	36.8
Lag. Chulluncani	17.1	8.4	44600	38.0	–	–	13250	4074	32.7
Pastos Grandes (spring)	31.1	6.7	1938	1.5	22	26	485	53	82.0
Lag. Pastos Grandes	18.0	8.9	3409	2.6	300	510	896	142	41.9
Lag. Chiar Khota	23.2	8.0	82980	70.5	1184	1690	39932	4069	81.3
Lag. Cañapa	16.2	8.8	61090	52.0	–	–	31332	1242	43.3
Lag. Ballivian	20.0	8.2	36770	31.2	648	352	10304	1068	43.5
Lag. Honda	18.5	8.6	48360	41.1	204	282	15750	1593	32.9
Lag. Ramaditas	15.5	8.2	34770	29.5	1152	405	8531	914	95.7
Lag. Pujio	18.7	8.6	30570	26.0	192	158	8860	693	50.1
Lag. Polques (spring)	40.2	8.2	1435	1.9	54	12	318	31	26.0
Lag. Polques	21.6	8.5	15720	13.2	168	132	5554	334	14.7

* All samples were collected between the 14th and the 19th of November 1987. Analysis were made by the SENAMHI laboratory in La Paz.

++ = between 2 and 10; +++ = between 11 and 100; ++++ = more than 100.

Results

+ Physico-chemical characteristics of the studied environments

As our purpose was not a detailed study of the physico-chemical conditions, analyses of water (Table 1) were carried out only to check conditions at the time of sampling, in order to detect changes that might have occured since the previous studies of Ballivian & Risacher (1981) and Iltis *et al.* (1984).

The lakes are mainly very shallow (0.2–1 m deep). Laguna Verde has a depth of several meters. Bottom sediments are usually mud, covered by a fine layer of silt which can easily be disturbed by the strong winds frequent in that region. Transparency then is very low, especially when the plankton is dense.

Diel temperature variation is great, particularly during the spring (September to December), when the nights are very cold and the days are sunny. A light ice layer can build up during the night, but disappear in the morning as water temperatures can reach 20 °C.

Some of the springs feeding the lakes have outflow temperatures that exceed 40 °C, as at Salar de Chalviri, for example.

Salinity varies notably in time and space, and our data have been compared in Table 2 to those of Iltis *et al.* (1984), showing the interannual variability of this factor. At small spatial scales, salinity variation can be strongly influenced by whether freshwater input is from diffuse seepage or by discrete springs. Such variation can produce corresponding gradients in the distribution of the invertebrate fauna.

The chemical composition of water varies from one lake to another, but three types can be recognized (Iltis *et al.*, 1984):

- the sodium chloride type (Chiar Khota, Ramaditas, Laguna Verde, Pujio, Honda, Ballivian, Colorada);

Table 2. Temporal changes in salinity (in $g\,l^{-1}$) for some saline lakes of the Sud Lipez region. All values determined with an optical salinometer.

Lakes studied	November 1987	November 1982	Earlier studies
Lag. Chulluncani	14	7	11.6
Lag. Honda	45	12	21.4
Lag. Cañapa	80	13	11.5
Lag. Pujio	36	18	31.1
Lag. Ramaditas	33	20	27.7
Lag. Ballivian	35	28	45.3
Laguna Verde	20	46.5	66
Lag. Hedionda	60	57	67.2
Lag. Cachi	90	86	43.5–322
Lag. Chiar Khota	124	119	69.3
Lag. Colorada	200	137	120

- the sodium carbonate type (Cachi);
- the sodium sulfate type (Cañapa, Chulluncani).

Lakewater pH varied from 8 to 9. Freshwater springs were mostly basic (pH 7.5–8), but the freshwater hot spring at the Salar de Pastos Grandes had a pH of 6.7.

Benthic invertebrates assemblages

Laguna Cañapa

Located in the northern part of the studied area, this small lake is often divided in two separate basins. Both basins were sampled in different places, with the salinity ranging from less than $1\,g\,l^{-1}$ in small springs present along the shore (site F1 in the northern basin and site F3 in the southern one) to $80\,g\,l^{-1}$ in the lake itself (site S2). A shoreline area of the southern basin, fed by a diffuse groundwater was also sampled (site S1), as well as a deep hole receiving a freshwater spring and covered with aquatic macrophytes (site F2).

The greatest diversity of invertebrates at Laguna Cañapa was found in the freshwater habitats (Table 3).

Apart from the amphipod *Hyalella* cf. *dentata inermis* (present at 3 sites) and two species of the midge *Parochlus* (2 sites), each sampling site had

Table 3. Macroinvertebrate assemblages found in some freshwater habitats related to saline lakes in the Sud Lipez region.

Taxa collected		Cañapa		Hedionda	Chiar Khota	Honda	Pujio	Ballivian	Caliente		Ramaditas	Cachi	Polques	Laguna Colorada	Rio Sulor		Rio Tapaquilcha
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17
Salinity (mg l^{-1})	680	600	720	930	1760	2040	1920	2400	620	870	410	1930	2044	1910	661	820	420
Hirudinea Glossiphoniidae sp. L38						+++			++	+++							
Tubificidae *Rhyacodrilus* sp. L61						+++		+									
Naididae *Nais andina*											+++	+++					
Naididae *Paranais litoralis*	++																
Naididae *Nais simplex*	+																
Euplanaria dorotocephala		++								++		++				+	
Orthocladiinae *Cricotopus* sp. L17			+++		++	++		++						+++			
Orthocladiinae sp. L3															+++		
Orthoclodiinae sp. L4		++													+++		
Orthoclodiinae sp. L5															++		
Orthoclodiinae sp. L6															+		++
Orthoclodiinae sp. L7		++													+		
Orthoclodiinae sp. L72	+++																
Orthoclodiinae sp. L80																	+++
Podonominae *Parochlus* sp. L1															++++		
Podonominae *Parochlus* sp. L22		+++	+														+
Podonominae *Parochlus* sp. L23		++															
Tanypodinae *Procladius* sp. L81																	+
Tanypodinae *Ablabesmyia* sp. L82																	+
Simuliidae spp.																	++
Ceratopogonidae sp. L25		+++			++		+						+				
Tipulidae sp. L41										++		+					
Ephydridae sp. L18				+								++					
Ephydridae sp. L19							++							++			++
Ephydridae sp. L33		++															
Ephydridae sp. L34												+					+
Ephydridae sp. L63						+											
Corixidae *Ectemnostegella quechua* Bachman		+++					++					++				+	++
Corixidae *Ectemnostegella stridulata* Hungerford		++										++					
Claudioperla sp. L14															+		
Baetidae sp. L12															++		+++
Leptoceridae sp. L84																	++
Hydroptilidae *Hydroptila* sp. L78																	++
Hydroptilidae *Leucotrichia* sp. L83																	++
Protallagma titicacae Calvert	+																
Elmidae *Austrelmis consors* Hinton						++++	++	++	++++	++++	+++	+++	++	++		+	+++
Dytiscidae *Lancetes nigriceps* Guignot																	++
Hydracarina sp. L9																+	
Hydracarina sp. L10																+	
Hydracarina sp. L52								++									
Hydracarina sp. L59					+												
Hydrachnella sp. L53							+										
Oribatei *Hydrozetes* sp. L31				+													
Oribatei *Hydrozetes* sp. L62						+++											
Oribatei *Hydrozetes* sp. L64						++											
Oribatei *Hydrozetes* sp. L70	+++																
Orchestidae *Hyalella* cf. *dentata inermis* Smith	+	+++	++			++++		+++	+++	+++		++++					+++
Planorbiidae *Tropicorbis canonicus* Cousin													++				
Hydrobiidae *Littoridina* cf. *languiensis*											++++						
Total number of taxa collected	6	10	3	2	3	8	5	5	3	5	3	9	3	3	8	5	16
Total number of individuals collected	37	116	75	2	54	304	16	39	209	247	231	230	11	24	532	17	199

a distinct fauna despite their proximity. This situation, commonly encountered is South Lipez aquatic environments, will be discussed later. The saline site had a poor fauna.

Lakes Hedionda and Chiar Khota

Laguna Hedionda has an area of *ca* 5–6 km^2, and is fed by freshwater springs on its south-eastern and western margins. The spring discharge is high enough to form a shallow channel 10 m long (site F4), ending at the shoreline level in a small branched delta (site S3), where the freshwater rapidly mixes with the saline water of the open lake (site S4). The salinity gradient along this system ranges from $< 1\ g\ l^{-1}$ to $60\ g\ l^{-1}$.

The channel, with its strong salinity gradient, had the most diversified biota, especially in the section where the salinity was about $10\ g\ l^{-1}$ and the bottom covered with algae. In contrast, invertebrates were very scarce in the clean sandy bottom of the spring outflow. A similar situation existed in the near open lake itself, possibly due to its high salinity, and only a few *Artemia salina* were found in open water.

Lying south of and close to Lag. Hedionda, Lag. Chiar Khota was smaller, very shallow, and with a salinity of $120\ g\ l^{-1}$ (site S5) during our visit there. Only a small area of diffuse outflow occurring near the shoreline was sampled, by brushing small stones half covered by semi-stagnant water (site F5). The fauna there was sparse and only chironomids and ceratopogonids were present in some abundance;

Lakes Honda, Ballivian and Pujio

Very close together, these three lakes are small, have similar salinities (35, 36 and $45\ g\ l^{-1}$, respectively) and receive freshwater mainly via small shoreline springs or diffuse seeps. Bottoms are muddy with a superficial silt deposit mixed with algae. Small pools supplied by freshwater seeps were occasionally present along the shoreline (sites F6, F8 and F7).

Austrelmis consors and *Cricotopus* sp L17 were the most common invertebrates, the first species occurring mainly in the freshwater habitats and the second one in the saline areas (Tables 3 and 4). It is however interesting to note that *A. consors*, a very common freshwater elmid found throughout the Altiplano, was also present in Laguna Ballivian at a place where the salinity was $31.2\ g\ l^{-1}$.

Salar de Pastos Grandes

This is the largest saline depression of the Sud Lipez region, but water bodies were only sparsely scattered over it. We sampled the western side of the depression where there was a lake (Laguna Caliente) fed by both cold (14 °C, site F9) and hot (32 °C, site F10) freshwater spring inflows. A low salinity water area located some 10 m outside the hot spring outflow but directly under its influence was also sampled, as well as a site (S10) in the central area of the salar. In contrast to the situation found at the preceding lakes, the fauna at Salar de Pastos Grandes was more diverse in the saline water than in the freshwater outflows (Tables 3 and 4). *Cricotopus* sp. L17 was again dominant in saline water. In freshwater habitats, amphipods, elmids and leeches were dominant and about equally abundant in both cold and hot outflows. In the saline environments, the most diverse fauna was found some 10 m away (site S10: salinity = $3\ g\ l^{-1}$; 9 species) from the spring outflows, but apart from the abundant *Cricotopus* mentioned above, all species were scarce. At a somewhat higher salinity ($5–10\ g\ l^{-1}$, site S9) we found only 7 species (5 of them very abundant), fewer substrate types being present here than near the spring outflows (stones, gravel and macrophytes were lacking).

Laguna Ramaditas

The depression of Laguna Ramaditas is about 10 km^2, but the open water area during our visit was restricted to a narrow area along the north-eastern margin, a small waterbody in the middle of the depression, surrounded by emerged area with muddy sediments covering old ice deposits (Hulbert & Chang, 1988), and a larger open water area along the southern side. The salinity of this last zone (site S11) was more than $30\ g\ l^{-1}$, and on the water surface we found many dead or dying amphipods. Possibly this resulted

Table 4. Macroinvertebrate assemblages found in some saline lakes from the Sud Lipez region.

Taxa collected	Cañapa		Hedionda		Chiar Khota	Honda	Pujio	Ballivian	Caliente		Ramaditas	Cachi	Polques			Laguna Verde	
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Salinity ($g\,l^{-1}$)	8.5	80	9.8	60	120	35	45	36	5–10	38	33	12.4	4.9	12	15	20.2	20.2
Hirudinea Glossiphoniidae sp. L38			++													+++	
Naididae *Nais andina*			++													++	++
Naididae *Nais elinguis*													++				
Naididae *Paranais litoralis*			++						+++	++							
Euplanaria dorotocephala Woodworth													+++				
Orthocladiinae *Cricotopus* sp. L17	++					+++	+++	+++	+++	++++	+++		+++	++	+++		
Orthocladiinae *Paratrichocladius* sp. L15			+++													+++	+++
Orthocladiinae sp. L3														++			
Orthoclodiinae sp. L24										++							
Orthoclodiinae sp. L40			+++														
Orthoclodiinae sp. L46		++															
Podonominae *parochlus* sp. L1													++	++	++		
Podonominae *Parochlus* sp. L22	++		+							++			++	++			
Podonominae *Parochlus* sp. L23										++							
Podonominae *Parochlus* sp. L27											+						
Podonominae *Parochlus* sp. L35													++				
Ceratopogonidae sp. L25	++									+			+				
Ephydridae sp. L18										+			++				
Ephydridae sp. L19									++	++			+	++	++		
Ephydridae sp. L20										++							
Ephydridae sp. L33	+++		+										++				
Ephydridae sp. L34												++	++				
Ephydridae sp. L56				+													
Ephydridae sp. L63																	
Ephydridae sp. L76			+														
Corixidae *Ectemnostegella quechua* Bachman			+++						+++				+				
Corixidae *Ectemnostegella stridulata* Hungerford			+++														
Elmidae *Austrelmis consors* Hinton	+		+++					++	+++			+++	++++	+++	++	++	
Dytiscidae *Uvarus* sp. L29													+++				
Hydracarina sp. L28													+++				
Oribatei *Hydrozetes* sp. L55													+				
Orchestidae *Hyalella* cf. *dentata inermis* Smith			+++						+++		+++	++++	+++	+++	++	++	
Artemia salina		+++		++++	++												
Planorbiidae *Tropicorbis canonicus* Cousin													+++				
Hydrobiidae *Littoridina* cf. *languiensis*									+							++	
Total number of taxa collected	5	2	12	2	1	1	1	2	7	9	3	3	18	7	5	6	2
Total number of individuals collected	35	62	199	170	43	10	26	27	162	191	53	144	452	88	41	68	189

from a rapid increase in salinity caused by evaporation.

Apart from *Hyalella* cf. *dentata inermis* which possibly reached at that time its tolerance limit of salinity, we found in that saline area a classical invertebrate assemblage with the presence of Orthocladiinae and Podonominae larvae.

Diffuse groundwater inflows were sampled along the southern shore, as well as a freshwater well fed by a low discharge spring (site F11). In these areas we again found widespread elements such as Elmidae and Oligochaeta, and for the first time in Sud Lipez lakes we found numerous molluscs that we attributed to *Littoridina languiensis*, and also some Dytiscidae larvae.

There were numerous ducks swimming around in the freshwater outflow and feeding on the bottom, perhaps attracted by the abundant benthic fauna (molluscs) or by the aquatic plant *Ruppia* sp., which was present in this lake.

Laguna Cachi

A bit larger than Ramaditas, the saline depression of Cachi Laguna also had a marginal flooded area. We sampled on the western shoreline of this lake, a freshwater spring with a discharge of some litres per second (site F12). The water came out from two well defined outlets (temperature: 17 °C) and then flows over a patchily substratum.

The salinity was about $2\ g\ l^{-1}$ at the outlet and rapidly increased as the flow ran over evaporites and mixed with the lake water, which had a salinity $>90\ g\ l^{-1}$. Invertebrates were present only in the spring pools and in the short outflow channels (site S12). None were found in the lake itself where the black and anoxic sediments appeared to contain abundant decomposing organic matter. The fauna of the low salinity sections (site F12) was dominated by amphipods, elmids and oligochaetes (Tables 3 and 4).

Laguna Polques

This is one of many lakes in Salar de Chalviri. We sampled it on its western shore, alongside the road going from Laguna Colorada to Laguna Verde. Many diffuse inflows were entering the lake there, as well as a freshwater hot spring with sufficient discharge to create a long outflow channel 2–3 m wide and about 50 cm deep.

At our visit, the water was emerging from the ground at a temperature of 42 °C, with a salinity of about $2\ g\ l^{-1}$. The temperature rapidly decreased and salinity increased along the outflow channel. Salinity was $12\ g\ l^{-1}$ at twenty meters away from the spring and $15\ g\ l^{-1}$ at about thirty meters, where the channelized outflow mixes with the lake water. The benthic fauna was sampled at four sites (F13, S13, S14 and S15) along the salinity gradient (Tables 3 and 4).

No invertebrates were found until about 3 m downstream from the spring outlet. The first species appeared on the sides of the channel where the temperature decreased to about 30 °C, but the most diverse fauna was found only 10 m downstream, where the salinity was $5\ g\ l^{-1}$ and the temperature not more than 25 °C. The density of organisms was high, with elmids, amphipods and tricladids dominating. Only 5 species were collected at the last and most saline sampling site (S15, $15\ g\ l^{-1}$), where *Cricotopus* sp. L17 larvae dominated.

The presence of *Euplanaria dorotocephala* in relatively saline, warm water is unusual, the normal habitat of this triclad being mainly fresh and cold water of Altiplano brooks.

Laguna Colorada and Rio Sulor

Supporting a large flamingo population, this is one of the most famous lakes of the Sud Lipez, because of its red waters colored by halobacteria and *Dunaliella*, because of its ancient ice deposits and also because the proximity of an important center for geothermal energy exploitation. This lake was sampled in different places but we never found a single macroinvertebrate, perhaps because of the very high salinity at the time of our visit ($200\ g\ l^{-1}$). Copepods (*Boeckella* sp.), colored red probably by β-carotene from the *Dunaliella*, were on the other hand so abundant that they formed blood red accumulations several cm thick in many places along the shoreline.

Elmids, ephydrids and *Cricotopus sp.* were found around a freshwater artificial captage overflowing into a small pool connected with the lake itself (Table 3, site F14). A small river, Rio Sulor, feeds the lake on its western shore and was sampled some 50 m above Laguna Colorada, both in flowing sections (site F15) and in stagnant pools (site F16). This river is permanent and had a discharge of about 2 m^3 at the time of our visit. *Austrelmis consors* was the only element common to both biotopes, and apart from the small corixid *Ectemnostegella quechua*, found also in saline environments of the Sud Lipez region, the assemblages found in the river were very different from those normally encountered in small freshwater brooks or spring outflows of the region (Table 3). It was an assemblage more typical of the permanent rivers of the Altiplano (Marin, 1989). The absence of amphipods in the Laguna Colorada aquatic environment was notable and remains without clear explanation.

Laguna Verde

This was the southermost lake studied. It also has the greatest water volume, with a depth of several m and a length of 3–4 km at the time of our visit. A pebble and sand substratum occupied the shoreline zone, which was regularly washed by waves. Two sites (S16 and S17) were sampled there at depths of 20 and 60 cm. At the deeper site, the sediment was formed of a mixture of sand and compact clay covered by a fine greenish silt layer.

The fauna of soft sediments was dominated by chironomid larvae never found in other lakes (possibly *Paratrichocladius*, Hurlbert pers. comm.). The fauna of pebbles was more diverse, and in addition to common elements such as amphipods and elmids, we also found some living *Littoridina* (cf. *languiensis*) which indicate that this species is able to support saline water conditions. We also found a single uninhabited shell of a snail very close to the form *Littoridina andecola andecola* living in Lake Titicaca. The shell was well preserved, but no living specimens belonging to the same species were found.

Rio Tapaquilcha

Rio Tapaquilcha (site F17) runs close to the Mina Corina encampment (Fig. 1). This river is permanent, unpolluted above the mine encampment, and presents a high variety of habitats such as muddy or sandy bottoms in shoreline pools, gravels in riffle sections, stones in faster currents, and aquatic vegetation along its margin. It can be then regarded as one of the most suitable habitat for freshwater macroinvertebrates in the region.

Of the 16 taxa found in this river (Table 3), only 7 were also collected in other aquatic habitats of the region and the general faunal assemblage was similar to that of central Altiplano and Cordillera rivers (Marin, 1989). Dominant groups were Orthocladiinae, mayflies and beetles (mainly elmids).

Discussion and conclusions

The present study suggests that several ecological factors play a role in the distribution of the benthos in aquatic habitats of the Sud Lipez.

All lakes appear to present two types of biotopes that grade into one another: unstable freshwater-shoreline habitats (springs, phreatic inflows) and saline open water environments. In some cases the limit between these two types of biotopes fluctuates in time and space, according to the action of various abiotic factors. The taxa living in this transition area are mainly the most euryhaline ones. Variation of salinity in lake open waters due to variability in precipitation certainly induces important changes in faunal composition. That was possibly the reason why we found so many amphipods dying at Laguna Ramaditas during our visit and why a dead, but no live, *Littoridina andecola andecola* was found in Laguna Verde. Of course, this single specimen could have been carried into the lake by a bird or other source of transport and died on arrival.

The benthic fauna of biotopes with more than 10 g l^{-1} is in general of low diversity. Orthocladiinae and Podonominae larvae typically are dominant. In some cases ephydrid larvae, oligochaetes and nematodes are also present but are never abundant.

Freshwater springs or diffuse marginal inflows of groundwater origin are usually colonized by a rich and relatively diverse fauna. Exceptions would be the points of outflow of hot springs or of cold springs that churn the sediments. In these cases, the high temperature or the mechanical action of shifting sand around the outlet does not allow the establishment of invertebrates. Low salinity sites (2–6 g l^{-1}) with abundant food sources and heterogenous substrates, also often contain a diverse fauna with a mixture of freshwater and euryhaline taxa.

From one lake to another the faunal composition can be very different, apart from some ubiquitous and cosmopolitan taxa. In this respect the lakes appear quite isolated one from another, and cross-colonization may be limited. Insects can be able to colonize a lot of habitats during their aerial adult phase, but after hatching only the most ubiquitous may have chance to survive in diverses biotopes. That is mainly the case for Ephemeroptera, Trichoptera or Plecoptera which are living on the Altiplano and are generally unable to tolerate a salinity of more than 1 g l^{-1}. Such a situation occurs probably in Lake Titicaca, where among those groups, only a few species of Trichoptera, carried in by inflow rivers, can survive in the lake, close to the river entrance (Dejoux, 1991). Strictly aquatic forms like molluscs, amphipods or water mites possess less effective means of colonization; possible, birds commonly living in the Sud Lipez region (flamingos, ducks, phalaropes) transport invertebrates when they move from one lake to another.

It is difficult to compare directly the benthic populations found in the Sud Lipez lakes to those of other saline lakes in the world. Numerous factors are important in determining the presence or absence of a particular taxa. If the salinity level is in many cases one of the most important, others, such as the ionic composition or the climatic environment must also be taken into account.

In the Sud Lipez region the aquatic faunal diversity is enhanced by the presence of relatively permanent sources of freshwater, and gradients of biotopes with different physico-chemical conditions between these sources and the saline lakes are frequent. This allows species with differing ecological requirements to persist in close proximity to one another.

Despite this positive aspect, freshwater habitats created by springs very close to the lake shorelines, are frequently affected by changes in salinity and lake level. In this way such habitats differ from permanent streams like Rio Sulor or Rio Tapachilqua. On the other hand, such larger streams may not contribute very much to the faunal diversity of the small freshwater biotopes found at the margins of the Sud Lipez lakes. It is clear that many aquatic invertebrates would not find in these small habitats sufficiently stable ecological conditions to establish themselves permanently. Such may be the case for example for the Simuliidae, Plecoptera, Trichoptera and Ephemeroptera present in the Rio Tapaquilcha.

The present study gives only a momentary picture of the benthic fauna of these lakes. Longer term studies of population dynamics, diversity and colonization patterns at one or a few lakes in relation to environmental change would be useful.

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