A. INVESTIGACIONES

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Some abiotic characteristics of shallow ponds included in an Andean peatland of the transitional desert of Chile

Algunas características abióticas de pozas superficiales interiores presentes en una vega altoandina del desierto transicional de Chile

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ABSTRACT

The study ponds are part of a peatland located in the Elqui river basin of the Andes. They turned out to be heliotropic (homoeothermic), mesotrophic and mesopoikilohaline microlimnotopes. The ponds showed high content of dissolved metals, mainly Ca (mean ~205 mg/l), Na (~60 mg/l), Mg (~60 mg/l) and K (~13 mg/l), and the inorganic non-metals sulfate (~976 mg/l), chloride (~34.2 mg/l), phosphate (~23 mg/l), bicarbonate (~11 mg/l) and nitrate (~3.3 mg/l). Excluding Hg, Se and nitrite, trace elements were represented by Al, As, Cd, CN, Cu, Cr, Fe, Ba, Be, Co, Zn, Mo, Ni, Pb, Li, Ag, and V. The cationic pattern of ponds was Ca > Na > Mg > K >Mn; whereas the anionic pattern was sulfate > chloride > phosphate > carbonate > Fl. Although we did not study, the hydrochemical characteristics of these water bodies seem to reflect the characteristics of the geological substrate of the mountains through which the water drains into the peatland.

Key words: Andean hydrochemistry, Andean wetlands, desert ponds, temporary ponds, saline ponds.

RESUMEN

Las pozas estudiadas forman parte de una vega ubicada en el piso altoandino de la hoya hidrográfica del río Elqui. Estas resultaron ser microlimnotopos heliotópicos (homeotérmicos), mesotróficos y mesopoikilohalinos. Las pozas mostraron niveles elevados de metales disueltos, principalmente Ca (promedio: ~205 mg/l), Na (~60 mg/l), Mg (~60 mg/l) y K (~13 mg/l), y los inorgánicos no metálicos sulfato (~976 mg/l), cloruro (~34,2 mg/l), fosfato (~23 mg/l), bicarbonato (~11 mg/l) y nitrato (~3,3 mg/l). Excluyendo Hg, Se y nitrito, las pozas presentaron niveles traza de Al, As total, Cd, CN, Cu, Cr, Fe, Ba, Be, Co, Zn, Mo, Ni, Pb, Li, Ag y V. El patrón catiónico de las pozas fue Ca > Na > Mg > K > Mn; a su vez, el patrón aniónico fue sulfato > cloruro > fosfato > carbonato > Fl. Aunque no fue estudiado por nosotros, las características hidroquímicas de estos cuerpos de agua parecen reflejar las características del sustrato geológico de las montañas por medio del que el agua fluye hacia la vega.

Palabras clave: *hidroquímica andina, humedales andinos, charcas desérticas, charcas temporales, charcas salinas.*

Introduction

The geological and geomorphologic heterogeneity of the highlands of the transitional desert of Chile create a mosaic of environmental conditions in which habitats with highly contrasting features develop. For instance, peatlands originate in areas where water accumulates or emerges to the surface (Squeo *et al.,* 2006). Contrasting with the arid surroundings, these landscape units provide good living conditions for animal and plant communities (Cepeda-Pizarro *et al*., 2006). Because of this, peatlands of the Andes transitional desert are considered spots of biodiversity. Nowadays, the possible effects of climate change and stress due to heavy water consumption by mining and the local human population have raised public concern about the well-being of these landscape units (Contreras, 2002; Souvignet *et al*., 2012).

A diverse array of environmental conditions of the highlands of the transitional desert are the main local factors shaping these peatlands as habitats

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(Squeo *et al.,* 2006). Ponds, both permanent and temporary, are characteristic landscape components of these peatlands (Coronel *et al.,* 2004). Given that they offer an array of microhabitats susceptible of being colonized and exploited by a diversity of small organisms, mainly insects in their larval stages (Cepeda-Pizarro & Pola, 2013), these aquatic habitats can contribute disproportionately to regional diversity (Williams, 1999). Nevertheless, water quality is a matter of adaptation and survival for this type of organism (Coronel *et al*., 2007). Although some information is available about the physical and chemical characteristics of ponds in the northern Andes (e.g., López *et al*., 1999; Risacher *et al.* 2002, 2003), little is known about the abiotic conditions of ponds located in the Andean transitional desert. Consequently, the aims of this study were to (1) describe the ponds in terms of their main physical and chemical attributes, and (2) compare their characteristics with those of ponds found in the Andes further north.

Materials and Methods

Study site and ponds

The present study was conducted in a peatland locally referred to as "vega Tambo-Puquíos" (VTP hereafter), located in the high-Andean section of the Elqui river basin (Figure 1). The VTP is located in a narrow valley, at 3850-4000 mamsl. It has an extension of ~6 km and a surface area of ~10 km^2. It derives its water from small arroyos and rivulets that flow down slope from the surrounding mountains, from its own snow cover formed during winter and from subterranean water. The VTP is flat in most sectors, with a micro-topographic pattern of vegetation formed by hassocks and hummocks. In other sectors, it is narrow and discontinuous. The aquatic habitats are a rivulet (the Tambo rivulet), water linked to its peat matrix and the underlying mineral soil, and a series of small and shallow ponds, most of them temporary (PQP henceforth).

Physical and chemical analysis

The study is based on the analysis of four PQPs (Figure 2). They had a surface area ranging from 50 to 1250 m^2 and a depth of 0.3 to 0.5 m (Figure 3). The physical parameters examined were total hardness, electrical conductivity, turbidity, alkalinity, total dissolved solids, total suspended solids and total solids. The chemical parameters were pH, dissolved metals, inorganic nonmetallic ions and the following trace-elements: Al, total As, Ba, Cu, B, Cd, Co, Cr, Fe, Pb, Li, Ni, Zn, and CN. Monitoring of these

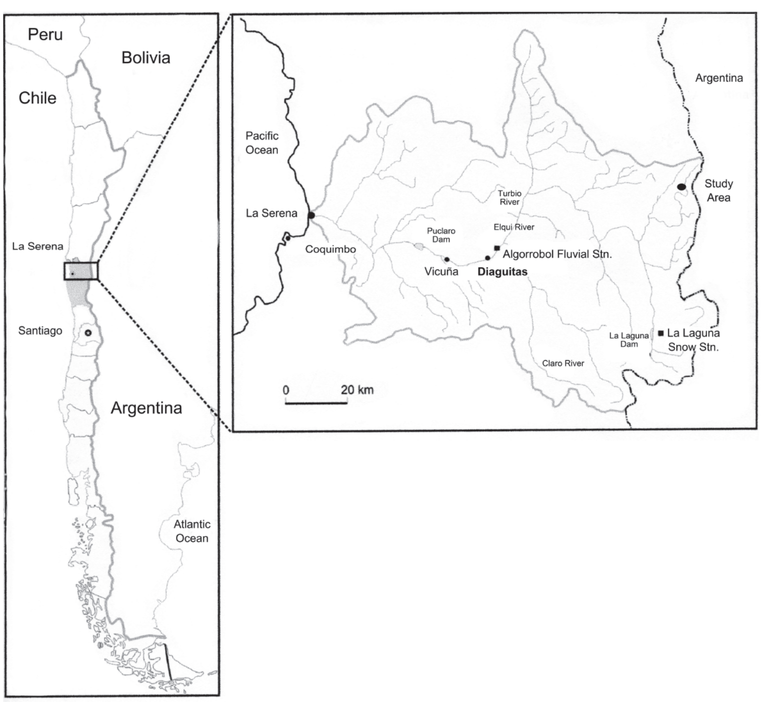

Figure 1. Geographic location of study area in the Elqui river basin (Chile).

Figura 2. General view of study peatland (Tambo-Puquios peatland, 3850 mamsl). The dark parches are shallow ponds included in it. The clear spots in the peatland and its margins are sulfate crusts.

Figura 3. A close up of study pond Nº 1, with sulfate deposits on its margins.

parameters was done in accordance with Chilean environmental regulations (CONAMA, 2000). Water sampling was performed during three consecutive summers (January or February). The samples were taken from the surface (0.0-0.2 m). Both sampling and chemical analyses were conducted out by a specialized contractor (SITAC, 2001). The analytical chemical techniques were standard and are fully described in APHA *et al.* (1985). The comparisons with ponds found in the Andes further north were based on published data.

Results and Discussion

In general, the water of the PQPs was hard (mean ~834.0 mg/l $CaCO_3$ equivalent) and transparent (~9.0 NTU), with a rather small fraction of total suspended solids (7%) and electrical conductivity of ~1678.0 µS/cm. On average the pond water was slightly alkaline (i. e. pH ~8.5; ~131.0 mg $CaCO_3$/l), with a dissolved O_2 content of ~10.0 mg/l (Table 1). The dominant metal ions were Ca, Na, Mg, and K. The dominant inorganic non-metals ions were sulfate, chloride, phosphate, and bicarbonate. The content of sulfate + Ca accounted for 96% of total dissolved solids. The surveillance detected the presence of Al, total As, Ba, Be, B, Cd, Co, total Cr, Fe, Pb, Li, total Mn, Mo, Ni, Ag, V, and Zn; but no Hg, Se or nitrite. The sequence of content of these trace-elements was B > Li > Al = Ba > As = Fe > Cr = Ni > Co > Pb > Cu > Cd = Zn > CN (Tables 2, 3).

Table 1. Mean (± se; n=4) of some physical and chemical parameters of shallow ponds of the Andes transitional desert of Chile.

Parameter*	mean ± se
1. Physical	
EC (µS/cm at 25 ºC)	1678.0 ± 0.2
TH (mg/l $CaCO_3$)	834.3 ± 85.0
TDS (180 ºC)	1229.5 ± 0.0
TSS (105 ºC)	127.7 ± 23.1
TS (105 ºC)	1806.0 ± 134.0
TUR (ntu)	8.9 ± 4.2
2. Chemical	
pH (at 22.5 ºC)	8.5 ± 0.5
Dissolved O_2	9.7 ± 0.0

*In this and following tables, numbers are expressed in mg/l except when indicated.

Table 2. Mean content (± se; n=4) of dissolved metals and trace elements in Andean shallow ponds of the transitional desert of Chile. Units as in Table 1.

Parameter	mean ± se
Al	0.5 ± 0.0
Total As	0.3 ± 0.0
Ba	0.5 ± 0.0
Be	0.1 ± 0.0
B	1.9 ± 0.0
Cd	0.01 ± 0.0
Ca	204.8 ± 45.7
Co	0.04 ± 0.0
Total Cr	0.1 ± 0.0
Cu	0.02 ± 0.0
Fe	0.3 ± 0.0
Pb	0.03 ± 0.0
Li	0.8 ± 0.0
Mg	59.7 ± 0.0
Total Mn	2.4 ± 0.0
Hg	0.00 ± 0.0
Mo	0.01 ± 0.0
Ni	0.05 ± 0.0
K	12.8 ± 3.6
Se	0.00 ± 0.0
Ag	0.01 ± 0.0
Na	159.5 ± 0.0
Na (%)	47.5 ± 0.0
V	0.01±0.0
Zn	0.01±0.0

Table 3. Mean content (± se; n=4) of inorganic non -metals in Andean shallow ponds of the transitional desert of Chile.

Parameter	mean ± se
Alkalinity (mg $CaCO_3$/l)	130.9 ± 19.9
Chloride (mg/l Cl-)	34.2 ± 0.0
Total CN	0.01 ± 0.0
Fluoride (mg/l F-)	1.4 ± 0.3
Bicarbonate (mg $CaCO_3$/l)	10.9 ± 4.6
Nitrate (mg N/l)	3.3 ± 2.6
Nitrite (mg N/l)	0.0 ± 0.0
Phosphate	22.4 ± 30.9
Sulfate	975.6 ± 36.3

A remarkable renaissance in the study of pond ecology has taken place in the last decades (Cereghino *et al.,* 2008); however, this assertion does not fully apply to mountain aquatic ecosystems. In the case of wetlands, the attention to conservation of large-scale systems has led to a general neglect of small-scale landscape elements such as pools and ponds, especially those of arid lands (Williams, 1999). From a typological viewpoint, the study ponds are heliotopic, mesotrophic, and mesopoikilohaline microlimnotopes. Their thermal stratification is monomictic, with few degrees of temperature difference between surface and bottom (Ringuelet, 1962). Water overturn is achieved by the frequent strong winds and convective currents that occur during nocturnal cooling (Cepeda-Pizarro & Novoa, 2006). The characteristics of their water are in between those of freshwater ponds and those truly saline. The water is hard and very close to the inferior limit for brackish water.

Compared to data reported in the literature for natural lentic freshwaters (e. g., Chapman, 1996), the study ponds are very high in phosphate, Ca and sulfate content, and high in fluoride, Fe, K, Mg, Cl, nitrate and total suspended solids, but lower in bicarbonate and CN content. Clearly, these chemical characteristics constrain the existence of biota as compared to water-bodies of better quality found in close basins (Ginocchio *et al.*, 2008). Compared to data reported in the literature, the water of the study ponds is alkaline and higher in electrical conductivity, dissolved O_2 and sulfate content than the water of lentic habitats found in Chile further north; but lower in the content of dissolved metals, non-metals and trace-elements (Tables 4 through 7). In turn, salinity, as measured by TDS, is at the low margin of this range (Table 8). The greater variability of the hydrochemical characteristics of the northern ponds compared to the ones studied in this work is clear in this table. This high intra-site variability seems to be frequent in water bodies of arid ecosystems, as previously reported from field work (e.g., López *et al*., 1999; Risacher *et al*., 2002, 2003; Coronel *et al*., 2004).

The cationic pattern of the study ponds is Ca>Na>Mg>K>Mn. This pattern is different than those recorded in highland meadows of central Chile (Ginocchio *et al*., 2008) and in ponds of the Gorbea salt flat (Risacher *et al.,* 2002), Llamará (Garcés *et al.* 1998) and Ignorado (Risacher *et al*., 2002). The Mg/Ca index of the study ponds is ~0.29, a much lower value that the ones reported from more northern ponds (Garcés *et al.,* 1999; López *et al*., 1999; Risacher *et al.,* 2002; Demergasso *et al.,* 2003). In turn, the (Mg+Ca)/(Na+K) index is close

Table 4. Mean content or range of some hydrochemical parameters of Andean ponds. Units as in former tables.

Site or location	pH	EC	Alkalinity	dO_2	Reference
This site	8.2-8.9	1635.0	116.8-145.0	9.2-10.5	This study
High alpine meadows (Central-Chile)	5.6-7.6	380-700.0		–	Ginocchio *et al.* (2008)
Salar de Llamará (Atacama Desert)	7.5-8.2	20-5110.0	–	–	Demargaso *et al*. (2003)
Salar de Llamará (Atacama Desert)	7.1-8.3	–	–	–	Garcés *et al.* (1998)
Salar de Llamará (Atacama Desert)	7.0-8.3	–	–	–	López *et al*. (1999)
Salar de Gorbea (Northern Andes of Chile)	1.3-7.2	–	–	0.32-5.8	Risacher *et al.* (2002)
Salar de Ignorado (Northern Andes of Chile)	2.7-3.9	–	–	3.8-8.6	Risacher *et al.* (2002)
Cordillera de Tunari (Bolivian Andes)	4.9-9.7	5.3-238.0	0-31.2	3.4-11.6	Coronel *et al.* (2004)

–: unavailable data.

Table 5. Range for dissolved metals in Andean ponds. Units as in former tables.

Site or location	Ca	Mg	K	Na	Mn	Reference
Tambo-Puquíos site	162.7-253.3	58.3-61.1	10.2-17.0	147.5-171.5	1.5-6.0	This study
Salar de Llamará	741.1-1120.0	534-3063.0	534-3063	9919.7-74976.3	–	Demargaso *et al*. (2003)
Salar de Llamará	332.6-910.0	141-1799	222-4066	7471-113473.0	–	López *et al*. (1999
Salar de Gorbea	200.3-1050.0	9.7-27956	43-5786	253-51035	3.3-489.0	Risacher *et al.* (2002)
Salar de Ignorado	469-529	182-5761.0	86-4027	301.1-13126	2.2-93.4	Risacher *et al.* (2002)
Cordillera de Tunari	0.5-9.6	0-6.3	0.1-1.5	0.1.-5.3	–	Coronel *et al*. (2004)

–: unavailable data.

Table 6. Content of dissolved inorganic nonmetals in Andean ponds*. Units as in former tables.

Site or location	Cl	SO_4	NO_3	PO_4	HCO_3	Reference
This site	27.7-40.7	940.2-1013.2	1.4-5.4	0.6-44.3	7.6-14.2	This study
Salar de Llamará	381-2674	89-507	–	–	234-1520	Demargaso *et al*. (2003)
Salar de Llamará	304-4021	61-603.4	–	–	1.8-4.7	López *et al*. (1999)
Salar de Gorbea	3.4-3490	5.2-893	–	–	–	Risacher *et al.* (2002)
Salar de Ignorado	4-141	28.6-683	–	–	–	Risacher *et al. (*2002)
Cordillera de Tunari	0.3-7.1	0.6-114.6	0-0.4	0.01-0.63	–	Coronel *et al.* (2004)

–: unavailable data.

Table 7. Mean or range for dissolved trace elements in Andean temporary ponds.

Site	Al	As	Ba	Cu	B	Cd	Co	Cr	Fe	Pb	Li	Ni	Zn	CN	Reference
This site	0.5	0.3	0.5	0.02	1.8-2.0	0.01	0.04								This study
Salar de Llamará	–	–	–	–	9.7-102.0	–	–	0.1	0.3	und	0.7-0.9	0.1	0.01	0.005	López *et al.* (1999).
Salar de Gorbea	2.4-4560.0	0.4-10.5	–	–	5.4-1610	–	–	–	–	–	2.0-33.8	–	–	–	Risacher *et al*. (2002).
Salar de Ignorado	18.9-2919.0	0.4	–	–	3.2-193.5	–	–	–	0.1-145.0	-	0.34-123.3	–	0.3-52.3	–	Risacher *et al.* (2002).

-: not reported; und: undetected.

Table 8. TDS contents in some Andean ponds of northern Chile (range of altitude: 3000-3950 m asl). Units as in former tables.

Site or location	Altitude (m asl)	TDS (mg/l)
This site (pond water)	3850	1229.5
This site (peat water)	3930	471-654
Gorbea salt flat (Northern Andes of Chile)	3950	2850-297000
del Huasco salt flat (Northern Andes of Chile)	3778	108-113093
Coposa salt flat (Northern Andes of Chile)	3730	119-330671
Carcote salt flat (Northern Andes of Chile)	3690	88-335536
Ascotán salt flat (Northern Andes of Chile)	3716	89-119853
Aguas Calientes 3 salt flat (Northern Andes of Chile)	3950	2491-25150
Capur salt flat (Northern Andes of Chile)	3950	6589-221804
Aguas Calientes 4 salt flat (Northern Andes of Chile)	3665	851-341759
Pajonales salt flat (Northern Andes of Chile)	3537	11728-246674
La Azufrera salt flat (Northern Andes of Chile)	3580	548-23473
Agua Amarg asalt flat (Northern Andes of Chile)	3558	7656-196672
Aguilar salt flat (Northern Andes of Chile)	3320	177044-334882
La Isla salt flat (Northern Andes of Chile)	3950	6229-329693
Las Parinas salt flat (Northern Andes of Chile)	3987	8907-333942
Grande salt flat (Northern Andes of Chile)	3950	8277-129707
Infieles salt flat (Northern Andes of Chile)	3520	1677-318744
La Laguna saltflat (Northern Andes of Chile)	3494	3288-20430
Pedernales salt flat (Northern Andes of Chile)	3370	85-326745
Maricunga salt flat (Northern Andes of Chile)	3760	144-331453

*Sources: this study; Risacher *et al.* (2003); Echaniz *et al.* (2006).

to those found in ponds of the Gorbea and Ignorado salt flats (i.e. 0.12-1.30) (Risacher *et al*., 2002). The anionic pattern of the study ponds is sulfate > Cl > phosphate > carbonate >Fl, similar to that reported from ponds of the Gorbea and Ignorado salt flats (Risacher *et al.,* 2002), but different than the one observed in the Llamará site due to the dominance of chloride in the latter (López *et al*., 1999). In turn, the study ponds are lower in content of trace elements compared to salt flat ponds of northern Chile (Table 7), but have higher concentrations compared to natural fresh waters (e.g., Chapman, 1996).

The geochemical properties of the surrounding mountains can play an important role in defining the hydrochemical features of Andean water bodies, and thus, in the biota to be found in them (López *et al.,* 1999; Risacher *et al*., 2002, 2003; Boschetti *et al.,* 2007; Cooper *et al*., 2010; Alvial *et al*., 2013). For instance, the abundance of native sulfur leads to sulfate-rich inflow waters, which in turn produce by evaporative concentration sulfate-rich ponds (see Figures 2-3). As expected, the hydrochemistry of the study ponds is responding to this pattern, as the volume of sulfur, sulfides and sulfates is considerable and hydrothermal mineralization is quite active (Veit, 1993).

Conclusions

The study ponds are somewhere in between freshwater and truly saline ponds. Their water quality is very close to the inferior limit for brackish water. Because of their alkaline condition, they are insensitive to acidification. The ponds show a clear transition from north to south compared to high alpine meadows of central Chile and with ponds from northern Chile. Compared to data reported in the literature for natural lentic freshwaters, the study ponds are very high in phosphate and sulfate content, high in fluoride, Na, Fe, K, Mg, chloride and nitrate content, and low in bicarbonate and CN. Compared to ponds from northern Chile, except for sulfate they are lower in the content of most dissolved metals, inorganic non-metals, and trace-elements. Apparently, the water chemistry of these ponds is related to the geological environment of the surrounding mountains.

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