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Original Article

Community structure of benthic invertebrates in the Allipén River basin, North Patagonia, Araucania region (38º S, Chile)

Estrutura da comunidade de invertebrados bentônicos na bacia do rio Allipén, Patagônia Norte, Região da Araucanía (38º S, Chile)

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Abstract

One of the biological indicators most used to determine the health of a fluvial ecosystem are the benthic macroinvertebrates. The presence of recurrent species in a wide gradient of latitudes, dominates the biogeographic pattern of the benthic macroinvertebrates in Chilean fresh waters, nevertheless the knowledge on the communitarian ecology of these in the Chilean rivers continues to be scarce. Null models became a powerful statistical tool for describing the ecological mechanisms that drive the structure of an ecological community and the underlying patterns of diversity. The objective of this study was to determine the community structure of benthic invertebrates in the Allipén River by describing their composition, richness and abundance of species through richness models and null models based on presence/absence. The results reveal a high family richness and low diversity, three phyla, five classes, 11 orders and 28 families were identified in the study area during the four seasons of the year. The Arthropoda phylum was the most representative in abundance and richness. Regarding to richness, Trichoptera (7 families) and Diptera (6 families) followed by Ephemeroptera (3 families) were the orders that showed the greatest diversity of families, however, a low diversity with a H'≤ 1.5 nit was registered in the study area. We demonstrated through the null models, the randomization in the species associations corresponding to the three analyzed sites. The information provided here contributes to the understanding of the ecological patterns of the invertebrate communities in the Allipén River, establishing the basis for more complex ecological studies.

Keywords: macroinvertebrates, null models, fluvial habitat, Toltén river basin.

Resumo

Um dos indicadores biológicos mais utilizados para determinar a saúde de um ecossistema fluvial são os macroinvertebrados bentônicos. A presença de espécies recorrentes em um amplo gradiente de latitudes domina o padrão biogeográfico dos macroinvertebrados bentônicos nas águas doces do Chile; no entanto, o conhecimento sobre a ecologia comunitária destes nos rios chilenos continua escasso. Os modelos nulos se tornaram uma poderosa ferramenta estatística para descrever os mecanismos ecológicos que orientam a estrutura de uma comunidade ecológica e os padrões subjacentes da diversidade. O objetivo deste estudo foi determinar a estrutura da comunidade de invertebrados bentônicos no rio Allipén, descrevendo sua composição, riqueza e abundância de espécies através de modelos de riqueza e modelos nulos baseados na presença / ausência. Os resultados revelam alta riqueza de espécies e baixa diversidade, sendo identificados três filos, cinco classes, 11 ordens e 28 famílias na área de estudo durante as quatro estações do ano. O filo de Arthropoda foi o mais representativo em abundância e riqueza. Em relação à riqueza, Trichoptera (7) e Diptera (6) seguidos por Ephemeroptera (3) foram as ordens que mostraram a maior diversidade de famílias, no entanto, uma baixa diversidade com H'≤ 1,5 nit foi registrada na área de estudo. Demonstramos através dos modelos nulos, a randomização nas associações de espécies correspondentes aos três locais analisados. As informações aqui fornecidas contribuem para a compreensão dos padrões ecológicos das comunidades de invertebrados no rio Allipén, estabelecendo a base para estudos ecológicos mais complexos.

Palavras-chave: macroinvertebrados, modelos nulos, habitat fluvial, bacia do rio Toltén.

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1. Introduction

Freshwater courses represent an essential component in the protection of the natural and cultural community heritage; biologically speaking, they support one of the richest and most diverse habitats, but also include one of the most threatened ecosystems worldwide (Dudgeon et al., 2006; Gioria et al., 2010). An adequate description of the biological community can give indications about the general state of the system, since the properties of the biota depend on environmental processes that can determine distribution and abundance patterns in the river ecosystem (Vannote et al., 1980; Yoder, 1995; Resh et al., 1996). The evaluation by bioassays and bioindicators complemented with the physical and chemical components, leads to a comprehensive water quality biomonitoring, which contributes to provide information to determine environmental risk (Gerhardt et al., 2004). Anthropic activities are the modulating forces of ecosystem changes, which in most cases cause a decrease in water quality. In order to quickly know if the environmental pressures generate changes in the system, the use of biological indicators is recommended, which behave according to the physical-chemical changes, facilitating an integral analysis of the water resource (Springer et al., 2010).

Benthic macroinvertebrates are one of the biological indicators mostly used to determine the fluvial ecosystem health, which reflect the environmental conditions in a specific time and space because the different benthic species have specific tolerance to environmental conditions, that would imply the presence of specific groups under different environmental conditions (Figueroa et al., 2003, 2007). The response to these changes is observed in an increase or decrease of species within the community matrix (Machado, 1988). Therefore, the community composition serves as a predictor of the habitat quality and the biotic integrity of the water system (Rosenberg and Resh, 1993; Allan and Castillo, 2007).

The benthic communities of central-southern Chile rivers (located between 33°S and 39°S) have a specific composition that has adapted to the particular flow conditions that move mostly through mountainous regions, showing a turbulence effect on its route to the ocean, in addition to the relatively large amount of water during much of the year, as a product of the rains in the area in winter and snow melting in summer (Niemeyer and Cereceda, 1984; Arenas, 1995; Vega et al., 2017). These river ecosystems harbor multiple invertebrates' species with high conservation value which, at the same time, are influenced by human intervention (Figueroa et al., 2013). Although there are several studies on benthic macroinvertebrates in various watersheds from Chile, the information gaps are evident, being this, one of the main obstacles for water resources management and conservation (Ramírez and Gutierrez-Fonseca, 2014). Therefore, information of the invertebrate fauna community ecology in Chilean rivers and their specific environmental drivers, remains scarce (Figueroa et al., 2003, 2007, 2010; De los Ríos-Escalante et al., 2015a, b).

In this sense, null models are a powerful statistical tool to describe the ecological mechanisms that drive the structure of an ecological community and the underlying diversity patterns (De los Ríos et al., 2019). Null models for the co-occurrence of species assume a random pattern of associations (Tiho and Josens, 2007), and the absence of overlapping niches, that is, the absence of interspecific competition (Gotelli and Ellison, 2013; Carvajal-Quintero et al., 2015).

The objective of this study was to determine the community structure of benthic macroinvertebrates in the Allipén river describing their composition, the richness and abundance, through models of wealth and null models based on the presence / absence of species.

2. Materials and Methods

The Allipén River rises in the Andes Mountains, in the southern part of Chile, specifically in the La Araucanía region (Medina and Muñoz, 2020; Vargas et al., 2010), afterwards receives the waters of Trufultruful River and Zahuelhue River, it has a 108 km length and a 2,325 km^2 basin area (Figure 1). The river drains to the northern part of the Toltén basin and ends its route 15 km east of Pitrufquén, leading to the Toltén river (38º51'S and 71º45'W) (DGA, 2004). Sampling collection were carried out the months the times of drought or low flow (November 2016 and January 2017) and months the times of flood or high flow (May and August 2017). Three collection points were established along the ecological gradient of the river, from forests with little intervention to grassland areas and forest plantations.

The quantitative samples were carried out using a Surber network with a sampling surface area of 0.09 m^2 and 250 μm mesh opening, considering three replicates per site, standardizing the sampling sites with pebble bottoms (between 6-10 cm), with moderate velocities (0.1-0.2 m s^{-1}) and at a depth between 0.20 and 0.25 m (Figueroa et al., 2007), and were stored in plastic bags, labeled and fixed in Kahle solution for 36-48 hours (Peña, 2006), and then preserved in 95% alcohol. The identification was made up to family taxonomic level with an Olympus SZ 2-ILST stereomicroscope model and dissection material. Taxa identification was performed as described by McLellan et al. (2005), González (2003) and Domínguez and Fernández (2009).The results were expressed in an abundance matrix for each taxon per sampling station (Ind. * m^{-2}), where the community variables were analyzed, such as specific richness, Shannon Log2 (H ') and Simpson (D) diversity indexes (Table 1).

Statistical analysis was performed through multiple regression using the R software (R Development Core Team, 2009) and the HSAUR R package (Everitt and Hothorn, 2016). Two models were run: the first used the number of species and the second used the total abundance as a dependent variable (Tondoh, 2006; Tiho and Josens, 2007). In addition, a matrix of species´ presence / absence was constructed. The "C-score" was calculated as a quantitative occurrence index that measures the degree to which the species coexist, due to causality, less frequently than expected (Gotelli, 2000).

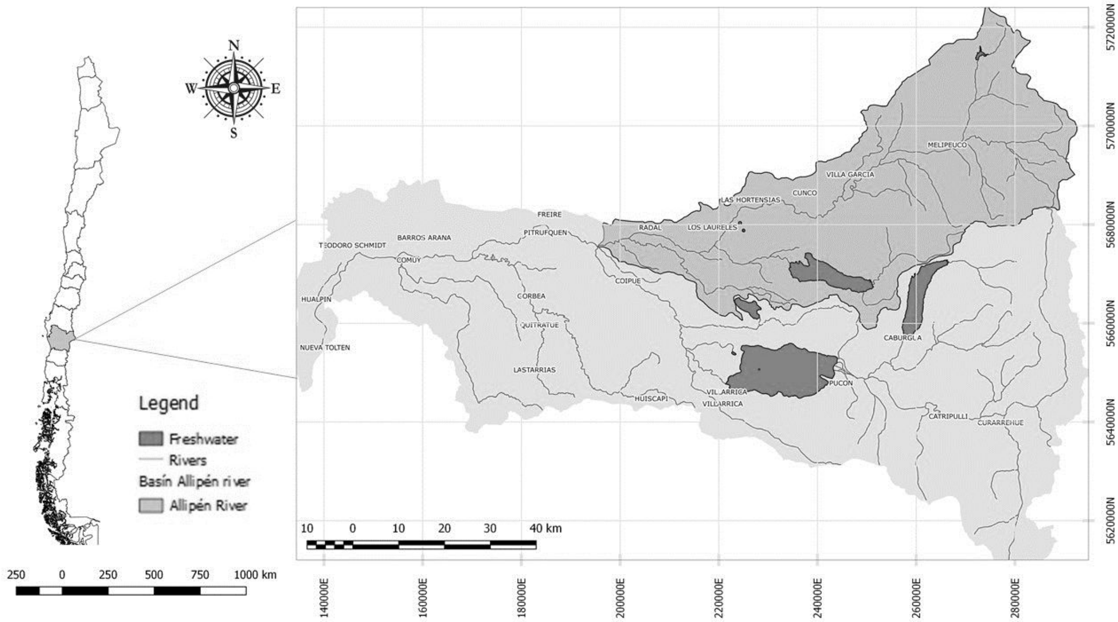

Figure 1. Map of Allipen river, Tolten river basin, La Araucania Region Chile. Where S1 "Melipeuco" (265639 S, 5694829 W), S2: "Huerere" (758774 S- 5681448 W) and S3: "Las Hortensias" (746454 S; 5684086 W) represent the specific sampling stations, respectively.

Table 1. Results of Shannon Log2 (H ') and Simpson (D) diversity indexes for community of benthic invertebrates the Allipén river.

	S1	S2	S3	Average	Standard deviation
Simpson_1-D	0.729	0.608	0.616	0.65	0.068
Shannon_H	1.566	1.314	1.354	1.41	0.135

The community is structured by competition when the C score is significantly higher than the expected by causality (Gotelli, 2000; Tondoh, 2006; Tiho and Josens, 2007). Consequently, we compared the co-occurrence patterns with the null expectations through simulation using Null Fixed-Fixed statistical models (Gotelli and Ellison, 2013). In this model, the row and column sums in the matrix are preserved and each random community contains the same number of families (fixed column), and each family occurs with the same frequency as the original community (fixed row).

3. Results

The fauna richness found in the study area is given in Table 2. A total of 3 phyla, 5 classes, 11 orders and 28 families were identified in the study area during the four seasons of the year, most of these are immature insect stages which account for 95% of the total. Specifically, 13 families were reported in autumn, 8 in winter, 12 families in spring and 13 families in summer (Tables 2, 3 and 4). Due to the impossibility of identifying all the taxa found at the species level, they are treated indistinctly (family, genus, species) as individual units. The Arthropoda phylum was the most representative in abundance and richness than the others phyla.

The orders that showed the greatest diversity of families were Trichoptera (7 families) and Diptera (6 families) followed by Ephemeroptera (3 families) were however, a low diversity with a H'≤ 1.5 unit was registered in the total study area (Table 5). The results for the null model analysis revealed that the associations for the registered families, are random, this mean that there are not structured pattern in species associations observed in studied site (Table 5).

The largest number of benthic macroinvertebrates taxa occurred during the dry season, including four orders and eight families. The most abundant groups were Elmidae (27%), Hydropsychidae (25%) and Chironomidae (18%), throughout the study area. Also important were the groups Gripopterygiidae, Leptophlebiidae, Baetidae and Blephariceridae. The Aeglidae showed the lowest relative abundance being present only in autumn and the Chilinidae (gastropod) nevertheless, it was found in all the sites studied (Tables 1, 2 and 3).

The Coleoptera order, with the Elmidae, showed the highest individual's relative abundance in the site 1 "Melipeuco", during the dry season (46.4%) (Table 1; Figure 2), followed by the Trichoptera order in which the Hydropsychidae showed a 40.3% in autumn. The Chironomidae showed a greater contribution in the site 2 "Huereré" (Table 2) with 34.4% for the site and with its maximum abundance (87.8%) during winter time,

Table 2. Benthic invertebrate abundances (ind/m^2) observed for first site (Melipeuco) during sampling period.

Phyllum	Class	Order	Family	Summer	Spring	Autumn	Winter
Annelida	Oligochaeta	Unidentified	Unidentified	1	0	0	0
Arthropoda	Arachnoidea	Acari	Unidentified	6	0	0	0
	Insecta	Coleoptera	Elmidae	1790	206	488	60
			Psephenidae	0	0	0	0
		Diptera	Athericidae	9	76	13	4
			Blephariceridae	0	1	0	0
			Chironomidae	79	7	169	266
			Empididae	1	0	5	2
			Simuliidae	0	6	35	0
			Tipulidae	1	7	0	50
			Ameltopsidae	0	0	1	0
		Ephemeroptera	Baetidae	78	52	102	42
			Leptophlebiidae	145	191	8	113
		Plecoptera	Austroperlidae	0	0	6	0
			Diamphipnoide	0	1	0	0
			Gripopterygiidae	558	36	300	17
			Notonemouridae	0	0	0	0
			Perlidae	15	3	0	0
			Glossosomatidae	0	0	0	0
			Hydropsychidae	1167	8	642	138
			Hydroptilidae	0	0	0	0
		Trichoptera	Hydrobiosidae	0	4	5	0
			Leptoceridae	0	28	2	1
			Limnephilidae	0	0	0	0
			Polycentropodidae	0	1	2	0
	Malacostraca	Amphipoda	Hyalellidae	0	1	3	4
		Decapoda	Aeglidae	0	0	0	0
Mollusca	Gastropoda	Basommatophora	Chilinidae	0	1	0	0

followed by the Plecoptera order, with the Gripopterygidae which showed an 8.6% abundance on the site and its maximum of 9.8% in autumn, and the Baetidae with 5.7% representativeness, with a maximum of 7.8% in the same season; it should be noted that the three mentioned families were reported in the four seasons of the year (Figure 3). In the Hortensies site 3 (Table 3), eight families were registered and three of them were reported during the four seasons of the year: the Chironomidae, with 43.7%, Elmidae with 18.1%, and Baetidae with 7.4% abundance (Figure 4).

4. Discussion

The Allipén River waters in its downstream route are derived for various anthropogenic activities, receiving wastewater discharges from a range of industrial activities. In some sections of the river system present an interruption of the natural flow, with the presence of agricultural and forestry activities in the marginal strip of the river, in addition to human settlement during the fishing season (Barile et al., 2020). The loss of this natural physical barrier disrupts the dynamics between the river and riverine vegetation favoring the direct entry of an excesses of agrochemicals and fertilizers into the river system, which affects the chemical characteristics and composition of the river biota.

In the upper zone of the basin Allipén River, the number of taxa of the Ephemeroptera, Plecoptera and Trichoptera orders remained relatively constant during the four seasons of the year, being replaced by the Diptera order taxa, in the downstream sites. This

Table 3. Benthic invertebrate abundances (ind/m^2) observed for second site (Huereré) during sampling period.

Phyllum	Class	Order	Family	Summer	Spring	Autumn	Winter
Annelida	Oligochaeta	Unidentified	Unidentified	0	0	0	0
Arthropoda	Arachnoidea	Acari	Unidentified	0	0	0	0
	Insecta	Coleoptera	Elmidae	45	125	19	6
			Psephenidae	0	0	0	0
		Diptera	Athericidae	1	0	0	0
			Blephariceridae	0	179	0	0
			Chironomidae	11	195	1	323
			Empididae	3	0	0	0
			Simuliidae	0	6	1	1
			Tipulidae	0	23	8	3
		Ephemeroptera	Ameltopsidae	0	1	0	0
			Baetidae	24	32	8	30
			Leptophlebiidae	85	88	19	59
			Austroperlidae	0	0	0	0
			Diamphipnoide	0	0	0	0
		Plecoptera	Gripopterygiidae	308	23	62	15
			Notonemouridae	0	0	0	0
			Perlidae	3	0	0	0
			Glossosomatidae	0	0	0	0
			Hydropsychidae	661	6	0	0
			Hydroptilidae	0	0	0	0
		Trichoptera	Hydrobiosidae	0	0	0	0
			Leptoceridae	0	9	0	0
			Limnephilidae	0	2	0	1
			Polycentropodidae	0	0	0	0
	Malacostraca	Amphipoda	Hyalellidae	0	0	2	0
		Decapoda	Aeglidae	0	0	0	0
Mollusca	Gastropoda	Basommatophora	Chilinidae	0	7	0	0

would suggest that the waters of the Allipén River in this area are well oxygenated water and in appropriate conditions for the development of these organisms due do ephemeropters prefer to live in good oxygenation places, in stone and sand substrates (Baptista et al., 2006; Romero et al., 2006; Moya et al., 2009; Oyanedel et al., 2008) and individuals of the Trichoptera order, in their larval phase are very well adapted to rapid water courses and stony substrates in high-speed rivers, and are distributed across all types of habitats, being very well represented in all river flows, except in highly polluted areas (Basaguren, 1990).

The Chironomidae, which prevailed in all Allipén river during the four seasons of the year, included individuals with a high capacity to tolerate high organic load concentrations, and long periods with low oxygen concentrations, facilitating high reproduction rates in these environments (Kay et al., 2001; Newall and Tiller, 2002; Rivera et al., 2004). This higher organic load concentrations could be associated with both urban centers and fish farms discharges, near the study area (FIP, 2017). According to studies by Figueroa et al. (2003, 2007, 2010), for river ecosystems in central southern Chile, only in the lower part, these taxa reach high abundance and biomass, being favored by their tolerance and the high organic detritus availability, which is part of their diet. The development of these activities without environmental criteria is leading to an excessive load of organic pollutants discharged, which minimize the waste elimination capacity of these aquatic ecosystems (Alonso and Camargo, 2005), risking its sustainability for food supply and biodiversity.

Table 4. Benthic invertebrate abundances (ind/m^2) observed for third site (Las Hortensias) during sampling period.

Phyllum	Class	Order	Family	Summer	Spring	Autumn	Winter
Annelida	Oligochaeta	unidentified	Unidentified	0	0	0	0
Arthropoda	Arachnoidea	Acari	Unidentified	0	0	0	0
	Insecta	Coleoptera	Elmidae	352	130	350	16
			Psephenidae	0	0	1	0
		Diptera	Athericidae	15	0	4	1
			Blephariceridae	0	23	0	0
			Chironomidae	289	587	296	188
			Empididae	1	0	1	0
			Simuliidae	0	123	0	0
			Tipulidae	24	0	3	0
		Ephemeroptera	Ameltopsidae	0	0	0	0
			Baetidae	0	19	63	9
			Leptophlebiidae	97	92	54	4
		Plecoptera	Austroperlidae	0	0	0	0
			Diamphipnoide	0	0	0	0
			Gripopterygiidae	121	10	121	3
			Perlidae	20	0	0	0
			Notonemouridae	0	0	2	0
		Trichoptera	Glossosomatidae	0	7	0	0
			Hydropsychidae	321	3	308	106
			Hydroptilidae	0	6	0	0
			Hydrobiosidae	0	2	4	0
			Leptoceridae	0	6	3	0
			Limnephilidae	0	0	0	0
			Polycentropodidae	0	0	2	0
	Malacostraca	Amphipoda	Hyalellidae	0	0	1	0
		Decapoda	Aeglidae	15	0	15	0
Mollusca	Gastropoda	Basommatophora	Chilinidae	0	0	10	1

Table 5. Results of null model analysis for studied sites (values lower than 0.05 denotes the existence of regulator factors in species associations).

Species co-occurrence					
	Observed index	**Mean index**	**Standard effect size**	**Variance**	**P**
Melipeuco	0.367	0.359	0.726	< 0.001	0.284
Huerere	0.382	0.366	0.671	< 0.001	0.256
Las Hortensias	0.484	0.499	-0.794	< 0.001	0.804

Some studies (March and Pringle, 2003; Yam and Dudgeon, 2005) have confirmed the dependence of aquatic invertebrates on allochthonous material that reaches rivers, such as leaves and pieces of wood (detritus) that are consumed as food, and their influence on physical and biological processes, especially in habitat diversification (Nakano et al., 1999; Thompson and Townsend, 2004; Lyon and Gross, 2005; Rios and Bailey, 2006). This aspect becomes vitally important when observe the a partial elimination of riverine vegetation, was detected downstream of the Allipen river (Huereré and Las Hortensias sites) producing an instability in the thermal characteristics of the water column, and an increase of the sediments frequency and aquatic macrophytes,

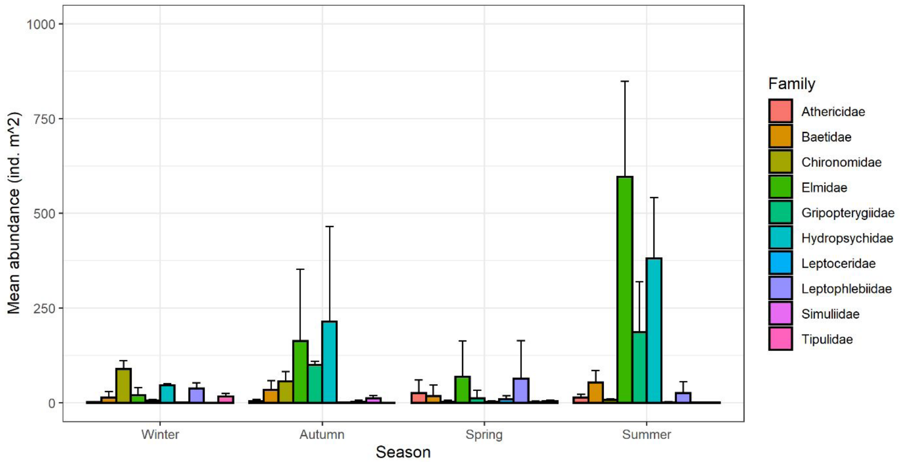

Figure 2. Mean abundance (individuals/m²) the families more representative of benthic macroinvertebrates at site 1 Melipeuco in the Allipen river.

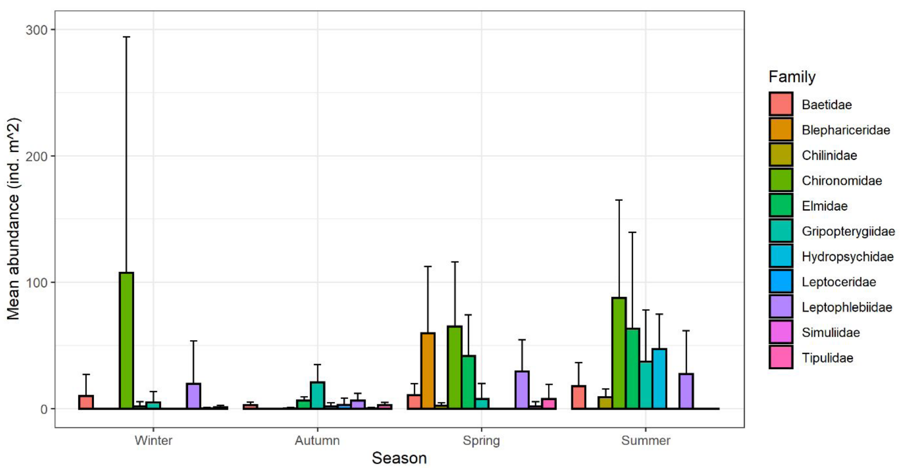

Figure 3. Mean abundance (individuals/m²) the families more representative of benthic macroinvertebrates at site 2 Huereré in the Allipen river.

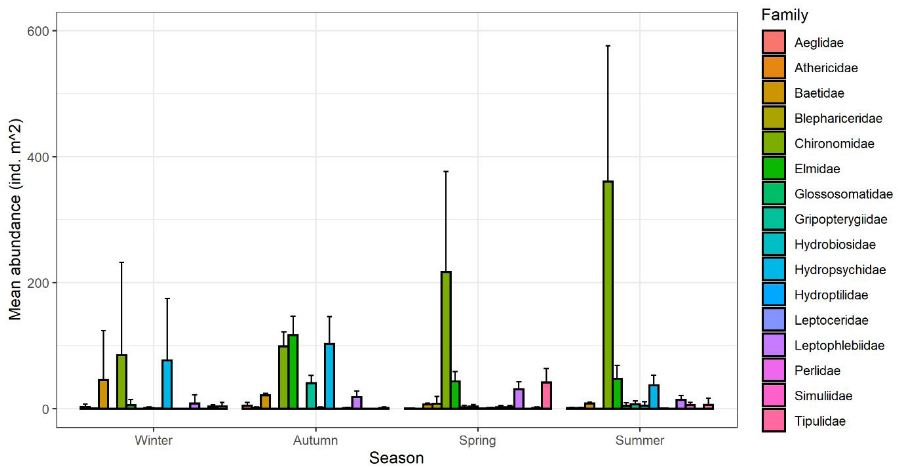

Figure 4. Mean abundance (individuals/m²) the families more representative of benthic macroinvertebrates at site 3 Las Hortensias in the Allipen river.

facilitating the contaminants entry into water bodies (Heartsill-Scalley and Aide, 2003). Among the most important consequences of this environmental pressures, are the water quality deterioration and the biodiversity reduction (Corbacho et al., 2003; Bonada et al., 2006). Over the past decade, studies have shown that the changes in land use have been one of the main drivers of biodiversity loss (Van Diggelen et al., 2005).

The results observed from co-occurrence null model analysis, revealed the absence of structuring pattern in species associations, it is due probably the presence of many species repeated in analyzed sites (Tondoh, 2006; Tiho and Josens, 2007), that is a similar situation observed for Chilean inland waters (De los Ríos et al., 2019; De los Ríos-Escalante et al., 2015b).

Finally, the benthonic macroinvertebrate community in the Allipen river is composed of three phyla; Arthropoda, Mollusca and Annelida five classes; Insecta, Arachnoidea, Malacostraca, Gastropoda and Oligochaeta; eleven orders and twenty-eight families. These results are presented as a first approximation to the biotic community of the Allipén River, so it is suggested, for future research, to incorporate taxonomic refinement at the gender level. However, these background is extremely important due to there is little knowledge about the aquatic biota of this area, moreover knowledge of the diversity of benthic macroinvertebrates in Chile is fragmentary, despite the efforts of many national and foreign researchers, especially since the 19th century (Valdovinos, 2018). From a river conservation perspective, there are no development policies in Chile (Figueroa et al., 2013). In consequence the results presented in this work have a high conservation value and provide unprecedented background information on the bentonite macroinvertebrates of the Allipén River in the Toltén Basin.

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