SALINITY EFFECTS ON THE ABUNDANCE OF *BOECKELLA POOPOENSIS* (COPEPODA, CALANOIDA) IN SALINE PONDS IN THE ATACAMA DESERT, NORTHERN CHILE

BY

PATRICIO DE LOS RIOS[1,3]) and JULIO E. CRESPO[2])

[1]) Departamento de Ciencias Biológicas y Químicas, Facultad de Ciencias, Universidad Católica de Temuco, Casilla 15-D, Temuco, Chile

[2]) Departamento de Ciencias Básicas Programa~ibam, ULA, Universidad de Los Lagos, Casilla 933, Osorno, Chile

ABSTRACT

The calanoid copepod, *Boeckella poopoensis* Marsh, 1906 inhabits shallow saline ponds located in the Andes mountains in Argentina, Bolivia, Chile, and Peru, as well as in the plains of southern Argentina. The species is halophilic and can tolerate salinity levels of 1 to 90 ppt. This paper describes the relative abundance of the species in shallow mountain ponds in northern Chile from 23° to 27°S. A direct correlation was observed between salinity and the relative abundance of *B. poopoensis* ($r^2 = 0.4139$), and between 45 and 90 ppt S the species was found to be dominant in zooplankton assemblages. Crustacean species richness at the sites studied showed a significant, inverse trend with salinity ($r^2 = 0.7329$), and this trend became even stronger ($r^2 = 0.7681$) when data previously published for the Bolivian Andean plateau were included. Ecological and biogeographical issues related with these results are discussed.

RESUMEN

El copépodo calanoideo *Boeckella poopoensis* Marsh, 1906 vive en lagunas salinas poco profundas localizadas en el altiplano Andino de Argentina, Bolivia, Chile y Perú, y en el sur de Argentina. Esta especie es marcadamente halofílica, y tolera salinidades entre 1 y 90 g/l, estos hábitats tienen una pobre riqueza específica de crustáceos zooplanctónicos. Este estudio describe la abundancia relativa de esta especie en lagunas poco profundas de montaña en el norte de Chile, entre los 23 y 27 grados sur de latitud. Se observó una relación directa notoria entre la salinidad y la abundancia relativa de *B. poopoensis* ($r^2 = 0.4139$), encontrándose prácticamente esta especie como habitante exclusivo a salinidades superiores entre 45 g/l y 90 g/l, lo que coincide con las descripciones de la literatura. La riqueza específica de especies de crustáceos presentó una relación inversa notoria con la salinidad en los sitios estudiados ($r^2 = 0.7329$), lo cual fue más robusto al incorporar información publicada para el Altiplano de Bolivia ($r^2 = 0.7681$). En este estudio se discutieron implicancias ecológicas y biogeográficas relacionadas con los resultados observados.

[3]) e-mail: prios@uct.cl

Crustaceana 77 (4): 417-423
Also available online: www.brill.nl

INTRODUCTION

The zooplankton assemblages in lakes and ponds in Chile are characterized by a dominance of calanoid copepods, mainly of the genus *Boeckella* (cf. Soto & Zúñiga, 1991), that inhabit the high-altitude shallow waters in the Andes (De los Rios, 2003). Until now, 6 species are known in this genus (Bayly, 1992, 1993; Menu-Marque et al., 2000), of which *Boeckella poopoensis* Marsh, 1906 is the most dominant at high salinity levels (1-90 ppt) in shallow saline ponds of Argentina, Bolivia, and Peru (Bayly, 1993; Williams et al., 1995; Menu-Marque et al., 2000). These habitats are associated with saline sulphate deposits of volcanic origin, in areas where the climate is markedly dry, with weak rains during January and February (Chong, 1988), causing a salinity gradient over the year (Gajardo et al., 1992; Zuñiga et al., 1994). These variations in salinity level will affect the zooplankton assemblage, because under 90 ppt *B. poopoensis* is dominant, while at values higher than 90 ppt *Artemia* spp. predominate (Williams et al., 1995).

The ponds in the Andes are rather inaccessible (Chong, 1988; Gajardo et al., 1992), which would explain the few studies of these ecosystems to date (Hurlbert et al., 1986; Zuñiga et al., 1991, 1994; Gajardo et al., 1992; Williams et al., 1995; Valero-Garcés et al., 1996). Some of these ponds are included in the Sistema Nacional de Areas Protegidas del Estado (SNASPE), administrated by the National Forestal Corporation — Chile. This study aims at presenting a description of new localities of species of Crustacea, and of the effects of salinity on the zooplankton assemblages from the Atacama desert, Northern Chile, focused on *B. poopoensis* populations. The present work also intends to show the need for an inventory of the zooplankton inhabiting the desert zones of our country.

MATERIAL AND METHODS

The habitats studied are located mainly in the Atacama desert (Antofagasta region). A total of six ponds were selected and characterized (table I). All localities were prospected twice, in the spring and summer of 2000 and 2001. Salinity, conductivity, and temperature were measured using a YSI-30 sensor, and zooplankton samples were taken through horizontal hauls with an Apstein net (80 μm mesh size). The zooplankton sampled was identified with the aid of Araya & Zuñiga (1985), and Bayly (1992). For each site, the abundance of total crustaceans and of *Boeckella poopoensis* (%) was estimated. The relationship between salinity versus *Boeckella poopoensis* abundance and of salinity versus crustacean species richness was calculated by simple regression. The species richness determined earlier for crustaceans inhabiting saline lakes on the Bolivian

TABLE I
Crustacean zooplankton assemblages, *Boeckella poopoensis* Marsh, 1906 abundance (%), and salinity, for each of the sites studied

	Gemela Este	Gemela Oeste	Miscanti lagoon	Miniques lagoon	Salar de Capur	Santa Rosa lagoon
Cladocera						
Alona pulchella King, 1853			X	X		X
Daphnia spp.			X	X		X
Chydoridae (unidentified)					X	
Copepoda						
Boeckella poopoensis Marsh, 1906	X	X	X	X	X	X
Cyclopoida (unidentified)			X	X	X	
% B. poopoensis	100	100	73	50	66	99
Salinity (ppt)	54.10	46.50	8.98	9.79	3.40	8.00

X = present.

altiplano (Williams et al., 1995) was used for comparison. Statistical analysis was performed using Statistica 5.0.

The shallow ponds "Gemela Este", and "Gemela Oeste" (23°30′S 68°14′W, 2400 m a.s.l.) are separated by approximately 100 m, have a depth < 7 m, an area less than 1 km^2, and a roughly circular circumference. They are located in the north of Salar de Atacama, in a plain named "Tebenquiche", which has numerous ponds with different salinity levels, and a crustacean fauna mainly composed of *Artemia* populations (Zuñiga et al., 1994).

The lagoons "Miscanti" (23°44′S 67°46′W, 4140 m a.s.l.) and "Miniques" (23°45′S 67°44′W, 4120 m a.s.l.) are relatively shallow, with a maximum depth of 9 and 5 m, and a surface area of 13.4 and 1.6 km^2, respectively (Valero-Garcés et al., 1996). Miscanti lagoon receives groundwater originating from Miniques lagoon by filtration (Valero-Garcés et al., 1996).

The pond located in "Salar de Capur" (23°00′S 67°43′W, 3950 m a.s.l.) belongs to an array of interconnected, shallow little ponds with depths less than 1.5 m, and an average surface area of 0.9 km^2 (Richaser et al., 1999).

"Santa Rosa" lagoon (27°05′S 69°10′W, 3000 m a.s.l.) presents a depth of < 1 m, and is located in the west of a saline deposit named "Salar de Maricunga". Data on the geographical, physical, and chemical characteristics of Santa Rosa lagoon have not been published yet.

All sites are located in the mountain zones of the Atacama desert and are associated with saline deposits ("Gemela Este", "Gemela Oeste", "Salar de Capur", and "Santa Rosa"), or basins with a raised content of soluble minerals, such as "Miscanti" and "Miniques" (Chong, 1988). Gemela Este, Gemela Oeste,

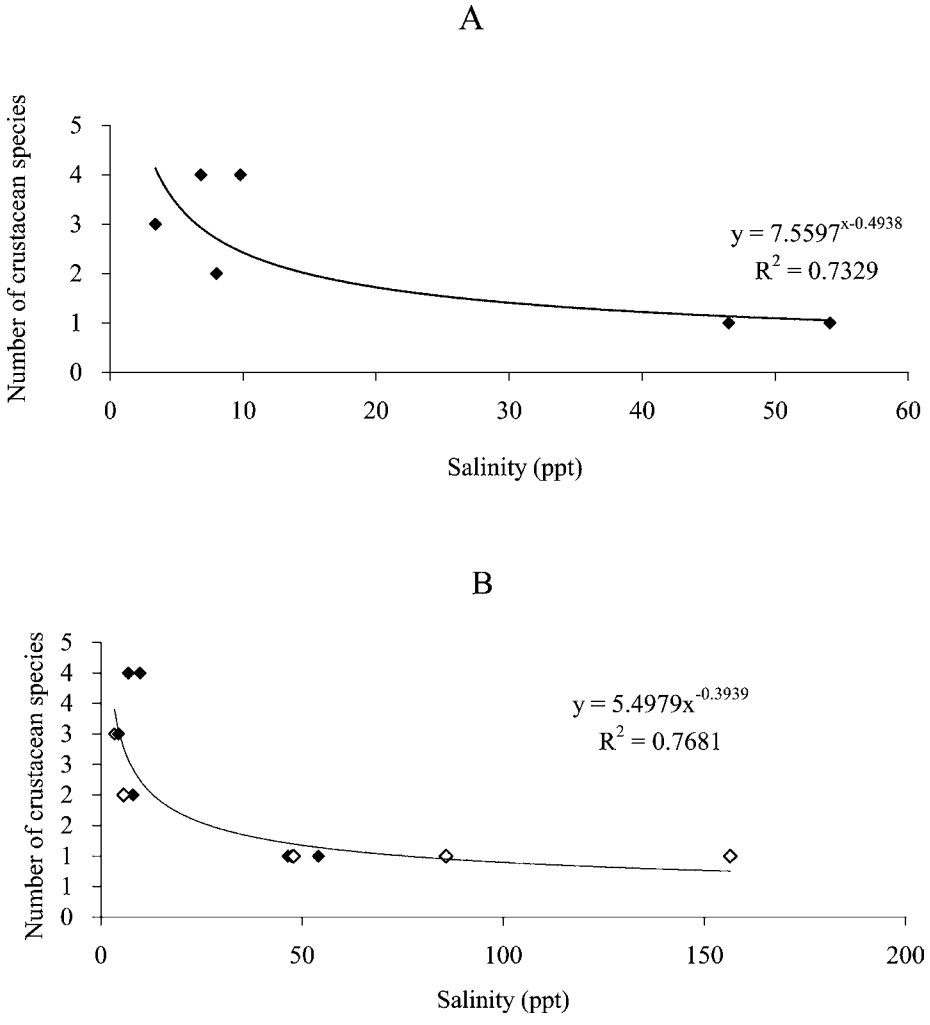

Fig. 1. Relationships between salinity and number of crustacean species: A, localities studied in this work; B, data for Chile (filled squares, present study) and Bolivia (open squares, Williams et al., 1995).

and Salar de Capur are not recognized as protected Areas of the National Forest Corporation (Chile). In contrast, Miscanti and Miniques lagoon and also Santa Rosa lagoon are included in "Los Flamencos National Reserve", and "Salar de Maricunga National Reserve", respectively. All these sites are nesting and feeding zones of waterbirds, such as the Chilean flamingo (*Phoenicopterus chilensis* Molina, 1782), the Andean flamingo (*Phoenicoparrus andinus* (Philippi, 1854)), or the James flamingo (*Phoenicoparrus jamesi* (Sclater, 1866)) all considered endangered species (Parada, 1990; Hurlbert et al., 1984).

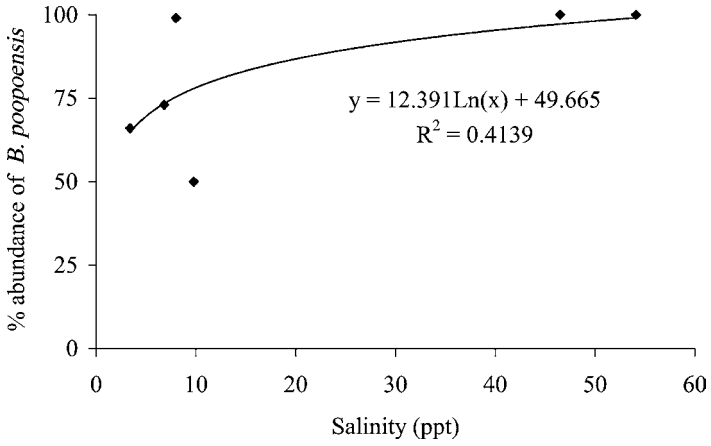

Fig. 2. Relationship between salinity and relative abundance of *Boeckella poopoensis* Marsh, 1906 at the Chilean localities studied.

RESULTS AND DISCUSSION

The species richness of lower Crustacea as determined for all localities is given in table I. An inverse relationship between salinity and crustacean species richness (fig. 1) was observed, which is in accordance with the data on the Bolivian plateau (Williams et al., 1995). Those results show that salinity values were always in excess of 45 ppt, and that the crustacean zooplankton consisted entirely by *Boeckella poopoensis*. Our results are supported by the correlation between salinity and the abundance of *Boeckella poopoensis* in the zooplankton assemblages obserwed at salinities higher than 45 ppt (fig. 2).

The crustacean species richness observed in the present study was lower, however, but similar to that found for other Chilean (Zuñiga et al., 1991; De los Rios, 2003) and Bolivian ponds (Williams et al., 1995). The low presence or complete absence of cladocerans or cyclopoid copepods at high salinity levels was also described for salt lakes in the Peruvian Andes (Hurlbert et al., 1986). In comparison to other halophilic copepods of the genus *Boeckella*, *B. poopoensis* is the most halotolerant: other South American species like *Boeckella meteoris* Kiefer, 1928 can tolerate levels lower than 6 ppt, while *B. titicacae* (Harding, 1955) and *B. occidentalis* Marsh, 1906 tolerate salinity levels lower than 3 ppt. The Australian *Boeckella triarticulata* (Thomson, 1883) inhabits water with levels lower than 22 ppt (Bayly, 1993). Nevertheless, the salinity tolerance of *Boeckella poopoensis* is lower as compared to other Australian halophilic calanoids, such as *Calamoecia salina* (Nicholls, 1944) and *Calamoecia clitellata* Bayly, 1962 that inhabit ranges of 7-195 ppt and 6-132 ppt, respectively (Bayly, 1992, 1993). This situation would explain the exclusive dominance of *Boeckella poopoensis* at some of the sites studied, because this species has a higher salinity tolerance

than, e.g., daphnid cladocerans (Hurlbert et al., 1986; Bayly, 1993). These results would be comparable with those obtained from zooplankton in New Zealand lakes, because at medium or higher salinity levels *Daphnia* has a lower survival and fecundity (Hall & Burns, 2002). All this would indicate that the salinity level would constitute a factor regulating both calanoid dominance, and a lower crustacean species richness in Andean lakes and ponds.

ACKNOWLEDGEMENTS

This study has been funded in part by grants from the Dirección de Investigación y Desarrollo de la Universidad Austral de Chile (grant N°2001-11), the Interamerican Institute for Global Change, and through financial support from CONICYT, Chile (Doctoral Thesis fellowship). We thank the Corporación Nacional Forestal-CONAF, Chile for research facilities in the National Reserves "Los Flamencos" and "Salar de Maricunga". The transport provided by Mr. Luis Escalante to "Salar de Atacama" is gratefully acknowledged.

REFERENCES

ARAYA, J. M. & L. ZÚÑIGA, 1985. Manual taxonómico del zooplancton lacustre chileno. Boletín Limnológico, Universidad Austral de Chile, Valdivia, **8**: 1-168.

BAYLY, I. A. E., 1993. The fauna of athalassic saline waters in Australia and the altiplano of South America: comparisons and historical perspectives. Hydrobiologia, **267**: 225-231.

— —, 1992. Fusion of the genera *Boeckella* and *Pseudoboeckella* (Copepoda) and revision of their species from South America and sub-Antarctic islands. Revista Chilena de Historia Natural, **65**: 17-63.

CHONG, G., 1988. The Cenozoic saline deposit of the Chilean Andes between 18°00 and 27°00 south latitude. Lecture Notes in Earth Sciences, **17**: 137-151.

DE LOS RIOS, 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. [In Spanish with English abstract.] (Doctoral Thesis, Austral University of Chile, Valdivia).

GAJARDO, G. M., R. WILSON & O. ZÚÑIGA, 1992. Report on the occurrence of *Artemia* in a saline deposit of the Chilean Andes (Branchiopoda, Anostraca). Crustaceana, **63**: 169-174.

HALL, K. J. & C. BURNS, 2002. Mortality and growth responses of *Daphnia carinata* to increases in temperature and salinity. Freshwater Biology, **47**: 451-458.

HURLBERT, S. H., W. LOAYSA & T. MORENO, 1986. Fish-flamingo-plankton interactions in the Peruvian Andes. Limnolology and Oceanography, **31**: 457-468.

HURLBERT, S. H., M. LÓPEZ & J. O. KEITH, 1984. Wilson's phalarope in the central Andes and its interaction with the Chilean flamingo. Revista Chilena de Historia Natural, **57**: 47-57.

MENU-MARQUE, S., J. J. MORRONE & C. LOCASCIO DE MITROVICH, 2000. Distributional patterns of the South American species of *Boeckella* (Copepoda, Centropagidae): a track analysis. Journal of Crustacean Biology, **20**: 262-272.

PARADA, M., 1990. Flamencos en el norte de Chile: distribución, abundancia y fluctuación en números. Acta I Reunión Internacional de Especialistas de Flamencos Sudamericanos: 67-79. (Corporación Nacional Forestal Chile and Zoological Society of New York).

RICHASER, F., H. ALONSO & C. SALAZAR, 1999. Geoquímica de aguas en cuencas cerradas: I, II y III regiones, Chile: 221-230. (Technical Report of the Dirección General de Aguas, Chile, the Universidad Católica del Norte, Chile, and the Institut de Recherche pour le Développement, France; Chilean Second District).

SOTO, D. & L. ZÚÑIGA, 1991. Zooplankton assemblages of Chilean temperate lakes: a comparison with North American counterparts. Revista Chilena de Historia Natural, **64**: 569-581.

VALERO-GARCÉS, B. L., M. GROSJEAN, A. SCHWALB, M. GEYN, B. MESSERLI & K. KELTS, 1996. Limnogeology of Laguna Miscanti: evidence for mid to late Holocene moisture changes in the Atacama altiplano. Journal of Paleolimnology, **16**: 1-21.

WILLIAMS, W. D., T. R. CARRIC, I. A. E. BAYLY, J. GREEN & D. B. HERBST, 1995. Invertebrates in salt lakes of the Bolivian altiplano. International Journal of Salt Lake Research, **4**: 65-77.

ZÚÑIGA, O., R. WILSON, R. RAMOS, E. RETAMALES & L. TAPIA, 1994. Ecología de *Artemia franciscana* en la laguna Cejas, Salar de Atacama, Chile. Estudios Oceanológicos, **13**: 71-84.

ZÚÑIGA, L., V. CAMPOS, H. PINOCHET & B. PRADO, 1991. A limnological reconnaisance of Lake Tebenquiche, Salar de Atacama, Chile. Hydrobiologia, **210**: 19-24.

First received 30 June 2003.
Final version accepted 24 February 2004.