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Null models for understand crustaceans communities in inland waters in San Pedro de Atacama and Salar de Atacama basin, Antofagasta region, Chile

Utilización de Modelos nulos para la comprensión de las comunidades de crustáceos en aguas continentales de las cuencas de San Pedro de Atacama y Salar de Atacama, Región de Antofagasta, Chile

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ABSTRACT

The inland waters in the Andes Mountains in the extreme north of Chile are in a zone with a marked arid climate in the called Atacama Desert (23º S, Antofagasta region, Chile) that has sporadic rains mainly in January or February (summer rains/Altiplano winter), many of these water bodies have high mineral contents due high mineral contents, and low species diversity (mainly crustacea and insecta). The present study aims to do a comparative analysis of inland water crustaceans in different kinds of water bodies in the surroundings of San Pedro de Atacama and Salar de Atacama in the north of Chile using co-occurrence null model analysis. The results revealed a scarce species richness and random species associations due to the lack of a structured pattern and many recurring species in the studied sites. Species reported, and species associations agree with literature descriptions. Nevertheless, more ecological studies would be necessary to understand the community patterns in these water bodies.
Keywords: Atacama Desert, saline lakes, water bodies, crustaceans, communities.

RESUMEN

Los cuerpos de agua en la cordillera de los Andes del extremo norte de Chile están en una zona con un clima árido marcado en el denominado Desierto de Atacama (23º S, Región de Antofagasta, Chile), que tiene lluvias esporádicas en enero o febrero (lluvias estivales/invierno altiplánico), muchos de estos cuerpos de agua tienen alto contenido de minerales y baja riqueza de especies (principalmente crustáceos e insectos). El objetivo del presente estudio es realizar un análisis comparativo de los crustáceos de aguas continentales en diferentes tipos de cuerpos de agua en los alrededores de San Pedro de Atacama y del Salar de Atacama en el norte de Chile usando análisis de modelos nulos de co-ocurrencia de especies. Los resultados revelaron que hay baja riqueza de especies y que las asociaciones de estas son aleatorias, debido a la carencia de un patrón estructurado, por la presencia de muchas especies repetidas en los sitios estudiados. Las especies reportadas y las asociaciones de especies reportadas concuerdan con los antecedentes de la literatura. No obstante, serían necesario más estudios ecológicos para comprender los patrones comunitarios en estos cuerpos de agua.
Palabras claves: *Desierto de Atacama, lagos salinos, cuerpos de agua, crustáceos, comunidades.*

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Introduction

The inland waters in the extreme north of Chile are located in a zone with a marked arid climate (Niemeyer and Cereceda, 1984; Luebert and Plitscoff, 2006), and these kinds of water bodies, mainly in the mountains, are characterized by the presence of intermittent streams that are originated in Andes mountains and disappear in saline plains, shallow lagoons, and wetlands with different salinity levels (Niemeyer and Cereceda, 1984). The crustacean fauna reported in these kinds of water bodies has low species richness that is due mainly to high mineral contents due the high evaporation, possibly found a significant inverse relation between salinity and species richness (De los Ríos-Escalante, 2010), also many or practically the totality of these ecosystems have not fishes, and the main zooplankton predator would be aquatic birds that would predate on different crustaceans species (Hurlbert *et al*., 1986; De los Ríos-Escalante, 2010).

The first studies of these sites were directed to native brine shrimps populations represented by the species *Artemia franciscana* Kellog, 1906 (Gajardo *et al*., 1998), that inhabit at salinity levels upper than 90 g/L being the exclusive component in zooplankton (De los Ríos-Escalante, 2010). Also, under salinities lower than 90 g/L, and upper than 10 g/L the exclusive component in crustacean assemblage is the halophilic copepod *Boeckella poopoensis* Marsh, 1906 (De los Ríos and Bayly, 2018), and in salinities levels lower than 10 g/L it is possibly found in crustaceans a wide kind of crustacean species mainly cladocerans (*Daphnia* sp., *Alona* sp) and other calanoids copepods of *Boeckella* genus such as *B. gracilipes, B. calcaris, B. occidentalis* (De los Ríos-Escalante, 2010). Nevertheless, in recent decades crustaceans have been reported in other types of freshwater wetlands that were not considered in previous studies, which present marked differences in the species reported (Muñoz-Pedreros *et al*., 2013, 2015, 2019).

The present study aims to carry out a literature revision of crustaceans species associations reported for different kinds of water bodies in the surroundings of San Pedro de Atacama and Salar de Atacama to understand the presence of potential structured patterns that can explain the crustacean community of these water bodies, using null models co-occurrence species associations. Furthermore, carry out a comparative study with other ecosystems in the northeast of Algeria.

Material and methods

Data on inland water crustaceans on water bodies for surroundings of San Pedro de Atacama and Salar de Atacama were obtained from the literature (De los Ríos and Crespo, 2004; De los Ríos-Escalante, 2010; 2011; De los Ríos-Escalante *et al*., 2015; Muñoz-Pedreros *et al*., 2013, 2015, 2019); sites without species reported were omitted for analysis (Table 1).

The analysis of the data is performed according to the null models' point of view, that is, the absence of regulatory factors in the community structure, which means determining the random presence or absence in the community structure (Gotelli and Entsminger, 2009), from this point of view, three types of null models were considered: species co-occurrence, size structure, and shared niche. About the species co-occurrence, the data were ordered using an absence/presence matrix. This kind of null model was applied to data from two field periods. A Checkerboard score ("C-score"), a quantitative index of occurrence, measured the extent to which species co-occur less frequently than expected by chance alone (Gotelli 2000). Gotelli and Entsminger (2009) suggested that the following robust statistical models should be used in a co-occurrence analysis. First, the matrix layout must include the species names in rows and the sites in columns. Second, the following models should be used: (1) Fixed-Fixed. In this model, the row and column sums of the matrix are preserved. Thus, each random community contains the same number of species as the original community (fixed column). Each species occurs with the same frequency as in the original community (fixed row). (2) Fixed-Equiprobable. In this algorithm, only the row sums are fixed, and the columns are treated as equiprobable. This null model considers all the sites (columns) equally available for all species, which occur in the same proportions as the original communities. (3) Fixed-Proportional. This model holds the same species occurrence totals as in the original community. The probability that a species occurs at a site (column) is proportional to the column total for that sample. A null model analysis used the software R (R Development Core Team, 2020) and the EcosimR R package (Gotelli and Ellison, 2013).

Results and discussion

The obtained results revealed a relatively low species number for all studied sites from

Table 1. Presence-absence species matrix for crustacean species reported for sites included in the present study.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	G3	G4	G5	G6	G7	G8	
Artemia franciscana Kellog, 1906	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Branchinecta leonensis Cesar, 1985	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	
Alonella excisa (Fisher, 1854)	0	1	1	1	0	1	1	1	1	0	0	0	0	0	0	
Alona pulchella (King, 1956)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Alona sp	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	
Chydorus sphaericus (O.F. Müller, 1785)	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	
Chydoridae indet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Daphnia sp.	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	
Macrothrix Atahualpa Brehm 1936	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	
Macrothrix palearis Harding, 1955	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Simocephalus vetulus (O.F. Müller, 1776)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Diacyclops andinus Locascio de Mitrovich and Menu-Marque, 2001	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	
Eucyclops serrulatus (Fisher, 1851)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cyclopoida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ostracoda	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	
Boeckella poopoensis Marsh, 1906	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Boeckella sp	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
Harpacticoida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hyalella fossamanchini Cavalieri, 1959	1	1	0	1	0	0	1	0	1	0	0	0	0	0	0	
Hyalella kochi González and Wattling 2001	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	
	L1	L3	L4	L5	L6	T	M1	M2	C1	A1	A3	S1	S2	S3	S4	S5
A. franciscana	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
B. leonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. excisa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. pulchella	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Alona sp	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Chydorus sphaericus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Chydoridae indet	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Macrothrix atahualpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macrothrix palearis	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Simocephalus vetulus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diacyclops andinus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Eucyclops serrulatus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cyclopoida	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0
Ostracoda	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Boeckella sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B. poopoensis	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0
Harpacticoida	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
H. fossamanchini	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
H. kochi	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0

Sites included: P (1 to 9): Putana bogs (Muñoz-Pedreros *et al.*, 2015) G (3 to 8): Guatin wetland (Muñoz-Pedreros *et al.*, 2019); L (1 to 6): Lejía lagoon (Muñoz-Pedreros *et al.*, 2013); T (Tebenquiche), M1 (Miscanti); M2 (Miniques); C1 (Capur) (De los Ríos and Crespo, 2004; De los Ríos-Escalante, 2011); A (1 and 2): Atacama river (De los Ríos-Escalante *et al.*, 2015); S (1 to 5): lagoons at Salar de Atacama (De los Ríos and Crespo, 2004; De los Ríos-Escalante, 2011).

one to seven species (Table 1), the sites with one species have halophilic crustaceans such as *Artemia franciscana* or *Boeckella poopoensis* (Table 1); whereas other sites with more species have mainly cladocerans and amphipods such as *Hyalella fossamanchini* and *H. kochi* that have widespread in many studied sites, an interesting situation was the report of *Branchinecta leonensis* that is a rare record considering the scarce report of *Branchinecta* genus in Chile (Table 1). The co-occurrence null model analysis results revealed the existence of random species associations for all models; nevertheless for fixed-fixed simulation the result was close to structured pattern (Table 2).

The obtained results would agree with observations for first observations for subsaline and saline lakes in the Andes Mountains of Argentina, Bolivia, and Peru (Williams *et al*., 1995; De los Ríos and Gajardo, 2010), where the null models revealed the existence of structured pattern for fixed-fixed simulation, whereas for fixed-proportional and fixed-equiprobable the results revealed random presence (De los Ríos and Gajardo, 2010). The difference in the obtained study was because the present data included data from freshwater wetlands (Muñoz-Pedreros *et al*., 2013, 2015, 2019; De los Ríos-Escalante *et al*., 2015) that were not included in the study of De los Ríos and Gajardo (2010). The inclusion of data from freshwater wetlands (Muñoz-Pedreros *et al*., 2013, 2015, 2019; De los Ríos-Escalante *et al*., 2015) that revealed different species composition would be important because these studies included new records of species such as cladocerans as *Macrothrix atahualpa*, *M. palearis*, and *Simocephalus vetulus* that have scare records in Chile (De los Ríos-Escalante and Kotov, 2015), and *Branchinecta leonensis* that has been reported for Argentina; however, this is its first report for Chile (Rogers *et al*., 2021).

These results obtained for northern Chilean saline lakes would be similar to results for saline lakes in the southern extreme of Chile, specifically in the Magallanes region, where it is possible to find many subsaline shallow temporal and permanent lagoons, with salinity range variation lower (5-90 g/L) than observed in Altiplano (5-150 g/L) (De los Ríos-Escalante, 2010). Saline and subsaline lakes in the extreme south of Chile have reported higher species richness than in northern Chile (De los Ríos-Escalante, 2010), including the presence of anostracans of the Branchinecta genus (De los Ríos-Escalante, 2017). The situation is different from that reported for saline lakes in central Argentina, where it is possible to find the presence of the halophilic copepod B. poopoensis with other crustacean species that are not very tolerant to salinity, such as Daphnia menucoensis Paggi, 1996, Moina eugeniae Olivier, 1954, or Cletocamptus deitersi (Richard, 1897) (Vignatti *et al*., 2007).

One interesting comparison between arid ecosystems can be between the north of Chile and the Algerian Sahara desert (De los Ríos-Escalante and Amourayache, 2016) because most of the previous inventories of the benthic fauna of the continental shelf of the Algerian west coast have not been updated (Belhadj Tahar *et al*., 2021) by comparing with Algeria. Research on the benthic macrofauna of the Algerian west coast is generally rare, fragmentary, and mainly concerns the study of a single species. On the one hand according to studies and inventories of macroinvertebrates carried out on the Algerian west coast, 1002 species have been identified, of which (342 are crustaceans) (Belhadj Tahar *et al*., 2021), whereas in eastern Algeria, 198 species have been identified, with 79 species of Crustaceans have been identified On the eastern Algerian coasts by (Derbal and Kara, 2005).

The present study revealed that more in-depth studies are needed to understand community ecological patterns in water bodies located in arid zones, mainly in the north of Chile considering its importance by its diversity and its use for different types of human activities such as subsistence agriculture by native people, or use of towns and industries.

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Table 2. Null model co-occurrence species analysis for studied sites.

Model	Observed index	Mean index	Variance	Standard effect size	P
Fixed-Fixed	11.237	10.954	0.025	1.755	0.051
Fixed-proportional	11.237	12.054	2.799	–0.488	0.673
Fixed-equiprobable	11.237	12.696	0.227	–3.062	0.999

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