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Short Communication

Crustacean zooplankton species richness in Chilean lakes and ponds (23º-51ºS)

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ABSTRACT. Chilean inland-water ecosystems are characterized by their low species-level biodiversity. This study analyses available data on surface area, maximum depth, conductivity, chlorophyll-*a* concentration, and zooplankton crustacean species number in lakes and ponds between 23º and 51ºS. The study uses multiple regression analysis to identify the potential factors affecting the species number. The partial correlation analysis indicated a direct significant correlation between chlorophyll-*a* concentration and species number, whereas the multiple regression analysis indicated a direct significant response of species number to latitude and chlorophyll-*a* concentration. These results agree with findings from comparable ecosystems in Argentina and New Zealand.

Keywords: species richness, zooplankton, chlorophyll-*a*, conductivity, limnology, Chilean Patagonia.

Riqueza de especies de crustáceos zooplanctónicos en lagos y lagunas chilenas (23°-51ºS)

RESUMEN. Los ecosistemas acuáticos continentales chilenos se caracterizan por su baja riqueza de especies. Este estudio analiza los datos disponibles en área superficial, área, profundidad máxima, conductividad, concentración de clorofila-*a* y número de especies de crustáceos zooplanctónicos en lagos y lagunas entre 23º y 51°S. El estudio utiliza el análisis de regresión múltiple para identificar factores potenciales que afectan el número de especies. El análisis de correlaciones parciales indicó la existencia de una correlación directa entre concentración de clorofila-*a* y el número de especies, mientras que el análisis de regresión múltiple indicó una respuesta directa entre el número de especies con la latitud y la concentración de clorofila-*a*. Estos resultados concuerdan con hallazgos en ecosistemas comparables, de Argentina y Nueva Zelanda.

Palabras clave: riqueza de especies, zooplancton, clorofila-*a*, conductividad, limnología, Patagonia chilena.

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Species number of Chilean inland waters has been studied mainly in Patagonian latitudes (38º-51ºS). The low species-level biodiversity found there is attributed to oligotrophy associated with these southern latitudes (Campos, 1984; Soto & Zúñiga, 1991; De los Ríos-Escalante, 2010). However, in the north of Chile, species-level biodiversity and conductivity show an inverse relationship (De los Ríos-Escalante, 2010). Southern regions (45º-53ºS), present a broad range of environmental conditions, from oligotrophic lakes to shallow ponds, and they exhibit correspondingly wide trophic status (Soto *et al.*, 1994). These environmental conditions are also associated with variation in species number and in species associations (De los Ríos, 2008). For example, descriptions of Torres del Paine National Park (51ºS), indicate that the species number is regulated directly by chlorophyll concentration and inversely by conductivity (Soto & De los Ríos, 2006). These studies are supported by De los Ríos-Escalante (2010), who described the zooplankton assemblages in each hydrological region (north of Chile, central Chile, Patagonian lakes and Patagonian ponds), as separate geographical systems not as integrated data.

The role of trophy as a regulator of species number has been described for Chilean lakes (Soto & Zúñiga, 1991; Woelfl, 2007). This finding is in agreement with the general principles of community ecology that indicate direct associations between species number and ecosystem productivity (Jaksic, 2001). Nevertheless, results based on descriptions of northern Hemisphere lakes indicate a direct association between lake surface area and species number (Dodson, 1992; Dodson & Silva-Briano, 1996; Waide *et al.*, 2003; Willing *et al.*, 2003; Dodson *et al.*, 2005;

Pinto-Coelho *et al.*, 2005). These results do not agree with observations for Chilean lakes (Soto & Zúñiga, 1991; De los Ríos-Escalante, 2010). The present study analyses the literature data on species number in Chilean lakes to identify the chlorophyll-*a* concentration (as a proxy for trophy level) and latitude, surface, maximum depth and conductivity as potentially affecting species number.

Literature addressing crustacean zooplankton species number for Chilean lakes (Campos *et al.*, 1983, 1988, 1990, 1992a, 1992b; 1994a, 1994b; Schmidt-Araya & Zúñiga 1992; Villalobos, 1999; Villalobos *et al.*, 2003; Soto & De los Ríos, 2006; De los Ríos, 2008; De los Ríos & Roa, 2010; De los Ríos *et al.*, 2010; Table 1) was reviewed for this study. The species considered corresponded exclusively to pelagial species in agreement with revised information; littoral zooplankton was not considered because the information of these species assemblages is unclear (De los Ríos-Escalante, 2010). The Chilean continental territory has numerous lakes, but in the present study only 40 lakes that have available information were considered, unfortunately in the north of Chile and Patagonia or Patagonian plains, there are many lakes and ponds located mainly in mountain zones with access problems or in very isolated zones (De los Ríos-Escalante, 2010). The data correspond to sampling works in the southern summer (december-february), that is the period with maximum species co-occurrences (Campos *et al.*, 1983, 1988, 1990, 1992a, 1992b; 1994a, 1994b; Villalobos *et al.*, 2003); lakes samples were collected in the daytime, by vertical hauls of 30 m, using a plankton net of 20 cm diameter and 80 µm mesh size, whereas for ponds samples were collected by filtration of known volume (60-80 L) of water, through 80 µm mesh net; more details are specified in Soto & De los Ríos (2006) and De los Rios (2008). Data on trophic status, latitude, surface area, maximum depth, conductivity, chlorophyll-*a* concentration, species number and synonymy of species nomenclature were rectified, based on descriptions in De los Ríos-Escalante (2010). The data obtained on surface area, maximum depth, conductivity, chlorophyll-*a* (chl-*a*) concentration and species number were log10 transformed in accordance with the procedures used by Dodson (1991, 1992). These data were used in a correlation matrix by standard parametric correlation analysis (with a Pearson's correlation), and in multiple regression analysis. The goal of these statistical analyses was to identify the potential factors that could regulate the reported species numbers. The statistical analyses were conducted using Statistica 5.0 software.

Low species number were found in two northern Chilean sites (Miscanti and Miniques lagoons), that have high conductivity and in very oligotrophic lakes located at 51ºS (Del Toro, Nordsdenkjold, Pehoe and Sarmiento, Table 1). High species number was reported in oligo-mesotrophic lakes located between 38º-42ºS (Table 1). The correlation matrix showed direct significant correlations between surface area and maximum depth, and between chl-*a* concentration and species number (Table 2). Significant negative correlations were identified between conductivity and surface area, and between conductivity and maximum depth (Table 2). The best multiple regression model for the data was statistically significant (Table 2). Multiple regression analysis yielded a direct significant relationship of species number with latitude and chl-*a* concentration. The regression equation describing this relationship was ($P < 0.01$):

$$Y = 0.0255828 + 0.296787X_1 + 0.364055X_2$$

where:

Y = species number

X_1 = latitude

X_2 = log10 (chl-*a* concentration).

These results indicate that a high species number would be found in southern latitudes and high chl-*a* concentrations (Table 1), whereas a low species number would be found in northern latitudes, probably owing to the high salinity reported at these northern sites (Table 1).

The results of this study indicate that trophic status, expressed by chl-*a* concentration, plays a regulatory role. This finding agrees with descriptions in the literature of Chilean lakes and ponds along a wide geographical gradient (Soto & Zúñiga, 1991; De los Ríos-Escalante, 2010). The study cited used principal component analysis and indicated that low species numbers occurred in northern Chilean saline lakes. That study, identified as representative species for northern Chilean inland waters the halophilic copepod *Boeckella poopoensis* Marsh, 1906, that is widespread and inhabits between 5-90 g L^{-1} (Bayly, 1993). The high species number of central Chilean saline lakes (33ºS) is associated with mesotrophic or meso-eutrophic status (Schmid-Araya & Zúñiga, 1992). In northern Chile, there are many saline lakes with *Artemia* Leach, 1819 populations, unfortunately, with scanty ecological information (Zúñiga *et al.*, 1999). There is not enough information about central Chilean lakes and reservoirs as well (De los Ríos-Escalante, 2010).

However, the situation is different for the Chilean Patagonia (37º-31ºS). In the lakes of this region, chl-*a* concentration and species number are directly associated (Woelfl, 2007); species number is inversely correlated with latitude (Soto & Zúñiga, 1991; De los Ríos-Escalante, 2010), and chl–*a* concentration is

Table 1. Geographical location, surface area (km^2), maximum depth (Zmax, m), chlorophyll-*a* concentration (Chl-*a*, µg L^{-1}), conductivity (mS cm^{-1}) and species richness (SR) for the sites included in the present study.

Site	Geographical location	Surface area	Zmax	Chl-*a*	Conductivity	SR	Reference
Miscanti	23º44'S, 67º48' W	13.4	9	1.0	7.73	3	De los Ríos *et al.* (2010)
Miniques	23º44'S, 67º48' W	1.6	5	1.0	15.42	1	De los Ríos *et al.* (2010)
Rungue	33º00'S, 70º53' W	0.48	15	65.9	0.33	4	Schmid-Araya & Zúñiga (1992)
Peñuelas	33º10'S, 71º29'W	19.0	15	57.4	0.12	11	Schmid-Araya & Zúñiga (1992)
Negrita	39°15'S, 71°42'W	0.1	1	0.3	2.7	5	De los Ríos & Roa (2010)
De los Patos	39°15'S, 71°42'W	0.1	0.1	0.2	10.6	4	De los Ríos & Roa (2010)
Escondida	39°15'S, 71°42'W	0.1	0.1	0.7	12.4	5	De los Ríos & Roa (2010)
Seca	39°15'S, 71°42'W	0.1	0.1	0.5	12.3	5	De los Ríos & Roa (2010)
Negra	39°15'S, 71°42'W	0.1	0.1	0.5	0.7	2	De los Ríos & Roa (2010)
Bella	39°15'S, 71°42'W	0.1	0.1	0.2	0.7	2	De los Ríos & Roa (2010)
Los Pastos	39°15'S, 71°42'W	0.1	0.1	0.5	0.5	4	De los Ríos & Roa (2010)
Vaca Hundida	39°15'S, 71°42'W	0.1	0.1	1.2	136.0	4	De los Ríos & Roa (2010)
Villarrica	39°18'S, 72°07'W	175.8	185	0.4	0.06	7	Campos *et al.* (1983)
Pirihueico	39°50'S, 71°48'W	30.5	145	0.6	0.05	5	Wölfl (1996)
Riñihue	39°50'S, 72°20'W	77.5	323	1.2	0.05	7	Wölfl (1996)
Ranco	40º13'S, 70º22'W	442.6	199	0.8	0.07	9	Campos *et al.* (1992a)
Puyehue	40º40'S, 72º30'W	165.4	123	2.1	0.08	7	Campos *et al.* (1989)
Rupanco	40º50'S, 72º30'W	235.0	273	1.2	0.06	4	Campos *et al.* (1992b)
Llanquihue	41º08'S, 72º50'W	870.5	317	0.5	0.11	3	Campos *et al.* (1988)
Todos los Santos	41º08'S, 72º50'W	178.5	335	0.4	0.04	4	Campos *et al.* (1990)
Cucao	42º38'S, 74º40'W	10.6	25	3.4	156.85	5	Villalobos *et al.* (2003)
Huillinco	42º40'S, 73º57'W	19.1	47	2.7	27.33	7	Villalobos *et al.* (2003)
Tarahuin	42º43'S, 73º45'W	7.7	33	8.4	50.9	10	Villalobos *et al.* (2003)
Natri	42º47'S, 73º50'W	33.2	58	16.4	41.4	7	Villalobos *et al.* (2003)
Tepuhuieco	42º47'S, 73º58'W	14.3	25	3.6	30.2	7	Villalobos *et al.* (2003)
Los Palos	45º19'S, 72º42'W	59.0	5	0.8	0.02	4	Villalobos (1999)
Riesco	45º39'S, 72º20'W	14.7	130	0.9	0.02	4	Villalobos (1999)
Escondida	45º49'S, 72º40'W	43.0	7	0.5	0.01	5	Villalobos (1999)
Larga	51º01'S, 72º52'W	0.1	5	0.9	3.45	6	Soto & De los Ríos (2006)
Cisnes	51º01'S, 72º52'W	0.1	1	93.7	16.51	6	Soto & De los Ríos (2006)
Redonda	51º01'S, 72º54'W	0.1	3	2.3	1.49	8	Soto & De los Ríos (2006)
Juncos	51º01'S, 72º52'W	0.1	3	1.8	2.29	6	Soto & De los Ríos (2006)
Nordensjold	51º01'S, 72º56'W	25.0	200	0.3	0.13	2	Soto & De los Ríos (2006)
Paso de la Muerte	51º02'S, 72º54'W	0.1	3	10.0	0.8	7	Soto & De los Ríos (2006)
Jovito	51º02'S, 72º54'W	0.1	3	4.0	1.38	5	Soto & De los Ríos (2006)
Melliza Oeste	51º03'S, 72º57'W	0.13	25	3.2	0.66	8	Soto & De los Ríos (2006)
Melliza Este	51º03'S, 72º57'W	0.12	16	5.3	0.8	8	Soto & De los Ríos (2006)
Sarmiento	51º03'S, 72º37'W	86.0	312	0.3	0.85	5	Campos *et al.* (1994a)
Pehoe	51º07'S, 72º53'W	15.0	200	3.2	0.2	2	Soto & De los Ríos (2006)
Del Toro	51º12'S, 72º38'W	196.0	300	0.4	0.07	4	Campos *et al.* (1994b)

inversely associated with latitude (Soto, 2002). The latter association result from variation in mixing depth, which is directly associated with latitude (Soto, 2002). In this scenario, the mixing depth represents a physical limitation on phytoplankton activity due to light limitation of phytoplankton production (Soto, 2002). Nevertheless, in extreme southern Chile, in specific areas such as Torres del Paine National Park, there are basins containing ultraoligotrophic large lakes with low species number, as well as mesotrophic small lakes and ponds exhibiting broad conductivity gradients and high species numbers (Soto & De los

Table 2. Results of correlation matrix observed for data considered in the present study. In bold are indicate the significant values ($P < 0.05$). SR: species richness.

	log Area	log Zmax	log Chl-*a*	log Conductivity	log SR
Latitude	-0.115	0.173	0.019	-0.125	0.304
log Area		**0.836**	-0.217	**-0.471**	0.040
log Zmax			-0.066	**-0.423**	0.167
log Chl-*a*				0.290	**0.370**
log Conductivity					0.072

Ríos, 2006). This can explain the direct relationship between species number and latitude observed in the present study. Many of these lakes are located at low altitude above sea level (<500 m a.s.l), with the exception of northern Chilean lakes Miscanti and Miniques (3800 m a.s.l., De los Ríos-Escalante, 2010). Unfortunately, there are too few studies about high mountain lakes for comparison (De los Ríos-Escalante, 2010). These results indicate the existence of a geographical gradient along with environmental heterogeneity that affects the species diversity (De los Ríos-Escalante, 2010). These findings agree with similar results from the Northern Hemisphere (Waide *et al.,* 2003; Willing *et al.,* 2003).

These results are also in agreement with data from lakes and ponds of Argentina (Quirós & Drago, 1999). Argentinean Patagonia has lakes and ponds similar to those in Torres del Paine National Park (Soto & De los Ríos, 2006), namely large oligotrophic lakes and small mesotrophic and eutrophic lagoons and ponds (Modenutti *et al.*, 1998; Balseiro *et al.*, 2001). Furthermore, these results correspond with the ones from New Zealand lakes and ponds (Jeppensen *et al.,* 1997, 2000) and northern Hemisphere lakes, where trophic status is an important regulatory factor of species number (Dodson, 1992; Dodson & Silva Briano, 1996; Dodson *et al.,* 2000, 2005; Pinto-Coelho *et al.,* 2005; Karatayev *et al.,* 2008).

Lakes of North America and Europe exhibit a direct association between species number and surface area (Dodson, 1991, 1992; Dodson & Silva-Briano, 1996). However, this correlation is not observed in southern Chilean lakes (Soto & Zúñiga, 1991). In North America, species number is high in lakes whose maximum depth is between 200-300 m, whereas more shallow lakes exhibit decreased species number (Soto & Zúñiga, 1991). Pinto-Coelho *et al.* (2005) and Dodson *et al.* (2000), found a quadratic relationship between species number and primary productivity that is due to oxygen limitation because oxygen, in most productive lakes, can disappear for most of the night when zooplankton compete with bacteria and algae for oxygen (Dodson, 1992). This pattern has not been observed in Chilean lakes.

The Chilean lakes lack invertebrate predators in zooplankton (Soto & Zúñiga, 1991; Woelfl, 2007). Nevertheless another important factor in Argentinean and Chilean Patagonian lakes would be the effect of introduced wild salmonids (Soto *et al.,* 1994, 2006, 2007; Becker *et al.*, 2007; Pascual *et al.*, 2007; Arismendi *et al.*, 2009). These salmonids would affect species number by feeding on large-bodied species such as daphnid cladocerans and calanoid copepods (Modenutti *et al.*, 1998; Reissig *et al.*, 2006). Different conditions would occur in sites without salmonids and at which only native fishes of the genus *Galaxias* were present. These native and introduced fishes would feed on a broad range of zooplankton (Soto *et al.,* 1994), but these sites exhibit high species number despite the occurrence of fish predation on zooplankton (Soto & De los Ríos, 2006). Finally, sites without fishes exhibited high values of zooplankton biomass and species number because there are not exposed to zooplankton predators (Soto *et al.,* 1994; Soto & De los Ríos, 2006). These results do not agree with similar findings for the Argentinean Patagonian counterparts of these sites (Reissig *et al.*, 2006).

As a conclusion, the present study would indicate that the chl-*a* concentration would be the main regulatory factor of the species number, because it would have low species number under oligotrophic status, and latitude because at southern latitude there are sites with high species number.

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