CRUSTACEAN (COPEPODA AND CLADOCERA) ZOOPLANKTON RICHNESS IN CHILEAN PATAGONIAN LAKES

BY

PATRICIO DE LOS RÍOS[1,3]) and DORIS SOTO[2,4])

[1]) Universidad Católica de Temuco, Facultad de Recursos Naturales, Escuela de Ciencias Ambientales, Casilla 15-D, Temuco, Chile

[2]) Universidad Austral de Chile, Laboratorio de Ecología Acuática, Casilla 1327, Puerto Montt, Chile

ABSTRACT

The Chilean Patagonian lakes are characterized by their oligotrophy, high endemism, significant predominance of calanoid copepods in comparison to daphnid cladocerans, and low species richness. These characteristics are in marked contrast to the situation in North American lakes. In the present study, published information of chlorophyll concentrations and species richness for Chilean Patagonian lakes was considered. The results denoted direct correlations between chlorophyll concentration and species richness, as well as an inverse correlation between latitude and species richness, whereas a relationship between lake surface and species richness was not observed. The results obtained would indicate that the oligotrophic status of the sites studied is the main cause of low species richness. Our conclusions most probably reveal the existence of different regulator mechanisms in comparison to North American lakes. Ecological and biogeographical topics are discussed.

RESUMEN

Los lagos de la Patagonia Chilena se caracterizan por su oligotrofia, alto endemismo, marcado predominio de los copépodos calanoideos en comparación a los cladóceros daphnidos y una baja diversidad de especies. Estas características son marcadamente opuestas a los lagos de América del Norte. En el presente estudio se consideró información publicada para lagos de la Patagonia Chilena. Los resultados indicaron que la riqueza de especies estuvo directamente relacionada con la concentración de clorofila, inversamente relacionada con la latitud, y no estuvo relacionada con la superficie del lago. Los resultados obtenidos en el presente estudio indican que la oligotrofía sería la causa principal de la baja riqueza de especies, y que habría una diferencia marcada en los mecanismos reguladores observados para lagos norteamericanos. Se discutieron aspectos ecológicos y biogeográficos en el presente estudio.

[3]) e-mail: prios@uct.cl; or: patorios@msn.com

[4]) Current address: Senior Fisheries Officer Inland Water Resources and Aquaculture Service (FIRI), Fisheries Department, FAO of UN, Via delle Terme di Caracalla, I-00100 Rome, Italy

Crustaceana 80 (3): 285-296
Also available online: www.brill.nl/cr

INTRODUCTION

The large Chilean Patagonian lakes are characterized by their oligotrophy, significant predominance of calanoids copepods in comparison to daphnid cladocerans, and low species richness (Campos, 1984; Soto & Zúñiga, 1991). Similar characteristics have been described for large lakes in Argentinean Patagonia (Modenutti et al., 1998). These characteristics are in marked contrast to the situation in North American lakes, which show a high predominance of daphnid cladocerans and high species richness (Soto & Zúñiga, 1991; Soto & Campos, 1995; Gillooly & Dodson, 2000).

The Chilean lakes have simple trophic chains that are characterized by the presence of phytoplankton, zooplankton with a predominance of calanoid copepods (mainly *Boeckella* spp.) and zooplanktivorous fishes (mainly Galaxiidae) in the pelagic zone (Soto & Zúñiga, 1991). These features are similar to those described for Argentinean lakes (Modenutti et al., 1998), and New Zealand lakes and ponds (Jeppensen et al., 1997, 2000). In a study done in lakes and ponds at different locations in the Torres del Paine National Park, we found that a relatively high species richness was observed in the absence of zooplanktivorous fish and the presence of a high chlorophyll concentration (Soto & De los Ríos, 2006). In an ecological community, species richness is an important attribute of that system, and this richness is conditioned by environmental factors such as productivity and habitat area (Jaksic, 2001; Guisande et al., 2003). The first study of zooplankton assemblages in Chilean lakes described a low species richness that is probably explained most by an oligotrophic status (Soto & Zúñiga, 1991). The aim of the present study is to determine the role of geographical characteristics and chlorophyll concentration on species richness in Chilean Patagonian lakes, mainly considering a review of the literature of deep Chilean lakes, and information collected in field work.

MATERIAL AND METHODS

Published information was considered first of all (Campos et al., 1982, 1983, 1988, 1990, 1992, 1994a, b; Soto et al., 1994; Campos, 1995; Wölfl, 1996; Villalobos, 1999; De los Ríos, 2003) for southern Chilean lakes between 38° (Villarrica Lake, fig. 1) to 51°S (Torres del Paine National Park, fig. 1). This included data of species richness, latitude, and chlorophyll concentration. Also, zooplankton samples were collected in lakes of the Aysen region during spring and summer 2001, a period when maximum zooplankton abundance occurs (Wölfl, 1996). Samples were collected in vertical hauls from 30 m depth to the surface, with an Apstein net. This layer constitutes the zone with maximum zooplankton abundance

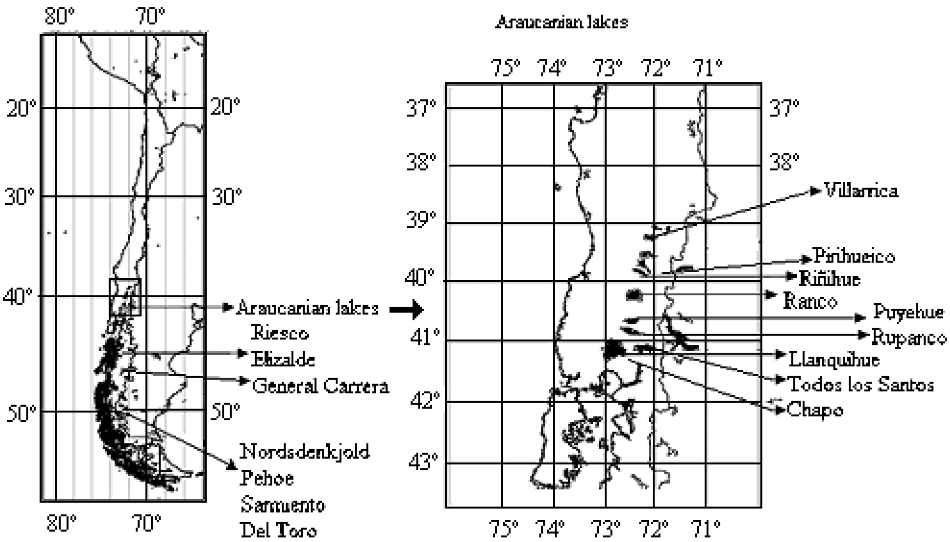

Fig. 1. Map of Chile with the sites (lakes) included in the present study.

(Wölfl, 1996). Specimens collected were fixed with absolute ethanol and identified with descriptions of Araya & Zuñiga (1985) and Bayly (1992). A Spearman non-parametric correlation test was applied considering species richness as the dependent variable, and as independent variables latitude, chlorophyll concentration, surface area, and maximum depth (Z_{max}). All statistical analyse used the software Statistica 5.0.

RESULTS AND DISCUSSION

The results obtained revealed that species richness at the studied sites was relatively low, and that richness decreases toward southern latitudes (table I). The results also revealed a marked oligotrophy mainly at the southernmost latitudes (table I). Accordingly, correlation analysis showed a significant, indirect correlation between latitude, species richness, and chlorophyll concentration, and a direct correlation between surface area and maximum depth (table II). A non-significant, direct correlation between species richness and surface area was observed, as well as between maximum depth and latitude; and also between surface area and chlorophyll (table II). Also, non-significant direct correlations were found between species richness and maximum depth; surface and latitude; and maximum depth and chlorophyll concentration (table II). The correlation graphs support only the existence of a significant correlation between species richness and latitude, and a non-significant correlation between species richness and surface area, as well as between maximum depth and chlorophyll concentration (fig. 2).

TABLE I

Geographical parameters, chlorophyll (Chl *a*) concentration, and species richness at the sites studied and reported upon herein (see also fig. 1)

Lake	Geographical location (°S)	Z_{max} (m)	Surface area (km^2)	Chl *a* (μg/l)	Species richness	Reference
Villarrica	39°18′	185.0	175.8	0.4	*Tumeodiaptomus diabolicus* Dussart, 1979 *Boeckella gracilipes* Daday, 1902 *Mesocyclops longisetus* Thiébaud, 1914 *Tropocyclops prasinus* Fisher, 1960 *Daphnia ambigua* Scourfield, 1967 *Diaphanosoma chilense* Daday, 1902 *Eubosmina hagmanni* Stingelin, 1903	Campos et al., 1983
Pirihueico	39°50′	145.0	30.5	0.6	*B. gracilipes* *M. longisetus* *T. prasinus* *E. hagmanni* *Ceriodaphnia dubia* Richard, 1894	Wölfl, 1996
Riñihue	39°50′	323.0	77.5	1.2	*T. diabolicus* *B. gracilipes* *M. longisetus* *T. prasinus* *D. ambigua* *D. chilense* *E. hagmanni*	Wölfl, 1996
Ranco	40°13′	199.0	442.6	0.8	*T. diabolicus* *B. gracilipes* *M. longisetus* *T. prasinus* *D. ambigua* *Daphnia pulex* De Geer, 1877 *D. chilense* *E. hagmanni* *Scapholeberis spinifera* Nicolet, 1848	Campos et al., 1992

TABLE I
(Continued)

Lake	Geographical location (°S)	Z_{max} (m)	Surface area (km^2)	Chl *a* (μg/l)	Species richness	Reference
Puyehue	40°40′	123.0	165.4	2.1	*T. diabolicus* *M. longisetus* *T. prasinus* *D. chilense* *D. ambigua* *C. dubia* *E. hagmanni*	Campos et al., 1989
Rupanco	40°50′	273.0	235.0	1.2	*B. gracilipes* *T. prasinus* *E. hagmanni* *Chydorus sphaericus* O.F. Müller, 1785	Campos, 1993
Llanquihue	41°08′	317.0	870.5	0.5	*B. gracilipes* *T. prasinus* *E. hagmanni*	Campos et al., 1988
Todos los Santos	41°08′	335.0	178.5	0.4	*B. gracilipes* *T. prasinus* *E. hagmanni* *D. pulex*	Campos et al., 1990
Chapo	41°27′	298.0	45.3	0.3	*B. gracilipes* *Acanthocyclops vernalis* Fisher, 1853 *T. prasinus* *D. chilense* *S. spinifera* *Neobosmina chilensis* Daday, 1902	Villalobos et al., 2003

TABLE I
(Continued)

Lake	Geographical location (°S)	Z_{max} (m)	Surface area (km^2)	Chl *a* (μg/l)	Species richness	Reference
Riesco	45°39′	130.0	14.7	0.9	*B. gracilipes* *Parabroteas sarsi* Daday, 1901 *T. prasinus* *N. chilensis*	Villalobos, 1999
Elizalde	45°44′	130.0	30.0	No data	*Boeckella michaelseni* Mrázek, 1901 *T. prasinus* *N. chilensis*	Present study
General Carrera	45°50′	410.0	1892.0	No data	*B. michaelseni* *T. prasinus* *N. chilensis*	Present study
Toro	51°12′	317.0	196.0	0.4	*B. gracilipes* *B. michaelseni* *M. longisetus* *T. prasinus*	Campos et al., 1994b
Sarmiento	51°03′	312.0	86.0	0.3	*B. gracilipes* *B. michaelseni* *T. prasinus* *M. longisetus* *Bosmina chilensis* Daday, 1902	Campos et al., 1994a
Pehoe	51°03′	200.0	15.0	0.4	*B. michaelseni* *T. prasinus*	Soto et al., 1994
Norsdenkjold	51°03′	200.0	25.0	0.3	*B. michaelseni* *T. prasinus*	Soto et al., 1994

Z_{max} = maximum depth of lake.

TABLE II

Non-parametric correlation matrix of the parameters considered in the present study; values in bold denote significant correlations ($p < 0.05$)

	Latitude	Surface	Z_{max}	Chl *a*
Species richness	**−0.689** $p = 0.002$ n = 16	−0.190 $p = 0.240$ n = 16	0.196 $p = 0.234$ n = 16	0.341 $p = 0.116$ n = 14
Latitude		0.242 $p = 0.183$ n = 16	−0.205 $p = 0.223$ n = 16	**−0.553** $p = 0.020$ n = 14
Surface			**0.526** $p = 0.018$ n = 16	−0.318 $p = 0.134$ n = 14
Zmax				0.199 $p = 0.248$ n = 14

Z_{max} = maximum depth.

These results agree with the first descriptions of Soto & Zuñiga (1991) that described a low species richness and an oligotrophic status. However, Soto & Zúñiga (1991) considered species richness by lake, from the descriptions of Ruiz & Bahamonde (1989), that include pelagic and littoral microcrustaceans. In contrast, the references considered in the present study only describe pelagic species (Campos et al., 1983, 1988, 1990, 1992, 1994a, b; Campos, 1995; Villalobos, 1999; Soto et al., 1994; Wölfl, 1996; De los Ríos, 2003). The first descriptions of Soto & Zúñiga (1991) agree with the observed inverse correlation between latitude and species richness within the 38-51°S latitudinal range, and the lack of significant correlations between species richness and both surface area and maximum depth. When the paper of Soto & Zúñiga (1991) was published, no information was available on the trophic status of many Chilean Patagonian lakes. Yet, this study hypothesized that oligotrophy would be an important cause of low species richness. The results obtained in the present study could be related to the observations of De los Ríos & Soto (2006) and Soto (2002), that describe inverse correlations between chlorophyll concentration, and both latitude and mixing depth. These last results would indicate that the significant inverse correlation between latitude and species richness (table II, fig. 2), can be explained by the inverse correlation between chlorophyll and latitude (table II; De los Ríos & Soto, 2006). These results agree with descriptions of the Torres del Paine National Park lake district, characterized by a different trophic status (Soto et al., 1994). Descriptions of zooplankton assemblages revealed the existence of inverse correlations between species richness and chlorophyll concentration (Soto & De los Ríos, 2006).

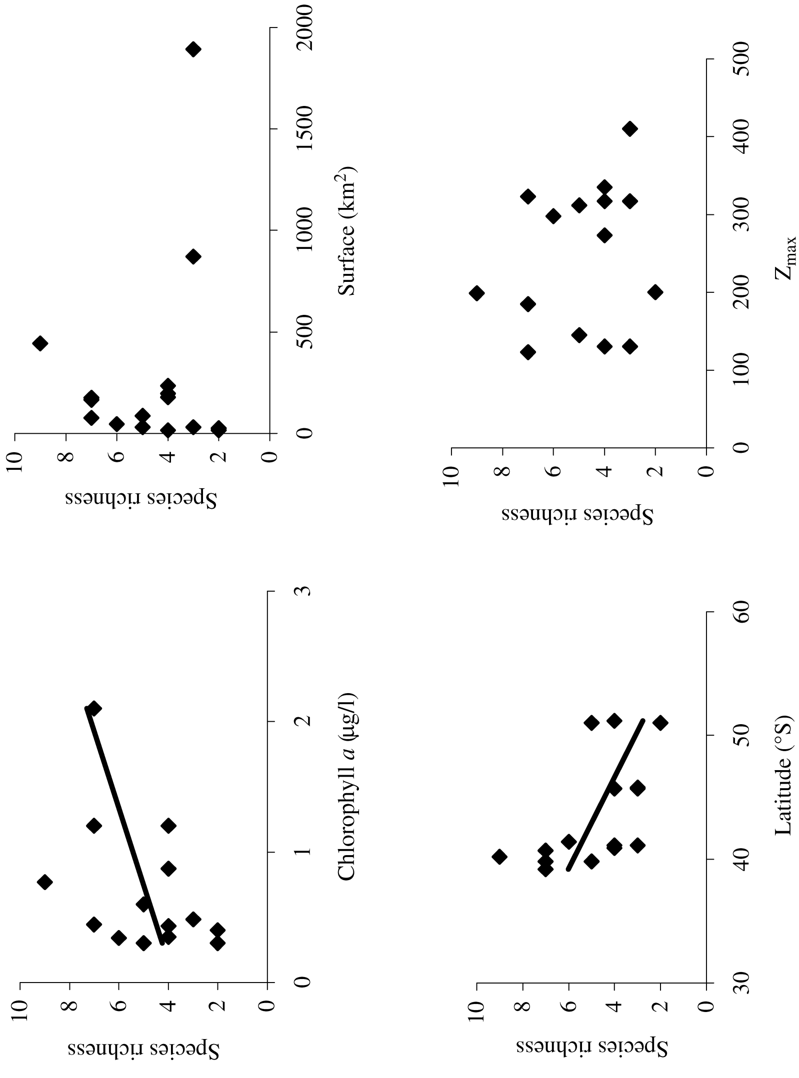

Fig. 2. Graphs of correlations between species richness of crustacean zooplankton and the parameters of the lakes considered in the present study; Z_{max}, maximum depth.

Reports on lakes in Mexico, the U.S.A., and Europe describe a direct relation between species richness and lake size (Dodson, 1991, 1992; Dodson & Silva-Briano, 1996), which is not in agreement with the observations for southern Chilean lakes (table II, fig. 2; Soto & Zúñiga, 1991). For North American great lakes an increase in species richness was found in lakes of medium depth (Z_{max}: 200-300 m), whereas richness decreased in deep lakes (Soto & Zúñiga, 1991). The descriptions of Pinto-Coelho et al. (2005) and Dodson et al. (2000) indicated the existence of a significant quadratic function between zooplankton species richness and primary productivity. Dodson et al. (2000) observed richness peaks at 67-179 gC/m^2/year, where many of Chilean lakes have primary productivity values lower than 70 gC/m^2/year (Montecino, 1991). These oligotrophic conditions, with a consistent predominance of calanoids and a low dominance of daphnids (Soto & Zúñiga, 1991; De los Ríos & Soto, 2006), are similar to the descriptions of the lakes in the Precambrian plain in the northern U.S.A., that have a predominance of *Leptodiaptomus minutus* (Lilljeborg, 1998) (cf. Rusak et al., 1999). Similar results were by found by Tomec et al. (2002), who described low species richness and copepod predominance in the oligotrophic Lake Vrana in Croatia.

Another important factor that would explain the low species richness in southern South American lakes would be the exposure to ultraviolet radiation (UVR), which shows an increase in penetration in Patagonia (Villafañe et al., 2001; Marinone et al., 2006). Thus, under high exposure to UVR, species richness decreases (Marinone et al., 2006), and the potential cause would be the vulnerability of some groups to exposure of high levels of natural UVR (De los Ríos & Soto, 2005; De los Ríos, 2005). In this scenario, we would conclude that the low species richness in Chilean deep lakes would be due to oligotrophy, probably enhanced by exposure to UVR.

ACKNOWLEDGEMENTS

The present study was a part of the doctoral thesis of the first author. This study was financed by projects DID-UACH 2001-11, IAI ("Enhanced ultraviolet B radiation in natural ecosystems as an added perturbation due to ozone depletion"), CONICYT-Chile (Doctoral grant, and Doctoral fellowship of support to a doctoral thesis), Graduate School of Science Faculty (Austral University of Chile), and the research direction of the Catholic University of Temuco. Also, we gratefully express our appreciation to Enrique Hauenstein (Catholic University of Temuco) for helpful comments on manuscript.

REFERENCES

ARAYA, J. M. & L. R. ZUÑIGA, 1985. Manual taxonómico del zooplancton lacustre de Chile. Boletín Limnológico, Universidad Austral de Chile, Valdivia, **8**: 1-169. [In Spanish.]

BAYLY, I. A. E., 1992. Fusion of the genera *Boeckella* and *Pseudoboeckella* (Copepoda) and revision of their species from South America and Sub-Antarctic islands. Rev. Chilena Hist. nat., **65**: 17-63.

CAMPOS, H., 1984. Limnological study of Araucanian lakes (Chile). Verh. int. Ver. theor. angew. Limnol., **22**: 1319-1327.

— —, 1995. Determinación de la capacidad de carga en el Lago Rupanco, X región. Technical report Fisheries Research Foundation-Chile, **FIP-IT/93-27**. [In Spanish.]

CAMPOS, H., J. ARENAS, W. STEFFEN, C. ROMÁN & G. AGÜERO, 1982. Limnological study of Lake Ranco (Chile) Morphometry, physics, chemistry and plankton. Arch. Hydrobiol., **94**: 137-171.

CAMPOS, H., D. SOTO, W. STEFFEN, G. AGUËRO, O. PARRA & L. ZÚÑIGA, 1994a. Limnological studies of Lake del Toro (Chile) morphometry, physics, chemistry and plankton. Arch. Hydrobiol., **99** (Suppl.): 199-215.

— —, — —, — —, — —, — — & — —, 1994b. Limnological studies of Lake Sarmiento (Chile): a subsaline lake from Chilean Patagonia. Arch. Hydrobiol., **99** (Suppl.): 217-234.

CAMPOS, H., W. STEFFEN, G. AGÜERO, O. PARRA & L. ZÚÑIGA, 1983. Limnological studies in lake Villarrica. Morphometric, physical, chemical, planktonical factors and primary productivity. Arch. Hydrobiol., **81** (Suppl.): 37-67.

— —, — —, — —, — — & — —, 1987. Limnology of Lake Riñihue. Limnologica, **18**: 339-357.

— —, — —, — —, — — & — —, 1988. Limnological study of lake Llanquihue (Chile): morphometry, physics, chemistry and primary productivity. Arch. Hydrobiol., **81** (Suppl.): 37-67.

— —, — —, — —, — — & — —, 1990. Limnological study of lake Todos los Santos (Chile): morphometry, physics, chemistry, plankton and primary productivity. Arch. Hydrobiol., **117**: 453-484.

— —, — —, — —, — — & — —, 1992. Limnology of Lake Ranco (Chile). Limnologica, **22**: 337-353.

DE LOS RÍOS, P., 2003. Efectos de las disponibilidades de recursos energéticos, estructurales y de protección sobre la distribución y abundancia de copépodos y cladóceros zooplanctónicos lacustres chilenos: 1-107. (Doctoral Thesis, Austral University of Chile, Valdivia). [In Spanish with English abstract.]

— —, 2005. Survival of pigmented freshwater zooplankton exposed to artificial ultraviolet radiation and two concentrations of dissolved organic carbon. Polish Journ. Ecol., **53**: 113-116.

DE LOS RÍOS, P. & D. SOTO, 2005. Survival of two species of crustacean zooplankton under two chlorophyll concentrations and protection from or exposure to natural ultraviolet radiation. Crustaceana, **78**: 163-169.

— — & — —, 2006. Effects of the availability of energetic and protective resources on the abundance of daphniids (Cladocera, Daphniidae) in Chilean Patagonian lakes (39°-51°S). Crustaceana, **79**: 23-32.

DODSON, S. I., 1991. Species richness of crustacean zooplankton in European lakes of different sizes. Verh. int. Ver. theor. angew. Limnol., **24**: 1223-1229.

— —, 1992. Predicting crustacean zooplankton species richness. Limnol. Oceanogr., **37**: 848-856.

DODSON, S. I., S. E. ARNOTT & K. L. COTTINGHAM, 2000. The relationship in lake communities between primary productivity and species richness. Ecology, **81**: 2662-2679.

DODSON, S. I. & M. SILVA-BRIANO, 1996. Crustacean zooplancton species richness and associations in reservoirs and ponds of Aguas Calientes, México. Hydrobiologia, **325**: 163-172.

GILLOOLY, J. F. & S. I. DODSON, 2000. Latitudinal patterns in the size distribution and seasonal dynamics of New World, freshwater cladocerans. Limnol. Oceanogr., **45**: 22-30.

GUISANDE, C., F. BARTUMEUS, M. VENTURA & J. CATALAN, 2003. Role of food partitioning in structuring the zooplankton community in mountain lakes. Oecologia, **136**: 627-634.

JAKSIC, F., 2001. Ecología de comunidades: 1-233. (Ediciones Pontificia Universidad Católica de Chile, Santiago de Chile). [In Spanish.]

JEPPENSEN, E., T. L. LAURIDSEN, S. F. MITCHELL & C. W. BURNS, 1997. Do planktivorous fish structure the zooplankton communities in New Zealand lakes? New Zealand Journ. mar. freshwat. Res., **31**: 163-173.

JEPPENSEN, E., T. L. LAURIDSEN, S. F. MITCHELL, K. CHRISTOFFERSEN & C. W. BURNS, 2000. Trophic structure in the pelagial of 25 shallow New Zealand lakes: changes along nutrient and fish gradients. Journ. Plankt. Res., **22**: 951-968.

MARINONE, M. C., S. MENU MARQUE, D. AÑÓN SUÁREZ, M. C. DIÉGUEZ, A. P. PÉREZ, P. DE LOS RÍOS, D. SOTO & H. E. ZAGARESE, 2006. UV radiation as a potential driving force for zooplankton community structure in Patagonian lakes. Photochem. Photobiol., **82**: 962-971.

MODENUTTI, B. E., E. G. BALSEIRO, C. P. QUEIMALIÑOS, D. A. AÑÓN SUÁREZ, M. DIÉGUEZ & R. J. ALBARIÑO, 1998. Structure and dynamics of food webs in Andean lakes. Lak. Res., (Res. Manag.) **3**: 179-186.

MONTECINO, V., 1991. Primary productivity in South American temperate lakes and reservoirs. Rev. Chilena Hist. nat., **64**: 555-567.

PINTO-COELHO, R., B. PINEL-ALLOUL, G. MÉTHOT & K. E. HAVENS, 2005. Crustacean species richness in lakes and reservoirs of temperate and tropical regions: variations with trophic status. Canadian. Journ. Fish. aquat. Sci., **62**: 348-361.

RUSAK, J. A., N. D. YAN, K. M. SOMMERS & D. J. MCQUEEN, 1999. The temporal coherence of zooplankton populations abundances in neighboring north-temperate lakes. American Nat., **153**: 46-58.

SOTO, D., 2002. Oligotrophic patterns in southern Chile lakes: the relevance of nutrients and mixing depth. Rev. Chilena Hist. nat., **75**: 377-393.

SOTO, D. & H. CAMPOS, 1995. Los lagos oligotróficos del bosque templado húmedo del sur de Chile. In: J. ARMESTO, M. KHALIN & M. VILLAGRÁN (eds.), Ecología del bosque Chileno: 134-148. (Editorial Universitaria, Santiago de Chile). [In Spanish.]

SOTO, D., H. CAMPOS, W. STEFFEN, O. PARRA & L. ZÚÑIGA, 1994. The Torres del Paine lake district (Chilean Patagonia): a case of potentially N-limited lakes and ponds. Arch. Hydrobiol., **99**: 181-197.

SOTO, D. & P. DE LOS RÍOS, 2006. Trophic status and conductivity as regulators in daphniid dominance and zooplankton assemblages in lakes and ponds of Torres del Paine National Park. Biologia, Bratislava, **61**: 541-546.

SOTO, D. & L. ZÚÑIGA, 1991. Zooplankton assemblages of Chilean temperate lakes: a comparison with North American counterparts. Rev. Chilena Hist. nat., **64**: 569-581.

TOMEC, M., I. TERNJEC, M. KEROVEC, E. TESKERREDZIC & M. MÉSTROV, 2002. Plankton in the oligotrophic lake Vrana (Croatia). Biologia, Bratislava, **57**: 579-588.

VILLAFAÑE, V. E., E. W. HELBLING & H. E. ZAGARESE, 2001. Solar ultraviolet radiation and its impact on aquatic ecosystems of Patagonia, South America. Ambio, **30**: 112-117.

VILLALOBOS, L., 1999. Determinación de capacidad de carga y balance de fósforo y nitrógeno de los lagos Riesco, Los Palos y Laguna Escondida en la XI región. Technical report Fisheries Research Foundation-Chile, **FIP-IT/97-39**. [In Spanish.]

VILLALOBOS, L., S. WÖLFL [as: WOELFL], O. PARRA & H. CAMPOS, 2003. Lake Chapo: a base line study of a deep, oligotrophic North Patagonian lake prior to its use for hydroelectricity generation: II. Biological properties. Hydrobiologia, **510**: 225-237.

WÖLFL, S., 1996. Untersuchungen zur Zooplanktonstruktur einschliesslich der mikrobiellen Gruppen unter Berücksichtigung der mixotrophen Ciliaten in zwei südchilenischen Andenfußseen: 1-242. (Universität Konstanz, Konstanz).

First received 22 June 2006.
Final version accepted 26 September 2006.