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FIRST DESCRIPTION OF INVERTEBRATE BENTHIC FAUNA IN MIDDLE ZONE OF THE LOA RIVER (CHILE)

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First Description of Invertebrate Benthic Fauna in the Middle Zone of the Loa River (Chile). De los Ríos-Escalante, P. R., Wilson, R., Norambuena, J. & Esse, C. — Aquatic insect communities in inland waters of Chile are characterised by the presence of certain species depending on water quality, but there is little information on statistical ecology in the structure of insect communities. The aim of the present study was to apply null models to explain the structure of aquatic insects in the middle zone of the Loa River, in the Atacama Desert (Antofagasta Region, Chile; 23° S). The results of the null models of species co-occurrence showed that species associations are random, while niche sharing showed that species share ecological niches and consequently there is interspecific competition. The reported taxa are similar to communities for other North Patagonian rivers in terms of community structure.

Key words: aquatic insects, invertebrate communities, null models, Loa River.

Introduction

Benthic macroinvertebrate communities in rivers vary according to water quality, because in high zones of the river the waters are oxygenated with high dominance of particulate organic matter, and shredding invertebrates, while in medium and low zones a gradual change with low oxygenated waters and filter organisms occurs (Allan et al., 2007). In this context, the literature has proposed the use of macroinvertebrates as indicators of water quality, based on the tolerance to oxygen concentration and organic matter of the benthic fauna (Figueroa et al., 2003, 2007), considering the marked variation of macroinvertebrate communities along the river bed (Figueroa & De los Ríos-Escalante, 2022).

Rivers of Chile are heterogeneous according to their latitudinal gradient: in the Atacama Desert there are small and intermittent rivers in the north (18–23° S), a zone without rivers is in the south (23–27° S), while in the central areas and northern Patagonia (27–38° S) there are rivers with mixed origins from winter rainfall and snowmelt in summer, between 38–41° S there are rivers originating from lake outflows, and south of 41° S there are rivers originating from lake outflows or glacier melt (Niemeyer & Cereceda, 1984; De los Rios-Escalante & Woelfl, in press).

The macroinvertebrate fauna in rivers of Chile was studied mainly between central Chile and central Patagonia (36–46° S) (Figueroa et al., 2003, 2007; Oyanedel et al., 2008; Moya et al., 2009; Vega et al., 2020; Figueroa & De los Ríos-Escalante, 2022; Solís-Lufí et al., 2022).

Northern Chilean rivers are poorly studied due to their geographical isolation: there are three rivers (Lluta, San José and Loa) with headwaters in the Andes that flow into the Pacific Ocean, intermittent rivers that originate in the Andes and reach the Pacific coast, and finally numerous streams that originate in the Andes and disappear in saline deposits (Niemeyer & Cereceda, 1984; De los Rios-Escalante & Woelfl, in press). The few faunal studies have mainly described the benthic crustacean fauna (De los Ríos et al., 2010) and its potential ecological role (De los Ríos-Escalante & Mardones, 2013).

One of the most important rivers in northern Chile is the Loa River, located in the Antofagasta region, which is the longest river in Chile 440 km of length, with three tributaries (San Pedro, Salado and Salvador rivers) (Niemeyer & Cereceda, 1984). The ecosystem of this river has been altered by the presence of introduced fishes, such as rainbow and brown trout in the high zones, and mosquitofish in the low zones, which exert a strong predation on the native invertebrate fauna (Wetzlar, 1979; Silva et al., 1985; Northland-Leppe et al., 2009; De los Rios et al., 2010; De los Rios-Escalante & Mardones, 2013). The aim of the present study is to make a first survey of benthic macroinvertebrates in the middle zone of the Loa River, using co-occurrence and niche sharing null models, in order to understand and characterise the community structure of benthic macroinvertebrates.

Material and Methods

Studied site

The site corresponds to the middle zone of the Loa River, specifically small shallow backwater zones, between the Chacance balneary and a zone close to the main road between the "oficina salitrera María Elena", a Chilean nitrate mining small town to Calama (fig. 1). The first site was "Chacance"or "Coya South Spa", a fluvial balneary where the Loa River receives the apport of the Salvador River (22°23′49″ S; 69°33′37″ W; fig. 1). This site has abundant populations of mosquitofish (*Gambusia affinis*). The Loa River before the Salvador River apportment is moderately saline due to the apportment of the second tributary, the Salado River, and the Salvador River apportment reduces salinity (Niemeyer & Cereceda, 1984; De los Ríos et al, 2010). The second site was a zone of the Loa River, located near the road between the "oficina salitrera María Elena" in the "Posada bridge" to Calama, both sites are located in an arid zone, and there are shrubs growing near the sites in the surrounding basin (22°16'48" S; 69°33'37" W; fig. 1); this site, unlike the first one, has no mosquitofish (*G. affinis*) populations. The study sites correspond to anthropogenic backwaters, as in the case of Chacance, because it was a balneological resort, and to natural flooding zones, as in the case of the second site. The study area was visited in March 2022, after the summer rainy season called "Bolivian winter".

Sampling procedures.

The backwater zones sampling consisted in filtering 5 L water at 100 mm mesh size, samples were fixed in situ absolute ethanol, identified and quantified in laboratory according to specialized literature (Fernández & Dominguez, 2001; González, 2003; Domínguez & Fernandez, 2009). Due that the sites were backwaters zones with many macrophytes abundances, the quantitative samples were considered as individuals by volume (Domínguez & Fernandez, 2009; De los Ríos-Escalante et al., 2020 a). The

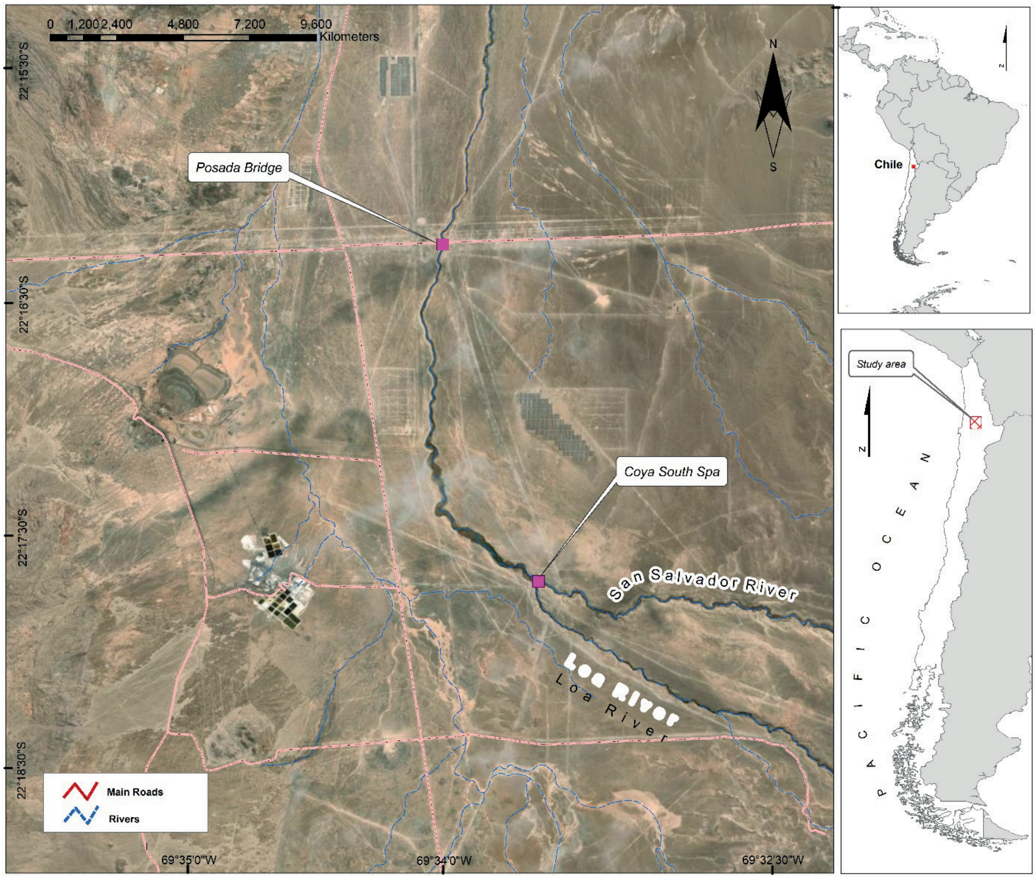

Fig. 1. Map of studied sites.

sampling procedure involves three stations in first site (Chacance or Coya Sur Spa) with three replicates each, because this site is relatively homogeneous, being dammed due to human intervention for the use of this site as a spa. A different situation was reported for the second site, which is relatively heterogeneous with floodplains with rocky and muddy bottoms and zones with high macrophyte abundance, and to reduce the variability of the data collected for this site 12 replicates were considered. In conclusion, more replicates were considered for the second site due to its marked heterogeneity compared to the first site (Brower et al., 1998; Zar, 1999).

Data analysis

A species absence/presence matrix was constructed, 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 expected by chance (Gotelli & Graves, 1996; Gotelli, 2000). A community is structured by competition when the C-score is significantly higher than expected by chance (Gotelli, 2000; Tondoh, 2006; Tiho & Johens, 2007). We also compared co-occurrence patterns with null expectations by simulation. Gotelli & Ellison (2013) proposed the fixed-fixed model as the statistical null model; in this model, the sums of the rows and columns 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). The null model analyses were performed using the "R" software (R Development Core Team, 2009) and the package EcosimR version 7.0 (Gotelli & Ellison, 2013; Carvajal-Quintero et al., 2015).

In a second step, the analysis was carried out under a niche sharing null model using Pianka's overlap index with retained niche breadth and reshuffled null states using 'R' software (R Development Core Team, 2009) and the EcosimR version 7.0 package (Gotelli & Ellison, 2013; Carvajal-Quintero et al., 2015). The EcosimR program also determines whether the measured overlap values differ from what would be expected from a random sample of species data. EcosimR performs Monte Carlo randomisations to create pseudo-communities and then statistically compares the patterns of these randomised communities with those in the real data matrix (Gotelli & Ellison, 2013). In our analysis, all values of the general matrix were randomised 1000 times and the niche width was retained for each species; in this way, the algorithm retained the degree of specialisation for each species (Gotelli & Ellison, 2013; Carvajal-Quintero et al., 2015).

Results and discussion

The results showed a lack of species at one site, and one species (Ostracoda indet.) at two sites specifically located at "Coya Sur Spa"; these sites showed an abundance of mosquitofish (*Gambussia affinis*), which can strongly predate on benthic invertebrates. The other site ("Posada Bridge") had a high number of species, ten species, with the larval stages of *Elmis* sp. being the most abundant and the amphipod *Hyalella kochi* the least abundant (table 1). The marked homogeneity of the three "Coya Sur Spa" sites and the presence of mosquitofish explain, firstly, the relative similarity of the species composition of these sites and the low abundance, especially the very low abundance of ostracods. The situation would be different for the "Posada Bridge" site, where due to the heterogeneity of the environment and the absence of mosquito-fish species composition and abundance differed markedly compared to the Coya Sur Spa site (table 1). Results of the null model analysis indicated that species associations were random and there was overlap of niches (table 2).

The results of the survey indicated that the invertebrate communities were dominated by members of the Coleoptera order, which according to Figueroa et al. (2003, 2007) tolerated waters with low oxygen and high organic matter concentrations, similar to observations for the Cautin River (Figueroa & De los Ríos-Escalante, 2022). However, in the case of the Loa River, the situation may be different due to the noise impact of the Salado River sub-salinity between the Chihu Chihu town and the area in front of the low salinity El Sal-

Table 1. Macroinvertebrate abundances (ind/L; mean ± standard deviation) reported for studied sites. (For each site in Coya South Spa had three replicates; for each site in Posada Bridge has 12 replicates)

Taxon	Coya South Spa 1 (n = 3)	Coya South Spa 2 (n = 3)	Coya South Spa 3 (n = 3)	Posada Bridge (n = 12)
Mollusca Gastropoda: Littorinimorpha: Cochiopidae				
Heleobia sp. Stimpson, 1865	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.08 ± 4.59
Insecta Coleoptera: Elmidae				
Elmis sp.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	6.92 ± 7.50
Insecta Coleoptera: Dytiscidae indet.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.08 ± 2.40
Insecta Plecoptera: **Perlidae** indet.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.19
Insecta Diptera:				
Chironomidae: Orthocladinae indet.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.58 ± 2.36
Tabanidae indet.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.17 ± 0.33
Ephydridae indet.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.29 ± 0.50
Insecta Odonata: Aeshnidae indet.	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.42 ± 1.44
Crustacea Oligostraca: Ostracoda indet.	0.00 ± 0.00	0.70 ± 0,64	0.07 ± 0.12	1.63 ± 3.70
Crustacea Multicrustacea: Malacostraca: Eumalacostraca:				
Peracarida: Amphipoda: Hyalellidae				
Hyalella kochi Gonzalez & Wattling, 2001	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.14

Table 2. Results of species co-occurrence and niche sharing null model analysis for studied sites. ("P" value for species co-occurrence null model upper than 0.05 denotes random in species associations, whereas "P" value for niche sharing null model lower than 0.05 denotes the presence of niche overlap)

Null model	Observed index	Mean index	Variance	Standard Effect size	P
Species co-occurrence	< 0.001	< 0.001	< 0.001	NaN	0.999
Niche sharing	0.983	0.266	0.003	11.569	< 0.001

vador River inflows, in this scenario this Loa River area will have a higher concentration of minerals and nutrients due to the intake of sub-saline waters (Niemeyer & Cereceda, 1984; De los Ríos et al., 2010), which is likely to create a noise effect in measure nutrient concentrations and, as a consequence, the increase in salinity would be inversely related to species richness (Williams, 1998).

The taxa presented for the study area are the first descriptions for the Loa River as there are reports of crustaceans, especially northern Chilean river shrimps (Morales & Meruane, 2013) and amphipods (Gonzalez, 2003; De los Ríos et al., 2010). Gonzalez (2003) mentioned only the presence of *H. fossamanchini* and *H. kochi* inhabiting north of 23° S including the Loa River. De los Rios et al. (2010) described both species for the high and middle channel areas of the Loa River, which is consistent with the observations of this study. The presence of ostracods in the study area is also consistent with the observations of De los Ríos et al. (2010) and the likely presence of this group in the presence of mosquitofish is due to their small body size, which protects them from predation.

Another important component that could affect invertebrate communities would be the presence of mosquitofish, as this species is an active predator of all types of littoral invertebrates and zooplankton species, and in previous observations on the Loa River, particularly at Quillagua approximately 60 km north of the study areas, no littoral or benthic invertebrates were recorded in the presence of mosquitofish (De los Ríos et al., 2010).

Similar observations have been reported for permanent lakes on Easter Island, where it was not possible to find littoral and benthic invertebrates (Dummont & Martens, 1996; De los Ríos-Escalante & Ibáñez, 2015). The presence of mosquitofish and their ecological role as active predators has been described by De los Ríos-Escalante & Mardones (2013). In this scenario, this predator would create competition to the detriment of native fishes such as northern Chilean silversides, or prey on larvae of northern Chilean shrimp.

Results from null models showed that randomness in species associations would be due to the presence of many sites with a single recurrent species, which is associated with active predation by mosquitofish on invertebrates; a situation with a large number of recurrent species in sites followed by randomness in species associations was reported for rivers in northern Patagonia and Chile (Soto et al., 2006, 2007; Vila et al., 1999; De los Ríos-Escalante et al, 2020 b; Solís-Lufí et al., 2022; Figueroa & De los Ríos-Escalante, in press). The presence of niche sharing followed by interspecific competition has also been reported for macroinvertebrate communities in Chilean rivers (De los Ríos-Escalante et al., 2020 b, 2021; Figueroa & De los Ríos-Escalante, 2023; De los Ríos-Escalante & Santibáñez, 2022). Such a result explains the pronounced interspecific competition with low resource availability, which in this case is probably the availability of protective resources against mosquitofish predation.

The results will provide important information on the macroinvertebrate communities in the Loa River in order to understand its ecological structure and functioning as well as to understand the biogeographic patterns of benthic invertebrate species in inland waters.

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