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Original Article

Benthic macroinvertebrate communities in Salado and Loa Rivers, Antofagasta Region, Chile

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Abstract: The Loa River is the longest Chilean river with 440 km, located in the Atacama Desert. It has three tributaries' rivers, and its fauna has been poorly studied, due to mainly access difficulties. The aim of the present study was the first characterization of benthic invertebrate community structure in a confluence of Loa and Salado rivers considering the derive invertebrates and benthic communities. The results revealed that species composition in benthic samples has no significant differences between Salado and Loa rivers before the confluence with Salado River, but both sites had significantly high species numbers in comparison to Loa River in Calama after Salado confluence whereas in derive species composition did not have species differences. Finally, the results of null models revealed that species number for three sites had no structured pattern for benthic and derive samples. Ecological and biogeographical topics were discussed here.

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Introduction

The inland waters in the north of Chile have only three permanent rivers viz. San José, Lluta, and Loa, and numerous intermittent and endorheic streams that originated mainly in the Andes mountains and its outflow can be saline plains called "Salar" (Niemeyer and Cereceda, 1984; Valdivieso et al., 2022). Within these water bodies, the Loa River is the longest in Chile, with 440 km length, with tributaries of the San Pedro, Salado, and Salvador rivers (Niemeyer and Cereceda, 1984; De los Ríos et al., 2010; Ruffino et al., 2022). Within these tributaries, the Salado River is characterized by a salinity relatively higher than the Loa River before its confluence (De los Ríos et al., 2010; Ruffino et al., 2022). The salinity of the Loa River after draining the Salado River increases; therefore, its surrounding basins are not proper for agricultural uses compared to the upper course before the Salado River confluence (Niemeyer and Cereceda, 1984; Ruffino et al., 2022).

The aquatic fauna in the Loa River basin was poorly studied; the fishes communities included native species such as *Mugil cephalus* in the lower course, *Basilichthys semotilus* in the lower and medium course, introduced species of *Gambussia affinis* in the lower and medium course, *Salmo trutta* and *Oncorhynchus mykiss* in the high course (De los Ríos-Escalante and Mardones, 2013). For invertebrate fauna, it was reported the presence of crustaceans, such as *Cryphiops caementarius* in lower zones (Meruane and Morales, 2013; De los Ríos-Escalante and Mardones, 2013), whereas in medium and upper zones there are amphipods of *Hyalella*, ostracods and cladocerans (De los Ríos et al., 2010). Although there are no published studies for other benthic invertebrate groups, such as aquatic insects and mollusks, Silva et al. (1985) reported that *O. mykiss* populations in Loa River predate on aquatic insects and molluscs without

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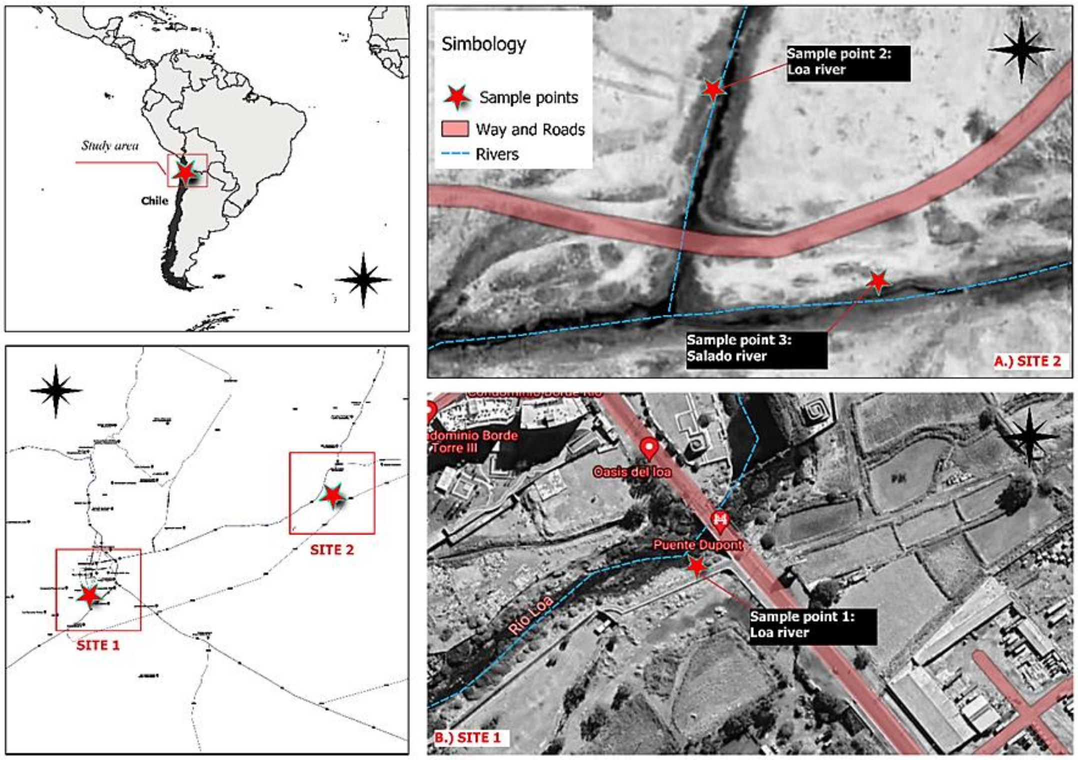

Figure 1. Map of the studied sites.

describing their taxonomical details. Based on De los Ríos et al. (2010), an inverse relation is present between salinity and crustacean species number along the Loa River course, a marked salinity increases from the Salado River confluence to the lower course. On this basis, the present study aimed to investigate the community composition in terms of species richness and species associations in the Loa River before the Salado River confluence, Salado River, and Loa River after the Salado confluence.

Materials and Methods

Study site: The studied site was the Loa River before the Salado River confluence at 40 km of Calama town, close to the Inca Coya lagoon (22°20'S; 68°35'W; Fig. 1), and Loa River in Calama after Salado River confluence, it was considered this zone of Loa River after Salado River confluence due access difficulties.

Loa River before the Salado confluence has low salinity (< 1.0 g/L; De los Ríos et al., 2010; Ruffino et al., 2022) that allows agricultural activities in small villages (Niemeyer and Cereceda, 1984; Ruffino et al., 2022). Whereas Salado is characterized by its relatively high salinity level (5 g/L), the Loa River after the Salado River confluence has a salinity increase until outflow (Niemeyer and Cereceda, 1984; De los Ríos et al., 2010; Ruffino et al., 2022).

Sampling: Benthic invertebrate samplings were collected using a Surber net of 20*20 cm and 500 mm mesh size, whereas derive samples were collected using a plankton net of 50 cm diameter and 100 mm mesh size. All collected specimens were fixed with absolute ethanol and identified according to literature descriptions (Fernandez and Dominguez, 2001; Gonzalez, 2003; Dominguez and Fernandez, 2009). Data from benthic samples were quantified for the use of an abundance matrix and presence-absence species matrix, whereas derive samples were not quantified for the use of a presence-absence matrix.

Data analysis: The first null model applied was based on an absence/presence matrix. It was constructed based on derive species and benthic samples, with the species in rows and the sites in columns. We calculated the Checkerboard score ("C-score"), which is a quantitative index of occurrence that measures the extent to which species co-occur less frequently than

Table 1. Species abundances (ind / 400 cm^2) observed for studied sites.

	Loa River (upper)	Salado River	Loa River (Calama)
Mollusca			
Gastropoda			
Littorinimorpha			
Cochiopidae			
Heleobia sp. Stimpson, 1865	4.333±4.933	0.667±0.577	0.333±0.577
Insecta			
Diptera			
Chironomidae			
Orthocladinae indet.	1.333±1.528	6.333±7.767	48.667±4.163
Tipulidae			
Simulium sp. Latreille, 1802	1.000±1.732	1.333±2.309	0.000±0.000
Trichoptera indet	5.333±2.887	0.333±0.577	0.000±0.000
Ephemeroptera indet.	1.000±1.000	0.000±0.000	0.000±0.000
Plecoptera indet.	0.000±0.000	0.333±0.577	0.000±0.000
Crustacea			
Peracarida			
Amphipoda			
Hyalellidae			
Hyalella sp. Juvenile.	0.000±0.000	2.333±2.082	0.333±0.577
Multicrustacea			
Ostracoda indet.	5.000±8.660	0.000±0.000	0.000±0.000

expected by chance (Gotelli, 2000). A community is structured by competition when the C-score is significantly larger than expected by chance (Gotelli, 2000; Tondoh, 2006; Tiho and Johens, 2007). In addition, we compared co-occurrence patterns with null expectations via simulation. 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), and each species occurs with the same frequency as in the original community (fixed row). In a fixed-equiprobable algorithm, only the row sums are fixed, and the columns are treated as equiprobable. This null model treats all the samples (columns) as equally suitable for all species (Tondoh, 2006; Tiho and Johens, 2007). In the fixed-proportional algorithm, the species occurrence totals are maintained as in the original community, and the probability that a species occurs in a sample (= column) is proportional to the column total for that sample (Tondoh, 2006; Tiho and Johens, 2007). The null model analyses were performed using the software R (R Development Core Team, 2022) and the package EcosimR (Gotelli and Ellison, 2013; Carvajal-Quintero et al., 2015).

A second null model is niche overlap analysis, an individual matrix was built in which rows and columns represented species and sites, respectively. This matrix was used to test if the niche overlaps significantly differed from the corresponding value under the null hypothesis (random assemblage). The models show the probability of niche sharing compared to the niche overlap of the theoretically simulated community (Gotelli and Ellison, 2013). The niche amplitude can be retained or reshuffled and when it is retained it preserves the specialization of each species. In contrast, when it is reshuffled, it uses a wide utilization gradient of specialisation. Furthermore, zero participation in the observed matrix can be maintained or omitted. In the present study, we used the RA3 algorithm (Gotelli and Ellison 2013; Carvajal-Quintero et al., 2015). This algorithm retains the amplitude and reshuffles the zero conditions (Gotelli and Ellison, 2013). This null model analysis was carried out using the software R (R Development Core Team, 2020) and the package EcosimR (Gotelli and Ellison, 2013; Carvajal-Quintero et al., 2015).

For data of derive species number was verified normal distribution with the Shapiro test and variance homogeneity with the Bartlet test, and due to the absence of both conditions a non-parametric Kruskall Wallis test with its respective multiple comparison tests were applied (Zar, 1999). This analysis was applied using software R (R Development Core Team, 2022). Finally, for benthic samples, a Shannon Index was estimated for each site (Zar, 1999; Gotelli and Ellison, 2013b), and a comparison between the Shannon Index by site was calculated based on literature descriptions (Zar, 1999; Magurran and McGill, 2011).

Results

The results revealed the presence of many aquatic insect species in benthic and derived samples (Tables 1, 2). The results of null models revealed the absence of a structured pattern or random presence for all sites and each site was separated for benthic and derived samples (Table 3). The niche overlaps null model revealed that reported species do not share an ecological niche, and in consequence, there is no interspecific competence for total sites, and each site is separated (Table 3).

The result of species number composition was not significantly different for all sites ($x2 = 5.181$, $df = 2$, $P = 0.074$; Table 1). The results of the Shannon Index comparison revealed that the Loa River (upper) after the Loa River before the Salado River confluence and the Salado River were similar in terms of the Shannon Index. In contrast, the Loa River in Calama was significantly different from the Loa River before the Salado confluence and Salado River (Table 4, Fig. 2). An overview, species number was low for all studied sites but it was found lower abundance in the Loa River in Calama in comparison to the other two studied sites (Tables 1, 2; Fig. 2).

Discussions

The results revealed significant differences in species composition for the Loa River in Calama compared to the Salado River and Loa River before the Salado

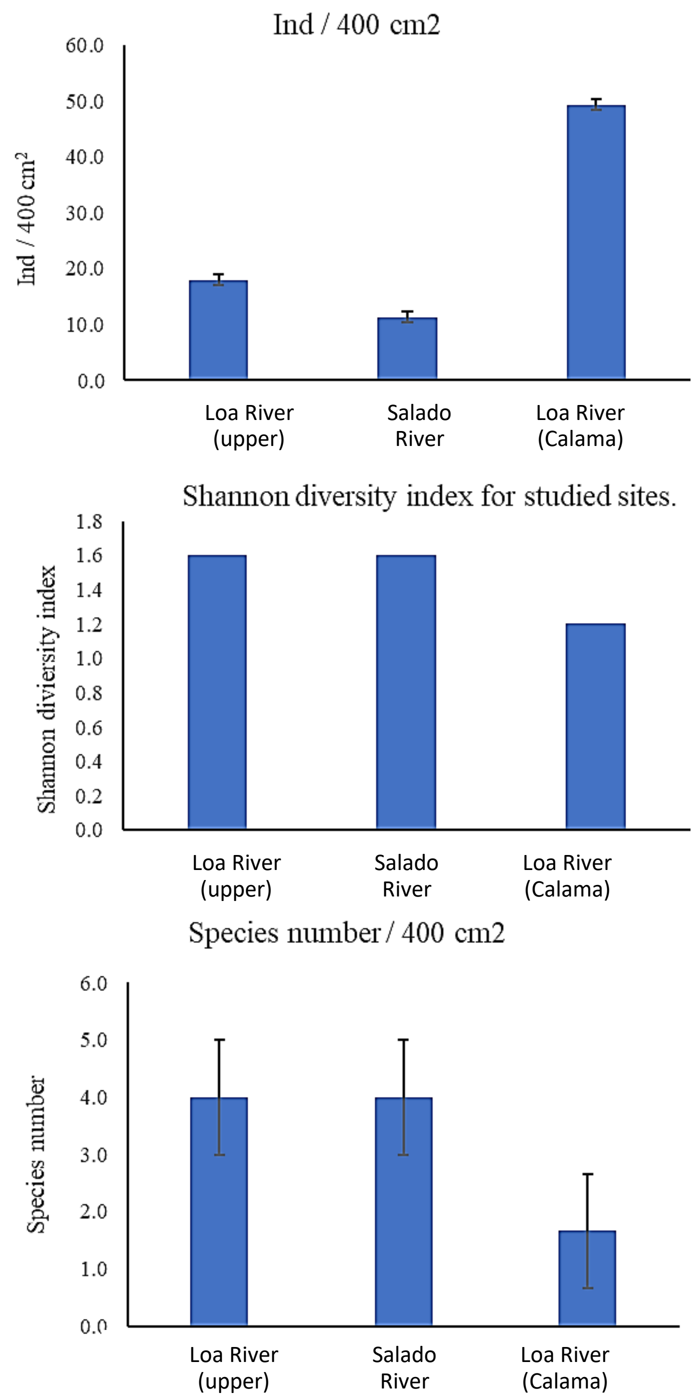

Figure 2. Graphs of species diversity characteristics for studied sites.

confluence. This due probably due to the salinity increase (Williams, 1998; Bradley, 2018) in the course of advanced Salado confluence (De los Ríos et al., 2010), and probably the effect of town in the surrounding basin (Figueroa and De los Ríos-Escalante, 2022). Based on Figueroa et al. (2003, 2007, 2013) and Figueroa and De los Ríos-Escalante

Table 2. Presence-absence matrix for invertebrate derive species for studied sites.

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10	S 11	S 12	S 13	S 14	S 15	S 16	S 17	S 18
Bivalvia indet.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heleobia sp.	0	1	0	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0
Elmis sp.	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Diptera indet.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Orthocladinae indet.	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	0	1
Simulium sp.	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Trichoptera indet.	1	1	1	1	0	1	1	1	1	1	1	0	0	1	0	0	1	0
Ephemeroptera indet.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera indet.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Ostracoda indet.	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hyalella juvenile indet.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Acari indet.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ostracoda indet.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total especies	3	5	3	1	1	6	3	4	3	2	4	4	2	2	1	2	2	2

Note: S1, S2, S3, S4, S5, and S6 = Loa River (Upper); S7, S8, S9, S10, S11, and S12 = Salado River; S13; S14; S15; S16; S17; S18 = Loa River (Calama).

(2022), in sites with low or without human intervention, high species number is found in comparison to sites with human intervention, such as towns and agricultural zones. Along the Loa River, in the lower and middle zones, there are low species numbers compared to the upper zones due to higher salinity increasing from the Salado River confluence, absence of precipitations, and evaporation increase (De los Ríos et al., 2010).

Although there is fish presence in Loa River (De los Ríos and Mardones, 2013), in the studied sites it was not reported fish species, because the trout populations are located in the high course (Silva et al., 1985; Northland-Leppe et al., 2009), and in studied sites would not present fish species (De los Rios et al., 2010; De los Ríos and Mardones, 2013). Then in this scenario, the invertebrate species reported composition would not be affected by fish presence. In terms of crustaceans, the species composition, was similar to the first literature descriptions for the Loa River (De los Rios et al., 2010), and for close high fishless Andean streams (Muñoz-Pedreros et al., 2015, 2019), and water bodies with fishes (Guzman and Sielfield, 2009; Riveros et al., 2013; Sobarzo, 2014; Guerrero et al., 2015).

On this basis, it is necessary to do more ecological studies on the Loa River considering the marked environmental heterogeneity, and climate characteristics of the surrounding basin. Also, the marked geographical isolation of the studied site would affect the endemism of invertebrate communities in terms of species composition. In addition, it is necessary to study the effect of native and introduced fish predation on benthic invertebrates, that generate a complex trophic interaction that would be different from the observations for other Chilean rivers and lakes.

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Table 3. Results of null models' analysis for studied sites. (P-values lower than 0.05 denotes structured species associations for species co-occurrence, or niche overlap).

Species co-occurrence null model: benthic samples				
Fixed-fixed	Total	Loa River (upper)	Salado River	Loa River (Calama)
Observed index	2.027	1.333	4.000	0.000
Mean index	2.005	1.524	3.862	0.000
Standard effect size	0.206	-1.160	0.453	NaN
Variance	0.011	0.027	0.091	0.000
P	0.442	0.999	0.394	0.999
Fixed-proportional	Total	Loa River (upper)	Salado River	Loa River (Calama)
Observed index	2.027	1.333	4.000	0.000
Mean index	2.158	1.198	1.721	0.000
Standard effect size	-0.192	0.145	1.904	-0.712
Variance	0.460	0.868	1.430	0.138
P	0.585	0.511	0.057	0.999
Fixed-equiprobable	Total	Loa River (upper)	Salado River	Loa River (Calama)
Observed index	2.027	1.333	4.000	0.000
Mean index	4.798	7.923	5.355	1.833
Standard effect size	-5.739	-2.630	-0.819	-2.921
Variance	0.232	6.277	2.745	0.393
P	0.999	0.999	0.767	0.999
Species co-occurrence null model: derive samples				
Fixed-fixed	Total	Loa River (upper)	Salado River	Loa River (Calama)
Observed index	1.475	1.466	1.033	0.933
Mean index	1.594	1.538	1.074	0.990
Standard effect size	-1.394	-0.446	-1.390	-0.689
Variance	0.010	0.025	< 0.001	0.006
P	0.909	0.746	0.972	0.999
Fixed-proportional				
Observed index	1.475	1.466	1.033	0.933
Mean index	2.962	2.079	1.104	0.656
Standard effect size	-1.495	-0.676	-0.306	0.723
Variance	0.315	0.821	0.053	0.146
P	0.935	0.744	0.647	0.267
Fixed-equiprobable				
Observed index	1.457	1.466	1.033	0.933
Mean index	4.501	4.740	1.068	2.641
Standard effect size	-14.784	-3.880	-0.408	-5.457
Variance	0.042	0.712	0.007	0.098
P	0.999	0.998	0.728	0.999
Niche overlap null model: benthic samples				
	Total	Loa River (upper)	Salado River	Loa River (Calama)
Observed index	0.249	0.659	0.458	0.727
Mean index	0.230	0.513	0.459	0.496
Standard effect size	0.360	0.626	-0.007	1.454
Variance	0.002	0.008	0.009	0.025
P	0.298	0.066	0.386	0.230

Table 4. Shannon index values (±variance) for studied sites, and results of Shannon index comparison for studied sites ("P" values lower than 0.05 denotes significant differences).

	Shannon index (H)		
Loa River (Upper) (S1)	1.6020±0.007		
Salado River (S2)	1.6020±0.021		
Loa River (Calama) (S3)	1.2041±0.004		
	S1-S2	S1-S3	S2-S3
T observed	0	5.7436	5.0618
n	68	23	34
T critical	1.9971	2.0738	2.0322
P	0.9999	< 0.0001	< 0.0001

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