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Distribution and seasonal fluctuations in the aquatic biodiversity of the southern Altiplano

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ABSTRACT

We compared the distribution and seasonal fluctuations in the aquatic biota in relation to chemical and physical water variables in the Altiplano watersheds of the Ascotán, Carcote and Huasco salars; Chungará and Cotacotani lakes; Isluga and Lauca Rivers and the Parinacota wetland. We sampled during the austral autumn–winter of 2006 and in the spring–summer of 2006–2007, using three sampling stations for each system. We used canonical correspondence analysis to establish relations between frequency of taxa and environmental variables.

We demonstrate that the structure and composition of the aquatic biota in humid areas of the Altiplano is determined by physical and chemical variables of the water. The most relevant one is total nitrogen, which is also the limiting nutrient for phytoplankton production in tropical systems.

Benthos and zooplankton showed significant associations with the set of environmental variables (Monte Carlo test, $p<0.05$); however, the association was not significant for phytoplankton. Lake Chungará showed the greatest variation in composition and abundance of zooplankton between autumn-winter and spring-summer, while in the Huasco salar the physical and chemical characteristics were related to the composition and abundance of the benthonic fauna. Thus, changes in the water volume of these systems would have repercussions in chemical and physical variables, altering the species assemblage and possibly the efficiency and stability of ecosystem functions.

Introduction

The Altiplano of the Andes Range, which extends from 14° to 22°S latitude, corresponds orographically to an extensive intermountain depression at an altitude above 4000 m; this elevation was reached due to tectonic activity during the Pliocene and the beginning of the Pleistocene (Lavenu 1991; Placzek et al. 2006). The area receives little annual rainfall, which comes mainly from occasional storms from the Amazon basin which manage to cross the inner range. Its drainage basin is one of the most arid on the planet; this hyper-arid condition dates from the Miocene (Alpers and Brimhall 1988). During the Quaternary (1.8 m years bp), the Altiplano was characterized by alternating humid and dry periods, shown by the existence of paleolakes of different depth and extension, different from those present today (Placzek et al. 2006). The SW region of the Altiplano (17°–22°S) or southern Altiplano is characterized by closed endorrheic basins with greater evaporation than precipitation. The salt lakes of the southern Altiplano are considered to be the remnants of the extensive lakes that once occupied the high plains. More recently, during the Quaternary, the region was subject to intense volcanic and sedimentary activity, which affected the lacustrine systems, converting them in evaporating drainages of different sizes. The limnic systems developed since the end of the Pleistocene vary from fresh water systems to lakes and salt lakes with high levels of sodium, chlorides and sulfates (Vila and Muhlhauser 1987; Risarcher et al. 2003). This has produced aquatic systems with physical and chemical characteristics very much dependent upon water availability (Chong 1988; Keller and Soto 1998; Risarcher et al. 2003).

It has been postulated that owing to the repeated extensions and contractions of the Altiplano lakes, their aquatic organisms have been submitted to drastic variations, both in water level and salt composition. The current period is characterized by a geographic fragmentation of the humid environments, generating lakes and salars scattered over the former area of the Altiplano paleolakes. The past and present history of the Altiplano has produced ecosystems with a high degree of endemism (Veloso

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and Bustos-Obregón 1982; Jaksic et al. 1997; Rundel and Palma 2000; Vargas et al. 2004). However, the increasing demands for water from mining and other industries and from urban centers, added to the perspective of aridization and shortage of water resources due to long-term climatic changes which are currently accelerating, put the dynamics and functioning of these wetlands at risk (Romero et al. 1997), and consequently the valuable biological and cultural patrimony which they house. It is likely that both water quality and quantity determine the biological diversity of wetland systems in the southern Altiplano, thus changes may influence the distribution and even the maintenance of the biota in these systems. Information about the systematics and ecology of the aquatic species of the southern Altiplano is scarce, and mostly restricted to contributions with a strong typological orientation. There is very little information about biodiversity, which makes it difficult to generate hypotheses about the functioning of these systems. Thus the objectives of the present contribution are: (a) provide basic information about the distribution and seasonal abundance of the aquatic biota; and (b) relate the variation of the biota in these systems to physical and chemical water variables.

Materials and methods

Study area

We studied eight aquatic systems representative of the Chilean Altiplano, located between 17° and 22°S. The systems studied were the Ascotán, Carcote and Huasco salars; Chungará and Cotacotani lakes; Isluga and Lauca rivers and the Parinacota wetland (Fig. 1). Only two of these systems are in protected areas: Lake Chungará is in the Lauca National Park, a UNESCO Biosphere Reserve and Huasco salar is a Ramsar site. Table 1 gives the UTM coordinates and altitude of the mentioned wetlands.

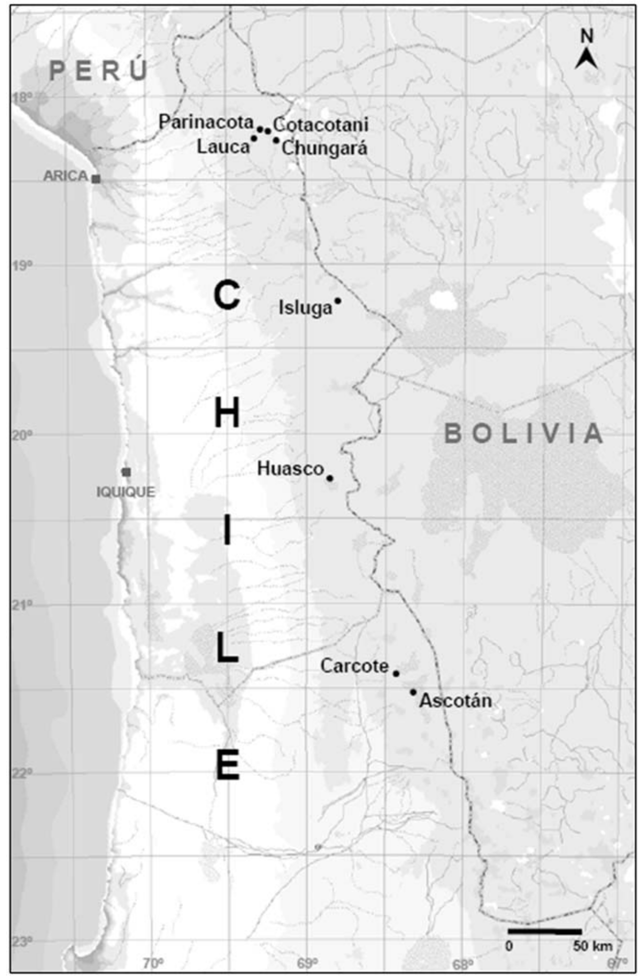

Fig. 1. Geographic location of the studied wetlands.

Determination of physical and chemical variables, and biological components

Since the altiplanic systems have different weather seasonality, samples were taken during the dry (autumn–winter) and wet periods (spring–summer). During December to February, the region presents the altiplanic winter which is characterized by intense rains.

In order to analyze the physical and chemical quality of the water and their seasonal changes, we sampled in 2006 and 2007, in dry and wet periods, three stations in each system. In each site we measured temperature with a Hanna Instruments digital thermometer (0.1° precision), conductivity with a Hanna conductivimeter, salinity with a WTW salinometer, pH with a WTW potentiometer and dissolved oxygen using Winkler's method. Water samples for total alkalinity, N/nitrates, P/phosphates and sulfates were kept cold until the return to the laboratory, where they were analyzed in a Shimadzu spectrophotometer using standard methodology. Ca, Mg, Na and K were measured by atomic absorption, ATI UNICAM.

For the analysis of the biological components, phytoplankton samples were taken with Van Dorn bottles and zooplankton with a 100 μm zooplankton net. Phytoplankton was fixed with Lugol and analyzed qualitatively and quantitatively using an inverted microscope according to Utermöhl (1958). The benthic fauna was collected quantitatively with a 500 μm Surber net. In the laboratory, zooplankton and benthic samples were separated, analyzed and determined to the level of species, genus or family using a standard method.

Table 1
Localization, UTM coordinates UTM and altitudes of wetlands of the Chilean Altiplano (adapted from Castro, 2007).

Wetland	Location	UTM	Altitude (m)
Salar de Ascotán	Ascotán	7624000	3723
Salar de Carcote	Carcote	7646900	3700
Lago Chungará	Quebrada Plazuela	7976000	4600
Lagunas Cotacotani	Laguna Cotacotani	7988000	4550
Salar de Huasco	–	7794700	4150
Río Isluga	Ríos Arabilla	7871400	3850
Río Lauca	Río Lauca	7980000	4350
Parinacota	Río Lauca	7991500	4450

Generation of biodiversity matrices

Biodiversity matrices were constructed separately for each group (phytoplankton, zooplankton and benthos). Since some individuals could not be identified to the level of species, organisms were grouped at the genus level in each of the matrices, according to their frequencies in each of the systems and sampling periods.

Multivariate analysis

We used Canonical Correspondence Analysis (CCA, Ter Braak 1986) to examine the relations among frequency of taxa and environmental variables in the different sampling sites. This analysis extracts axes of continuous variation using frequencies of taxa and environmental variables, with the restriction that the axes are combinations of linear variables; it thus assumes that the relation between factors is linear (Ter Braak 1986). In this way, the frequency matrices for each group (phytoplankton, zooplankton and benthos) were directly related to the physical and chemical variables measured in each site. The statistical significance of the relations found were determined using Monte Carlo simulations with 1000 permutations (Manly 1991). The CCA and permutations were performed using the program CANOCO v.4.5 (Ter Braak and Smilauer 1998) for each of the groups considered.

Results

Carcote and Ascotán, with water which originates in springs, had constant temperatures, around 22 °C. The other systems had autumn–winter temperatures between 7 and 14 °C, and spring–summer between 14 and 17 °C. Conductivity oscillated between 500 and 3500 μS/cm. The saline content was dominated by chloride and sulfate anions, and with the exception of Río Lauca, the predominant cation in all systems was Na. The pH was basic in all systems and the saturation percentage of dissolved oxygen below 100%. The values of N and P indicate eutrophic environments with the exception of Lake Cotacotani, which had the highest concentration of sulfates, which reached 373 mg/l during autumn–winter.

A little more than half (52.6%) of the phytoplankton is composed of Bacillarophyceae; *Synedra* and *Navicula* were the most frequent genera in both sampling seasons. Chlorophyceae and Cyanophyceae were the most abundant families in spring–summer, but they were not found in the systems with high salinities. In general the frequency of Chrysophyceae was low in all systems and seasons.

The zooplankton was dominated by: copepods of the genus *Boeckella*, the Cladocera *Bosmina* y *Alona* and Rotifera. Ostracoda were present in the shallowest systems. The benthic fauna was dominated by *Australelmis* (Coleoptera, Elmidae) and Diptera Chironomidae larvae in both seasons in all systems.

Only the benthos and zooplankton had significant associations in the canonical correspondence analysis (Table 2) with the environmental variables studied ($p<0.05$ Monte Carlo test, Manly 1991). Figs. 2 and 3 show the bivariate plots, which illustrate the relations among the study sites and the environmental variables (vectors). The positions of the sites in the graph are determined by the weighted mean of the taxa present in them.

Table 2
Monte Carlo significance tests for the first canonical axis and all axes. NS indicates $P>0.05$.

	First canonical axis		All canonical axes	
	F-ratio	*P*-value	*F*-ratio	*P*-value
Phytoplankton	0.245	NS	0.767	NS
Zooplankton	3.914	0.0010	2.711	0.0010
Benthos	3.433	0.0140	3.116	0.0010

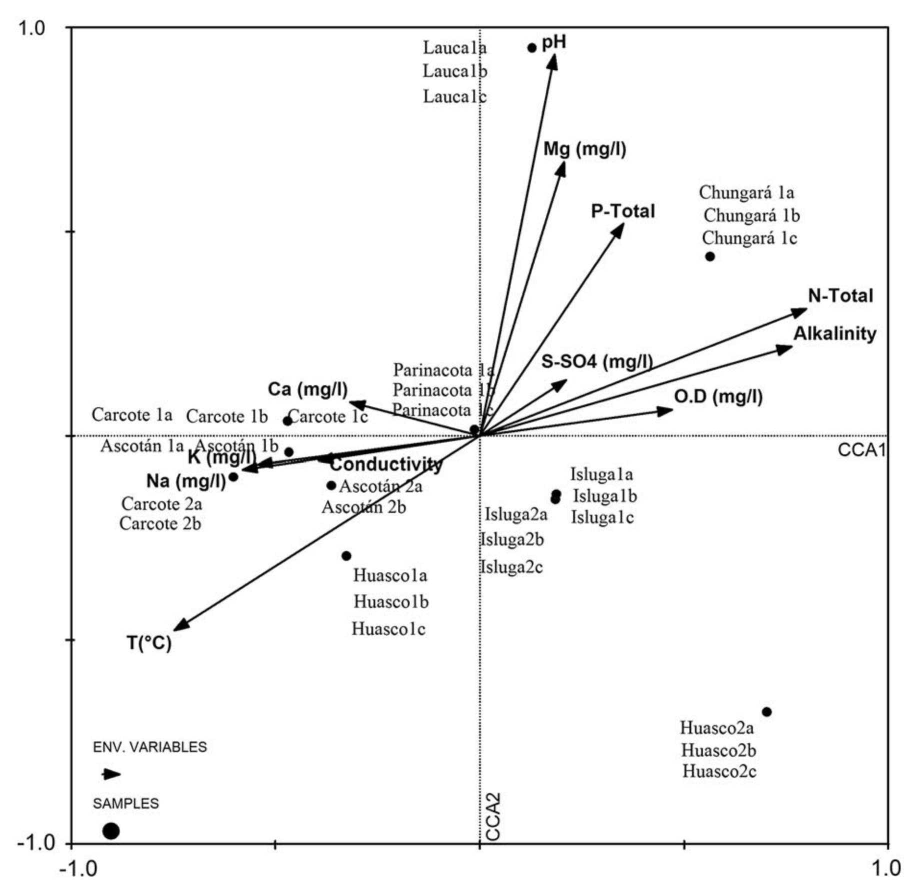

Fig. 2. Summary of the results of the canonical correspondence analysis for benthic fauna. The first two axes explain 43.7% of the total variance. The numbers and letters at the study sites correspond to the sampling period (1: autumn–winter; 2: spring–summer) and the different sampling stations in each locality.

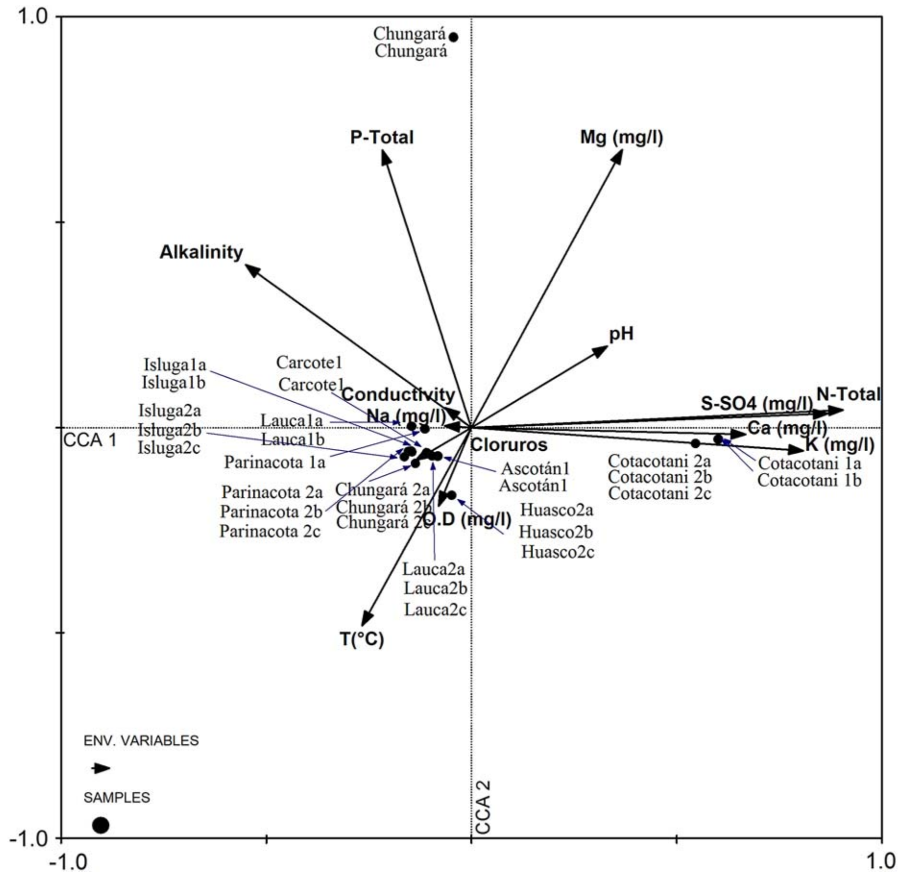

Fig. 3. Summary of the results of the canonical correspondence analysis for zooplankton. The first two axes explain 54.3% of the total variance. The numbers and letters at the study sites correspond to the sampling period (1: autumn–winter; 2: spring–summer) and the different sampling stations in each locality.

The first two axes of the canonical correspondence analysis of the benthos explained 43.7% of the total variation (Fig. 2). The first canonical axis, which explained 24.6% of the relation between taxa and environmental variables, was highly correlated with total nitrogen ($r = 0.78$), alkalinity ($r = 0.75$) and water temperature ($r = -0.73$), while the second axis was correlated with pH ($r = 0.91$). Lauca and Chungará lakes were clearly separated from each other and from the other localities, leaving a group formed by the watersheds of Ascotán and Carcote, and the Parinacota wetlands, and another formed by the Isluga river and the watershed of Huasco. There is a marked difference among seasons in the benthic fauna of Huasco, which is less apparent in Ascotán and Carcote, and imperceptible in Isluga River.

In the case of the zooplankton, the first two axes explained 54.3% of the total variance (Fig. 3). The first canonical axis, which explained 28.5% of the relation taxa – environmental variables, was highly correlated with total nitrogen ($r = 0.89$), sulfates ($r = 0.86$) and potassium ($r = 0.80$), while the second axis was correlated with magnesium ($r = 0.67$) and total phosphorous ($r = 0.67$). In the Fig. 3, Cotacotani and Chungará (autumn–winter) are clearly separated from the rest of the localities and from each other. The localities Carcote, Ascotán, Parinacota, Isluga, Lauca, Huasco and Chungará (spring–summer) are all close to each other. Chungará is the locality which presented the greatest variation in composition and abundance of zooplankton in autumn–winter compared to spring–summer.

Finally, the results for phytoplankton, which were not statistically significant, show that the first canonical axis, which represents 21.6% of the total variance, was highly correlated with calcium ($r = 0.96$), total nitrogen ($r = 0.90$), sulfates and potassium ($r = 0.88$). The second axis was correlated with chlorides ($r = -0.48$), water temperature ($r = -0.47$) and sodium ($r = -0.46$).

Discussion

In high elevation Andean ecosystems, the processes associated with the maintenance and perpetuation of limnic systems are very sensitive to changes produced by natural catastrophic events such as variations produced by intense precipitations which occur in a brief annual period known as the Altiplano winter (Aceituno 1997; Salazar 1997), and anthropic perturbations (Jaksic et al. 1997). Aspects related to the profundity of subterranean water, superficial current flow, estimated volume of reserve and its recharge rate have been suggested to be fundamental for the conservation of the systems (Messerli et al. 1997; Keller and Soto 1998). However, little attention has been paid to the composition and structure of the aquatic biological diversity and its association with environmental water variables. This information is relevant if we consider that the assemblage of species plays a fundamental role in the efficiency and stability of some ecosystem functions (Tilman and Downing 1994; Tilman et al. 1996).

The physical and chemical variables are quite labile in these systems both at a meso-scale (ENSO) and over seasons; factors which, according to the results presented here, significantly influence community structure, especially those related to changes in the salt content and water temperature. These changes are more significant in shallow lentic systems such as the Salar de Huasco, and when water volumes are at a minimum, even though they have high levels of nutrients. The N:P relation indicates a limitation of nitrogen, similar to that described for tropical systems (Wurtsbaugh et al. 1991).

The diatomaceous algae, present in all the studied systems and cited as abundant in the salars, are more tolerant to the high salinity found in these systems and are the base of the trophic chain, sustaining especially aquatic birds such as flamingos (Vargas et al. 2004). The phytoplankton did not show a significant association with the physical and chemical water quality, probably due to the fact that assemblages of microalgae have renewal cycles of greater than one year. Dorador et al. (2003) indicated that the species richness of microalgae is relatively low in these systems and that rather than being endemic, the dominant species, which are more or less cosmopolitan, present adaptations to the environmental conditions of each season. Oyanedel et al. (2008) also did not find for phytoplankton a distribution which could be explained by environmental variables. One of the explanations for this phenomenon suggests that the dispersion mechanisms of microalgae, in contrast to zooplankton, are not restricted to certain developmental stages, which favors the wide distribution of this group.

The benthic fauna and zooplankton showed a distribution which could be explained by the measured environmental variables. Both insects and zooplankton have annual growth cycles, which are reflected in the observed seasonal changes. With respect to the environmental variables relevant for the distribution and seasonality of the biota, the canonical correspondence analyses showed that the principal gradient for the three studied groups corresponds to total nitrogen. This nutrient limits the production of phytoplankton in lake Chungará (Dorador et al. 2003) and in other high-altitude Andean lakes (Wurtsbaugh et al. 1991), thus it is expected that it also limits the production in the aquatic systems considered in this contribution.

We observed a notable separation of lakes Cotacotani and Chungará from the rest of the localities as a function of the first and second axes, respectively (Fig. 3). This differentiation may be influenced by the composition of the zooplankton in these two bodies of water; Chungará showed the greatest variation in zooplankton composition and abundance over seasons, and the largest number of genera were registered in Cotacotani and Chungará. The genus *Daphnia* is notably dominant in Cotacotani (close to 70 individuals L^{-1}) in both sampling seasons. The qualitative differences in diversity between these two localities is fundamentally due to the absence of the smallest zooplankton genera of the phylum Rotifera in Cotacotani, which were present in Chungará, and to the differences in seasonality of occurrence of the genera in these lakes.

In terms of the biota temporal variation, the results show seasonality in the composition and abundance of the benthos and zooplankton for several localities. Specifically, benthic organisms show a marked seasonality in the Salar de Huasco, which showed great variation in its chemical composition, and some seasonality in Ascotán and Carcote. Also, the composition and abundance of zooplankton showed a marked seasonality in Lake Chungará. These variations between autumn–winter and spring–summer may be a result of the life cycles of both groups.

Our results show that the structure and composition of the aquatic biota in the wetlands of the southern Altiplano are determined by physical and chemical water variables. Thus, if the increasing demand for water modifies any of the variables mentioned as important, it will change the assemblage of species, and may reduce the efficiency and stability of ecosystem functions.

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