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Short Communication

A glimpse to Laguna de los Cisnes, a field laboratory and natural monument in the Chilean Patagonia

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ABSTRACT. Laguna de los Cisnes (53°15'S) is a remote and unusual salty lagoon located in the Chilean Patagonia, declared natural monument to protect bird diversity in the area, which could also serve as a natural laboratory to monitor climate change. This study reports basic water, sediment and plankton characteristics observed during a summer (December) sampling, when the lagoon was hypersaline (51 g L^{-1}), cold (9°C) and eutrophic, according to the high concentrations of phosphorous (0.30 ± 0.73 mg L^{-1}), nitrate (0.66 ± 0.14 mg L^{-1}) and chlorophyll-*a* (44.25 ± 2.52 µg L^{-1}). The microalgae *Spirogyra* sp. and the micro-crustacean *Artemia* are predominating plankton. Results are discussed in the context of the climatic conditions affecting this lagoon year-round.

Keywords: *Artemia*, plankton, algae, hydrographic parameters, salty lagoon, southern Chile.

Chile exhibits wide latitudinal (39° to 61°S) and altitudinal gradient (from sea level up 6,960 m above sea level in the Andes Mountains), along which hypersaline lakes and lagoons occur at very contrasting selective pressures (*e.g.*, day/night temperature variation, evaporation-rainfall rates) imposed by climatic conditions, the geo-morphology and the mineral composition of the endorheic basins in which they are located (Risarcher *et al*., 2003; Dorador *et al*., 2013). For example, there are inland hypersaline lakes in evaporitic basins in the highlands of the Atacama Desert, a sub- tropical and extremely dry desert (24°30'S, 69°15'W) (Demergasso *et al*., 2004; Dorador *et al*., 2013), and in the Patagonia, between 39 and 53°S, an arid and semi-humid climate, and steppe-like landscape (Campos *et al*., 1996). Patagonian hypersaline lagoons are special or atypical since conditions for maintaining brines (high salt concentration; up to 3 g L^{-1}), *i.e.*, high evaporation rates and low rainfall, are normally found in tropical and subtropical areas (Van Stappen, 2002). In fact, deep and oligotrophic freshwater lakes of glacier origin are common in Patagonia, whilst salty lagoons are relatively shallow and the exception. In the area conditions for high water evaporation and low rainfall are mainly observed in the dry season (December-March), but extremely windy conditions seem to play also a role in evaporation year-round (Saijo *et al.*, 1995; Campos *et al.*, 1996). Wind also tends to homogenize the water column. Another striking feature of salty lagoons in Patagonia is the high inter-annual variation in the water conditions, and the environmental situation, as reported by Campos *et al.* (1996) for Laguna Amarga, a mesohaline lagoon located (50°29'S, 73°45'W) at the entrance of Torres del Paine National Park. Other two salty lagoons are reported thus far close to the town Porvenir: Laguna de la Sal (Gajardo & Beristain, 2014) and Laguna de los Cisnes (Van Stappen, 2002; De los Ríos & Salgado, 2012). Owing to their unique condition and placement at southern latitudes, we highlight Laguna de los Cisnes (53°15'S, 70°22'W; Fig. 1), as a natural laboratory for biodiversity monitoring in a context of climate change.

This is relevant considering this 25.3 ha surface lagoon was declared natural monument by the Ministry of Agriculture (Supreme Decree, D.S. N°160) to protect black-neck swam *Cygnus melancoryphus* (Molina, 1782), which accounts for lagoon's name, one of the more than fifty bird species found in the area (Silva *et al.*, 2014). The lagoon is among the southernmost sites in the world containing the brine shrimp *Artemia*

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Figure 1. Laguna de los Cisnes, a natural monument where the black-neck swam and other bird species inhabit. The lagoon should be considered a natural laboratory to monitoring climate change in a context of climate change, as salinity fluctuations associated to rainfall determine the zooplankton and phytoplankton diversity. During summer in the southern hemisphere (December), the lagoon is heavily impacted by environmental conditions.

persimilis (Piccinelli & Prosdocimi, 1968), a species restricted to the Chilean and Argentinian Patagonia (Gajardo & Beardmore, 1993; Gajardo *et al*., 2002; Van Stappen, 2002) which is predated by flamingos and other water birds found in the lagoon associated to it. Owing to the ecosystemic relevance of Laguna de los Cisnes, this note reports water, sediment and planktonic composition obtained during a December (summer) *Artemia* sampling campaign.

Water, sediment and plankton samples were collected from five stations in December 2011, using a kayak, the results of physica and chemical variables showed not significant differences between sites ($P > 0.05$), due to the homogenizing effect of the wind factor in this shallow lagoon (maximum depth: 3 m). Chemical water composition was assessed following the standard methodology (APHA, 2005), sediment analyses were according to Sadzawka *et al*. (2006), whilst zooplankton was identified according to specialized literature. *Artemia persimilis* was identified according to species-specific traits (Gajardo *et al*., 2002). Microalgae identification was done with taxonomic keys, and chlorophyll-*a* biomass was quantified following Nusch (1980). The Shannon diversity (H'), Pielou's evenness (J') and Hill (N1) indexes were obtained using Primer v6 (Hedingham Gardens Roborough Plymouth PL6 7DX United Kingdom).

Laguna de los Cisnes is heavily impacted by west winds prevailing during December. During sampling in December the wind factor (18 knots) and UV Index (7.10) were amongst the highest registered in the local

Table 1. Average physical and chemical parameters obtained from the water column and sediments during December sampling (summer in the southern hemisphere) in five stations in Laguna de los Cisnes. Data are pooled as stations did not show significant differences (ANOVA, $P > 0.05$).

Water samples																			
Salinity (g L^{-1})	T (°C)	pH	Chl-*a* (µg L^{-1})	NO_3 (mg L^{-1})	P (mg L^{-1})	SO_4 (mg L^{-1})	Si (mg L^{-1})	Na (mg L^{-1})	Cl (mg L^{-1})	Cu (mg L^{-1})	Zn (mg L^{-1})	Fe (mg L^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})					
51.33 ± 2.31	9 ± 0.01	8.93 ± 0.12	44.25 ± 2.52	0.66 ± 0.14	0.3 ± 0.73	3959.33 ± 56.15	4.33 ± 1.53	190.02	60.10	0.31	0.02	0.24	40.32	943.58					
Sediment samples																			
P (%)	Ca (%)	Mg (%)	K (%)	Na (%)	Fe (mg L^{-1})	Mn (mg L^{-1})	Zn (mg L^{-1})	Cu (mg L^{-1})	B (mg L^{-1})	Al (mg L^{-1})	Ni (mg L^{-1})	$CaCO_3$ (mg L^{-1})							
0.22	18.3	2.36	0.03	0.86	1485	190	4.47	3.98	45	606	30	79.5							

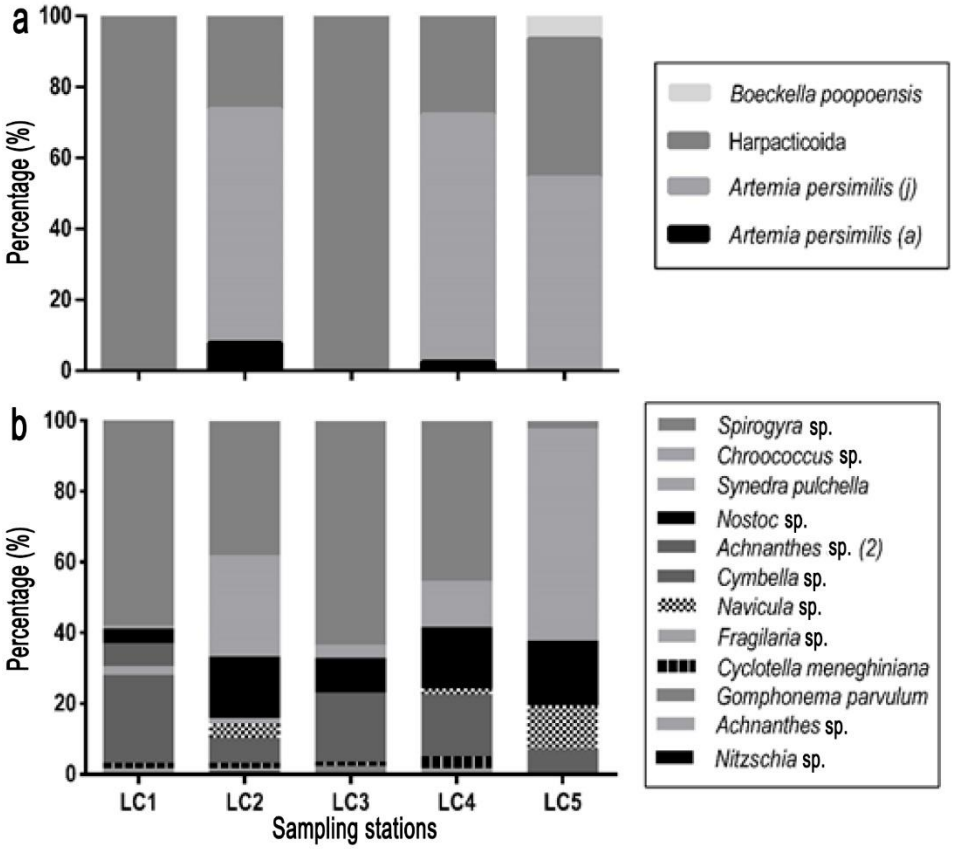

Figure 2. Relative abundance (%) of taxa: a) planktonic crustaceans (j: juvenile; a: adult) and b) microalgae, found in Laguna de los Cisnes during a December (summer) sampling.

meteorological station database (METEOCHILE, 2016). Indeed, a 14 years search (2001-2015) shows December as a critical month, exhibiting the highest UV Index (6.84 ± 0.63), and range of ambient temperatures, from 15.18 ± 1.31 to 6.25 ± 0.85°C. Water salt concentration was 51.33 ± 2.31 g L^{-1} which means the lagoon fits the definition of a hypersaline ecosystem (Hammer, 1986). Sulphates dominated the ionic water composition (Table 1), with the following anion abundance in the water column: SO_4 > Cl > NO_3. Cation abundance was: Mg > Na > Ca > Si > P> Cu> Zn. In the sediment, cation abundance was Fe > Al > Mn > Ni > Zn, plus $CaCO_3$, a somewhat similar finding made in northern salty lagoons (Risarcher *et al*., 2003; Dorador *et al*., 2013), and Laguna Amarga, which in addition to sulphate has carbonated water ionic composition (Saijo *et al*., 1995; Campos *et al*., 1996). The high sulphate concentration is likely to be explained by the continuous wash-out of oceanic rocks (Díaz *et al*., 1960; Campos *et al*., 1996).

Phosporus (0.30 ± 0.73 mg L^{-1}), nitrate (0.66 ± 0.14 mg L^{-1}) and Chl-*a* concentration (44.25 ± 2.52 µg L^{-1}) were high, as displayed in Table 1, which is characteristic of eutrophic conditions (OECD, 1982). De los Ríos & Soto (2009) also reported salty lakes in the area to be eutrophic as compared to freshwater lakes that are oligotrophic. The trophic condition and ionic composition of the water would be among the factors regulating planktonic communities in the lagoon. According to community indexes, crustacean biomass was high (8.3-75.7 ind L^{-1}), but species diversity low (H' < 1 ind $bits^{-1}$) and evenness high (J' < 0.9). As a matter of fact, *Artemia persimilis* was the dominant crustacean (59.2%), followed by two copepod types: harpacticoids (39.8%) and the halophilic calanoid *Boeckella poopoensis* Marsh, 1906 (0.98%) (Fig. 2a), both exhibiting wide salinity tolerance (5-90 g L^{-1}), but tend to predate on *Artemia* nauplii al low salt concentration (De los Ríos & Gajardo, 2010).

These copepods have been also reported in Laguna Amarga (De los Ríos & Gajardo, 2010), but tend to bloom in shallow freshwater ponds in the area (De los Ríos, 2005). The *Artemia*-calanoid coexistence is modulated by salinity fluctuation, but few systematic accounts on water conditions and zooplankton abundance are available for this lagoon. Judging from the rainfall database for December (14 years period), we could say that salinity should reach the highest and

lowest concentration in December and June, when rainfall is 50.6 mm and 27 mm, respectively (METEO CHILE, 2016). It is worth noting that Laguna de los Cisnes would be the southernmost salty lagoon with *Artemia* in the world, according to the location of sites reported to have the species in Argentinian Patagonia (Cohen, 2012). Microalgae abundance was high (4584.14-22597.31 cell mL^{-1}) and so was species diversity (<3 ind $bits^{-1}$), whilst evenness was low (J' < 0.8). A total of 12 species/genera were recorded (Fig. 2b), the most abundant being *Spirogyra* sp. (Chlorophyceae) with 46.8% of total abundance, *Bacillariophyceae* with 26.6% and *Chroococcus* sp. *y Nostoc* sp. (Cyano-phyceae) with 26.6%. In Laguna Amarga a similar number of algae species (13) was reported (Campos *et al*., 1996), though in January (1989) in this lagoon predominate (99.7%) Cyanophyceae species (*Anabaena* sp. and *Gloecapsa* sp.), the Bacillariophyceae *Gomphonema* sp. (0.2%) and the Cryptophyceae *Rhodomonas minuta* (0.1%) being less relevant. Instead, in the mesohaline Lago Chungará in the highlands of Andes Mountains in Atacama Desert the dominating algae taxa are Chlorophyceae and Bacillariophyceae, and no Cyanophyceae was found as in our study (Mühlhauser *et al*., 1995). Salinity is indeed a factor greatly affecting most microalgae species (Mirande & Tracanna, 2009; Stivaletta *et al*., 2011).

In summary, Laguna de los Cisnes is a natural monument with high bird diversity associated that may serve as a natural laboratory to monitor climate change, since its biotic and abiotic dynamics are heavily affected by environmental conditions year-round, December being a critical month in terms of selective pressures affecting plankton species. Salinity changes associated to rainfall affect plankton diversity, particularly *Artemia* abundance, the typical inhabitant of extremely salty lagoons, and such changes are likely to affect bird abundance as they feed on *Artemia*. In order to be able to monitor climate change, water biological and environmental characteristics of Laguna de los Cisnes need to be monitored on a more regular basis.

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