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Short Communication

Macrophytes assemblages in mountain lakes of Huerquehue National Park (39ºS, Araucanía Region, Chile)

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ABSTRACT. The lakes studied (Tinquilco, Verde, Toro, Chico) are located in the Huerquehue National Park (39°08'S, 71°40'W), Chile. An inventory of the aquatic and riparian species was performed between December 2005 and March 2006. A null model analysis was done to determine the existence of regulatory factors of species associations, and the Jaccard index was applied to determine floristic similarities. Seventy-five species were identified. The greatest number (54) and highest percentage of introduced species (37%) occurred at Tinquilco Lake, placing it in the category of "high human disturbance". Verde Lake, on the other hand, presented the lowest number of species (21), and the percentage of introduced species did not exceed 20% in the other three lakes, which are considered to have "low human disturbance". The analysis of the null model revealed the presence of regulatory factors in one of the three simulations. However, in the other two simulations, the species associations appeared to be random, presumably because many species were repeated at the study sites. According to the Jaccard index, Tinquilco Lake is noticeably different from the other lakes, probably due to its transition from oligotrophy to mesotrophy.

Keywords: oligotrophy, mesotrophy, macrophytes, null model, lakes, Patagonia, Chile.

Ensambles de macrófitas en lagos de montaña del Parque Nacional Huerquehue (39°S, Región de la Araucanía, Chile)

RESUMEN. Los lagos estudiados (Tinquilco, Verde, Toro, Chico) se localizan en el Parque Nacional Huerquehue (39°08'S, 71°40'W). Entre diciembre de 2005 y marzo de 2006, se inventarió su flora acuática y ribereña. Para determinar la influencia de factores reguladores en las asociaciones de especies se aplicó un análisis de modelo nulo y para determinar similitudes florísticas se aplicó el índice de Jaccard. Se identificaron 75 especies, donde el mayor número (54) y el mayor porcentaje de especies introducidas (37%) se registró en el lago Tinquilco, por lo que se incluye en la categoría de "altamente intervenido"; mientras que el menor número de especies se registró en el lago Verde con 21, y el porcentaje de especies introducidas no superó el 20% en los otros tres lagos, por lo cual se consideran como "poco intervenidos". Los análisis del modelo nulo muestran la presencia de factores reguladores en una de las tres simulaciones, mientras que en las dos restantes se sugiere una asociación aleatoria de las especies, supuestamente explicada por la presencia repetida en los sitios. El índice Jaccard reveló que el Tinquilco es notablemente diferente a los otros lagos, cuya probable causa se relacionaría con la transición de oligotrofía a mesotrofía.

Palabras clave: oligotrofía, mesotrofía, macrófitas, modelos nulos, lagos, Patagonia, Chile.

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The Chilean lakes of the north Patagonia are characterized by their oligotrophy, due to the native forest and chemical composition of the soil of their basin that avoid the nutrient entry from the land to the water, mainly in unpolluted mountain zones (Soto, 2002; Steinhart *et al*., 2002). Nevertheless, an oligotrophy to mesotrophy transition has been observed in some lakes located mainly between 38 to 41°S, due to the replacing of the native forest of their basin by agricultural zones, towns and industries (Soto, 2002). One of the biotic components that can be an indicator of trophic status is the assemblage of macrophytes (Hauenstein *et al.*, 2002; Nagasaka, 2004; Li *et al*., 2009). We define macrophytes according to Ramírez & Stegmeier (1982). The macrophytes in Chilean inland waters have numerous endemic species (79.3%) and a low amount of introduced species (20.7%); there are endangered species that would need more studies about conservation topics (Hauenstein, 2006), specially if we consider that some Chilean lagoons close to coastal zones, and small stands of plants in the lakes have human intervention (Soto, 2002; Hauenstein *et al*., 2008), with the consequent alterations in macrophytes assemblages (Hauenstein *et al*., 2002; Ramírez & San Martín, 2006).

According to this point of view, the macropytes and riparian assemblages are not random, that means that the regulator factors are deterministic. The absence of regulator factors, this is random distribution in species co-occurrence, is the basis of null models; one of these models used presence and absence of species to determine the absence of deterministic factors as regulator of co-occurrence species (Gotelli, 2000; Tiho & Johens, 2007). These null models are more robust in comparison with deterministic models (Gotelli, 2000). The aim of the present study is applying a null model analysis based in a presence-absence species matrix for determining the absence regulator factors to explain species associations in macrophytes of lakes in Huerquehue National Park.

Between December 2005 to March 2006 we worked in four lakes of a mountainous zone with *Nothofagus alpina, N. pumilio, N. dombeyi* and *Araucaria araucana* forests: Tinquilco Lake, at the main access of Huerquehue National Park (39º10'00''S, 71º43'25''W; 763 m a.s.l); it receives many small streams from the mountains. One of these streams called Tinquilco, is the effluent of a network of at least three lakes located higher in the mountains, Verde (39º08'10''S, 71º42'33''W; 1254 m a.s.l), Toro (39º08'20''S, 71º42'33''W; 1245 m a.s.l) and Chico (39º08'21''S, 71º42'33''W; 1240 m a.s.l), which are connected to each other by small streams, these studied lakes are oligotrophic with chlorophyll concentrations of 1.6; 2.0; 1.5 and 1.9 gL^{-1} respectively (De los Ríos *et al.*, 2007).

The riparian and macrophyte species were collected and identified, according to Matthei (1995), Espinoza (1996) and Hoffmann *et al*. (1997); the scientific names updated by means of Zuloaga *et al*. (2008) and in the following page web: (http://www.ipni.org/). The taxonomical classification and the phytogeographical origin, according to Marticorena & Quezada (1985), and the helophytes and hydrophytes taxa, according to the classification of Ramírez & Stegmeier (1982) and Ramírez & San Martín (2006). The degree of human intervention was determined on the basis, according to the proposal of Hauenstein *et al*. (1988) and the scale of assessment proposed by González (2000), who used the phytogeographical origin (percentage relationship between native and the introduced species) to establish the degree of human disturbance of a specific area.

The comparison of the data set gathered is useful to test the hypothesis that species reported are non-randomly associated. For this, we use the "C score" index (Tiho & Johens, 2007), which determines the presence-absence co-occurrence based on presence - absence matrices for zooplankton species in the sample. According to Gotelli (2000) and Tiho & Johens (2007) the presence/absence matrix was analysed as follows: (a) fixed-fixed: in this algorithm, the row and the column sums of the original matrix are preserved. Thus, each random community contains the same amount of species as the original community (fixed column), and each specie occurs with the same frequency as in the original community (fixed row). In this case, it is not prone to type I errors (falsely rejecting the null hypothesis) and it has a good power for detecting the non-randomness (Gotelli, 2000; Tiho & Johens, 2007). (b) Fixed-equiprobable: in this simulation, only the row sums are fixed, whereas the columns are treated as equiprobable. This null model treats all the samples (columns) as equally suitable for all species (Tiho & Johens, 2007; Gotelli, 2000). (c) Fixed-proportional: in this algorithm, the total of species occurrence is maintained as in the original community, and the probability that a specie occurs in a sample (= column) is proportional to the total column for that sample (Gotelli, 2000; Tiho & Johens, 2007). The data were analysed with the Ecosim program version 7.0 (Gotelli & Entsminger, 2009). Finally, it was applied a Jaccard index for determining the similarities between the studied sites (Gotelli & Graves, 1996), this analysis was applied using the software Biodiversity Pro. 2.0.

The results of the floristic analysis revealed the presence of 75 species (74 vascular plants and one non vascular plant) and, in decreasing order, the lakes with more species were Tinquilco, Toro, Chico and Verde with 54; 28; 22 and 21 species respectively. Table 1 shows the complete and current catalogue. The more represented species are Magnoliopsida with 58% and Liliopsida with 37%. The total flora includes 5 classes, 32 families and 50 genus, with a different distribution between the lakes: four classes, 27 families and 45 genus were found in Tinquilco Lake, in Toro Lake, four classes, 22 families and 56 genus, in Chico Lake, three classes, 16 families and 19 genus, and finally in Verde Lake, three classes, 14 families and 18 genus (Table 1).

Table 1. Catalogue of macrophytes in four lakes of the Huerquehue National Park. X: presence, empty space: absence; N: native, I: introduced.

Tabla 1. Catálogo de macrófitas en cuatro lagos del Parque Nacional Huerquehue. X: presencia, espacio en blanco: ausencia; N: nativa, I: introducida.

Species	Family	Origin	Lake			
			Verde	Toro	Chico	Tinquilco
CHAROPHYCEAE						
Nitella sp.	Characeae	N		X		
SPHENOPSIDA						
Equisetum bogotense Kunth	Equisetaceae	N				X
FILICOPSIDA						
Blechnum penna-marina (Poir.) Kuhn	Blechnaceae	N		X	X	X
Isoetes savatieri Franch.	Isoetaceae	N	X	X	X	X
MAGNOLIOPSIDA						
Acaena ovalifolia Ruiz & Pav.	Rosaceae	N	X	X	X	
Anagallis alternifolia Cav.	Primulaceae	N	X			X
Anagallis arvensis L.	Primulaceae	I				X
Azara lanceolata Hook. f.	Flacourtiaceae	N		X		
Baccharis sp.	Asteraceae	N				X
Berberis sp.	Berberidaceae	N		X		
Callitriche palustris L.	Callitrichaceae	I		X	X	
Callitriche terrestris DC.	Callitrichaceae	N	X	X		
Drimys andina (Reiche) R.A. Rodr. & Quezada	Winteraceae	N		X		
Drimys winteri J.R. Forst. & G. Forst.	Winteraceae	N				X
Escallonia virgata Pers.	Escalloniaceae	N	X	X	X	X
Galium aparine L.	Rubiaceae	I	X		X	X
Geum magellanicum Lechler ex Sheutz	Rosaceae	N		X		
Gratiola peruviana L.	Scrophulariaceae	N				X
Gunnera magellanica Lam.	Gunneraceae	N	X	X	X	
Hydrocotyle chamaemorus Cham. & Schltdl.	Apiaceae	N	X		X	X
Hydrocotyle ranunculoides L.f.	Apiaceae	N		X		X
Hypochaeris radicata L.	Asteraceae	I				X
Lotus pedunculatus Cav.	Fabaceae	I	X	X		X
Mentha aquatica L.	Lamiaceae	I				X
Myosotis scorpioides L.	Boraginaceae	I				X
Myrceugenia exsucca O. Berg	Myrtaceae	N		X		X
Myriophyllum aquaticum (Vell.) Verdc.	Haloragaceae	N	X	X	X	X
Nasturtium officinale R.Br.	Brassicaceae	I			X	
Nothofagus pumilio (Poepp. & Endl.) Krasser	Fagaceae	N		X	X	
Oldenlandia salzmannii (DC.) Benth. & Hook. f.	Rubiaceae	N				X
Osmorhiza chilensis Hook. & Arn.	Apiaceae	N				X
Perezia pedicularifolia Less.	Asteraceae	N			X	
Plantago lanceolata L.	Plantaginaceae	I				X
Plantago major L.	Plantaginaceae	I	X			
Polygonum hydropiperoides Michx.	Polygonaceae	I				X
Potentilla anserina L.	Rosaceae	I				X
Prunella vulgaris L.	Lamiaceae	I		X		X
Ranunculus bonariensis Poir.	Ranunculaceae	N			X	
Ranunculus sp.	Ranunculaceae	I		X		X
Rubus constrictus Lefevrè & P. J. Müll.	Rosaceae	I				X
Rumex conglomeratus Murr.	Polygonaceae	N				X
Rumex crispus L.	Polygonaceae	I				X
Senecio fistulosus Poepp. ex Less.	Asteraceae	N	X		X	
Taraxacum officinale Weber ex F.H. Wigg.	*Asteraceae*	I				X

Taxonomical category / scientific name	Family	Origin	Lake			
			Verde	Toro	Chico	Tinquilco
Trifolium pratense L.	Fabaceae	I				X
Trifolium repens L.	Fabaceae	I				X
LILIOPSIDA						
Agrostis capillaris L.	Poaceae	I		X	X	X
Bromus sp.	Poaceae	N		X		
Carex decidua Boott	Cyperaceae	N	X	X	X	
Carex distenta Kunze ex Kunth	Cyperaceae	N		X		X
Carex inconspicua Steud.	Cyperaceae	N	X		X	X
Carex macloviana d'Urv.	Cyperaceae	N		X		X
Carex sp.	Cyperaceae	N			X	
Chusquea montana Phil. f. *montana*	Poaceae	N		X		
Cortaderia pilosa (d'Urv.) Hackel	Poaceae	N	X			
Dactylis glomerata L.	Poaceae	I				X
Eleocharis acicularis (L.) Roem. & Schult.	Cyperaceae	N	X			X
Eleocharis pachycarpa C.B. Clarke	Cyperaceae	N				X
Eleocharis palustris (L.) Roem. & Schult.	Cyperaceae	N	X	X		X
Holcus lanatus L.	Poaceae	I				X
Juncus imbricatus Laharpe	Juncaceae	N				X
Juncus pallescens Lam.	Juncaceae	N				X
Juncus procerus E. Mey.	Juncaceae	N				X
Juncus cyperoides Laharpe	Juncaceae	N				X
Nothoscordum striatellum (Lindl.) Kunth	Alliaceae	N				X
Paspalum dasypleurum Desv.	Poaceae	N				X
Poa sp.	Poaceae	N				X
Polypogon australis Brongn.	Poaceae	N				X
Potamogetum linguatus Hagstr.	Potamogetonaceae	N			X	X
Rostraria cristata (L.) Tzvelev	Poaceae	I				X
Scirpus californicus (C.A.Mey.) Steud. var. *tatora* (Kunth) Barros	Cyperaceae	N	X	X	X	X
Scirpus inundatus (R.Br.) Spreng.	Cyperaceae	N	X		X	X
Sisyrinchium pearcei Phil.	Iridaceae	N				X
Trisetum sp.	Poaceae	N	X			

In the Great Lakes of the region of the Andean precordillera so-called "Araucanians", whose waters are oligotrophic and the lakes have a much larger surface area in study (Campos, 1984; Soto & Campos, 1995), there has been a greater variability in the richness of flora. While the lakes Llanquihue and Cayutué presented a richness of species similar to the lakes of this study, 40 and 37 respectively (Hauenstein *et al*., 1991, 1992), the lakes Villarrica, Caburgua and Calafquén are richer in diversity of species, registering 65, 64 and 69 species respectively (Hauenstein *et al*., 1996, 1998), of which the only one that presents characteristics of mesotrophy condition is Villarrica Lake, with values of 87 ug L^{-1} de NO_3 y de 20.4 ug L^{-1} of total phosphorus (Soto & Campos, 1995). The low amount of species of the four lakes surveyed confirms the oligotrophic character of their waters.

The phytogeographical origin shows that in the four lakes surveyed the native species are dominant (Table 1, Fig. 1). The relatively low percentage of

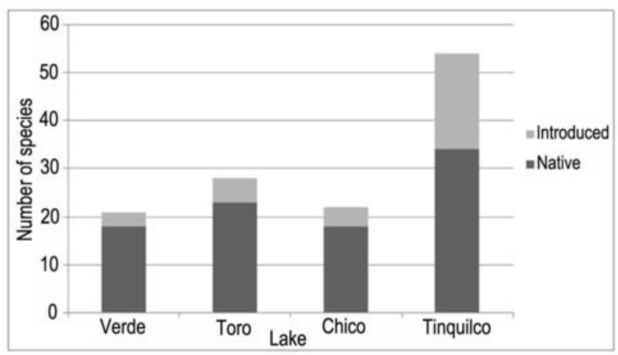

Figure 1. Phytogeographical origin of the flora in the lakes surveyed.

Figura 1. Origen fitogeográfico de la flora de los lagos estudiados.

non-native species indicates a certain anthropized degree on their banks (Hauenstein *et al*., 1988), which would below, according to the scale of González (2000), to the category of "low human disturbance"

Table 2. Results of the null model analysis for studied sites. $P < 0.05$ denote presence of non random (or regulator) factors as regulator of the species association.

Tabla 2. Resultados del análisis de modelo nulo para los sitios estudiados, valores de $P < 0,05$ denotan la presencia de factores no aleatorios (o reguladores) de la asociación de especies.

	Observed index	Mean index	Standard effect size	*P*
Fixed-Fixed	0.597	0.544	3.533	0.005
Fxed-Proportional	0.597	0.655	-1.320	0.899
Fixed-Equiprobable	0.597	0.735	-8.715	0.999

for the three lakes of higher altitude (Verde, Toro and Chico), since it does not exceed 20% of allochthonous species (14.3, 17.9, 18.2% respectively); instead the Tinquilco Lake has a percentage of allochthonous (32%), that has classified it in the category of "high human disturbance".

The results of null model analysis revealed the existence of regulator factors in species assemblages for Fixed-Fixed simulation ($P < 0.005$), whereas these results do not correspond to the Fixed-Proportional ($P < 0.899$) and Fixed-Equiprobable simulations ($P < 0.999$). A possible cause would be the presence of many repeated species (Table 2). In according to Bray-Curtis index, the most similar sites were lakes Verde and Chico with 45.5% of floristic similitude, Toro Lake has a floristic similitude of 41%, and finally Tinquilco Lake with only 29% (Fig. 2). This difference between Tinquilco Lake and other lakes studied, it is probably due to its lower altitude and the increasing presence of the human population in its banks, which is expressed in an increase of non-native species and in a greater contribution of nutrients (N and P) in its waters; on the other hand, the Verde, Chico and Toro lakes are pristine and surrounded by native forests (Steinhart *et al*., 2002; De los Ríos *et al*., 2007).

The results about littoral macrophytes are similar to the descriptions of mountain lakes; where the macrophytes are present contributing a high oxygen concentration (Nagasaka, 2004; Li *et al*., 2009). The high amount of species in Tinquilco Lake would be probably related to the transition from oligotrophy to mesotrophy observed in this lake (De los Ríos *et al*., 2007), these patterns are similar to other lakes of the same category, with changes in trophic status, where ultraoligotrophic lakes have a low amount of species and abundance (Nagasaka, 2004; Li *et al*., 2009).

Similar results of low amount of macrophytes species associated to diversity were observed for coastal wetlands in the Araucania region with different trophic status due to human intervention (Hauenstein

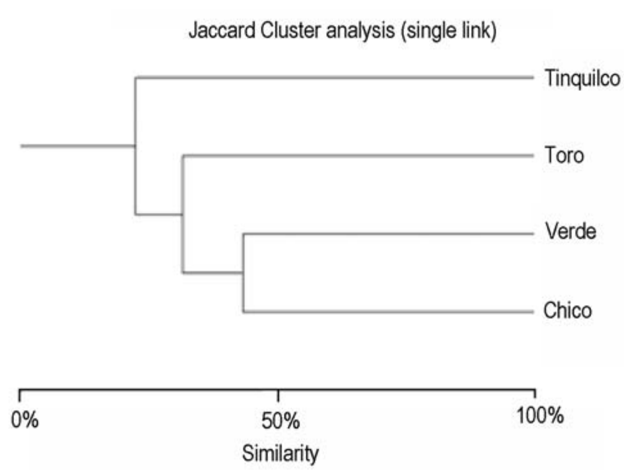

Figure 2. Dendrogram according to Jaccard index for the four lakes studied.

Figura 2. Dendrograma según el índice de Jaccard para los cuatro lagos estudiados.

et al., 2002; Peña-Cortés *et al*., 2006). By his part, Ramírez & San Martín (2006) signal that the aquatic flora is scarce in water bodies oligotrophic and that this tends to situate in slots well delimited in the littoral zone, process known as zoning, which depends of habit of the species (submerged, floating, emergent).

These results are the first observations for pristine mountain lakes of the north Patagonia, because this condition generates a different regulator mechanism in comparison to lakes of the north hemisphere (Soto, 2002; Steinhart *et al*., 2002).

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