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Spatial variability and trophic structure of aquatic macroinvertebrate communities in the semi-arid Quilca-Chili basin, Peru

Pastor Coayla-Peñaloza[1]*; https://orcid.org/0000-0002-2317-7154
André Cheneaux-Díaz[1]; https://orcid.org/0000-0002-7148-0174
Ingrid Caceres-Benavente[1]; https://orcid.org/0009-0007-7098-7479
Mauro Caceres-Olcon[1]; https://orcid.org/0009-0005-6728-0443
Maritza Maquera-Ccahua[1]; https://orcid.org/0009-0008-9343-4815
Fernando Cobo[2]; https://orcid.org/0000-0001-5684-266X
Cristina Damborenea[3]; https://orcid.org/0000-0002-6411-1282

1. Universidad Nacional de San Agustín de Arequipa, Av. Alcides Carrión s/n, Arequipa, Perú; pcoaylap@unsa.edu.pe* (Correspondence), acheneaux@unsa.edu.pe, icaceresbe@unsa.edu.pe, mcacereso@unsa.edu.pe, mmaquerac@unsa.edu.pe
2. Departamento de Zoología, Genética y Antropología Física, Facultad de Biología, Universidad de Santiago de Compostela, 15 782 Santiago de Compostela, España; ernando.cobo@usc.es
3. Consejo Nacional de Investigaciones Científicas y Técnicas, División de Zoología de Invertebrados, Facultad de Ciencias Naturales y Museo (FCNyM), Universidad Nacional de La Plata, Paseo del Bosque s/n -B1900FWA, La Plata, Argentina; cdambor@fcnym.unlp.edu.ar

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ABSTRACT

Introduction: The trophic structure of macroinvertebrate communities is of particular interest for understanding the functioning of the river ecosystems.

Objective: To determine the community structure and functional feeding groups of aquatic macroinvertebrates in the Quilca-Chili basin.

Methods: Two sampling campaigns were conducted at 26 stations, distributed across six sectors, from June to October 2022. The community structure was analyzed based on basic ecological parameters, including taxonomic richness, dominance, evenness, and diversity. Spatial variability was assessed through a similarity percentage analysis and non-metric multidimensional scaling using the Bray-Curtis distance index. The relationship with physicochemical variables was determined through canonical correlation analysis.

Results: A total of 51 families were identified and assigned to functional feeding groups: predator, shredder, collector-gatherer, scraper, and filterer. The highest and lowest diversity was observed in the Sihuas sector and the Chili and Lluta sectors, respectively. Differences in community structure indices were found between the six sectors of the basin. The most abundant functional feeding groups were scrapers, while shredders and predators were the least abundant.

Conclusion: The spatial distribution reflects the complexity and variability among physicochemical parameters and functional feeding groups in this basin.

Key words: functional feeding groups; macroinvertebrates; desert; high Andean; rivers.

RESUMEN

Variabilidad espacial y estructura trófica de las comunidades de macroinvertebrados acuáticos de la cuenca semiárida Quilca-Chili, Perú

Introducción: La estructura trófica de las comunidades de macroinvertebrados tiene un interés especial para comprender el funcionamiento del ecosistema fluvial.
Objetivo: Determinar la estructura de la comunidad y los grupos funcionales de alimentación de los macroinvertebrados acuáticos de la cuenca Quilca-Chili.
Métodos: Se realizaron dos muestreos en 26 estaciones, distribuidas en seis sectores, de junio a octubre del 2022. La estructura de la comunidad se analizó según los parámetros ecológicos básicos de riqueza taxonómica, dominancia, equidad y diversidad. La variabilidad espacial se valoró en función de un análisis de similitud porcentual y otro mediante el método no paramétrico de escalamiento multidimensional empleando el índice de distancia de Bray-Curtis. La relación con las variables fisicoquímicas se determinó con un análisis de correlación canónica.
Resultados: Se reconocieron 51 familias que se asignaron a los grupos funcionales de alimentación depredador, desmenuzador, recolector de depósito, raspador y filtrador. La mayor y menor diversidad se presentó en el sector de Sihuas y en los sectores de Chili y Lluta respectivamente. Existieron diferencias de los índices de estructura comunitaria entre los seis sectores de la cuenca. El grupo funcional de alimentación más abundante fue el de los raspadores y los menos abundantes desmenuzadores y depredadores.
Conclusión: La distribución espacial refleja la complejidad y variabilidad entre los parámetros fisicoquímicos y grupos funcionales de alimentación de esta cuenca.

Palabras clave: grupos funcionales de alimentación; macroinvertebrados; desierto; alto andino; ríos.

INTRODUCTION

The study of the trophic structure of macroinvertebrate communities is of particular interest for understanding the functioning of river ecosystems. By assigning these organisms to different functional feeding groups, according to the general classification established by Cummins (1973), we can simplify the taxonomic complexity of the community for each sector of the basin's watercourses and determine the basic functioning in relation to the relative importance of exogenous and endogenous materials. This also helps us understand potential disruptions in the normal flow of energy caused by external inputs (Cummins, 1995; Statzner et al., 2001; Vannote et al., 1980).

In general, the trophic strategies and distribution patterns of macroinvertebrate groups are well known in temperate regions of the globe (Cummins et al., 2008). However, in semi-arid and arid regions, they have been studied little, despite their importance for understanding the behavior of climate variability (Vidal-Abarca et al., 2004).

The arid and semi-arid regions of Peru are characterized by unique geological, geographic, and climatic conditions, subject to highly variable large-scale climatic events such as "El Niño" and "La Niña" (Arana-Maestre et al., 2021). The extreme spatial and temporal variability of climatic conditions in the region results in scarce rainfall that is highly variable in both space and time, which can lead to intense floods and persistent droughts in the rivers. The Quilca-Chili basin is located in the western part of the Andes Mountain range and is the most important in the Arequipa Region of Peru (Autoridad Nacional del Agua [ANA], 2013).

The spatial and temporal heterogeneity of river ecosystems in arid and semi-arid regions suggests that there may be significant differences in the organization of river ecosystems, presenting a scientific challenge to understand the keys to their structure and functioning (Gómez et al., 2001; Likens, 1999; Vidal-Abarca et al., 2004). The aim of this study was to determine the community structure and functional feeding groups of aquatic macroinvertebrates in the Quilca-Chili basin, with the aim of

understanding the role of these organisms in rivers within arid ecosystems of Peru. This valuable information will contribute to improving the integrated management of the basin.

MATERIAL AND METHODS

Study area: The Quilca-Chili basin administratively comprises the provinces of Arequipa, Caylloma, and Camaná in the Arequipa Region. It is located on the Southwestern coast of Peru, between Lat. 15°37'50" S & 16°47'10" S and Long. 70°49'15" W & 72°26'35" W. The basin covers an area of 13 457.01 km², representing 21.24 % of the total area of the region (63 418.34 km²) (ANA, 2023). The Quilca-Chili basin (Fig. 1) has most of its extension in the Province of Arequipa. Geographically, it is characterized by deep, rugged terrain with moderate slopes and narrow canyons, where the land shows a continuous and rapid descent from the summits toward the Pacific Ocean (ANA, 2023).

The main course of the basin takes different names depending on the sector considered (ANA, 2023). From its source in the districts of San Juan de Tarucani (Arequipa Province) and San Antonio de Chuca (Caylloma Province) to the confluence with the Blanco River, it is called the Sumbay River, with a length of 133.7 km. From the confluence with the Blanco River to the confluence with the Yura River in Palca, it is called the Chili River, with a length of 88.20 km. After this confluence, the Chili River changes its name to the Vítor River, with a length of 80.70 km. Further downstream, it receives the waters of the Sihuas River, and again changes its name to the Quilca River, with a length of 23.50 km, which empties into the Pacific Ocean (Carpio-Fernández et al., 2022).

Along this basin, 26 sampling stations were established (Fig. 1). Three stations were located in the Sumbay sector (E24, E25, E26), semi-arid, higher altitude zone, four stations in the Chili sector (E17, E18, E19, E20), which crosses the city of Arequipa, six stations in the Vítor sector (E01, E02, E03, E04, E05, E06), seven stations in the Sihuas sector (E07, E08, E09, E10, E11, E12, E13), three in the Lluta sector (E21, E22, E23), arid zone, and three stations in

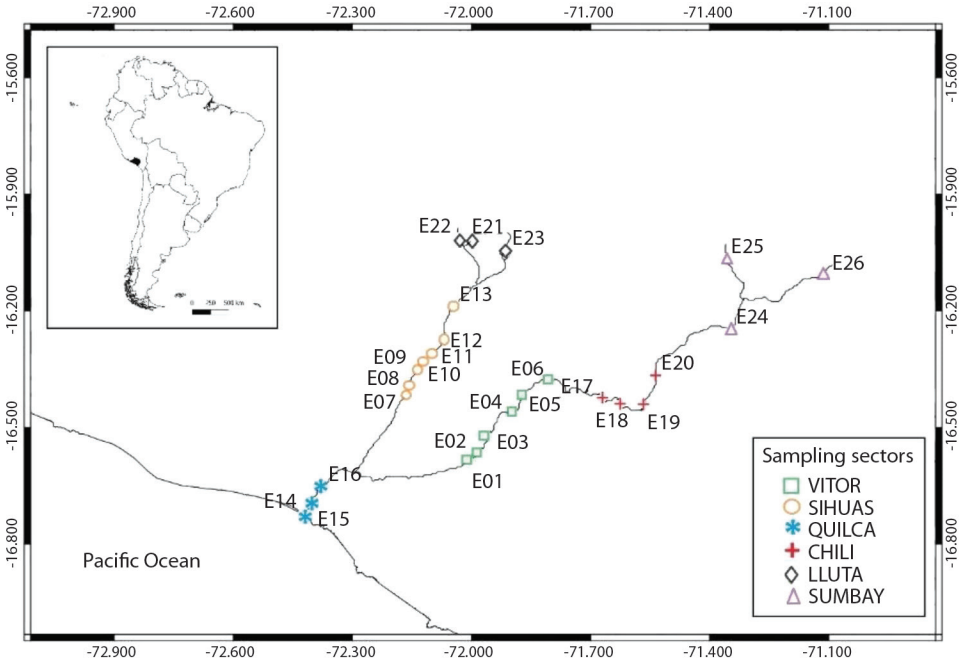

Fig. 1. Location of sampling sectors in the Quilca-Chili Basin of the Arequipa region, Perú.

the Quilca sector (E14, E15, E16), lower part of the river. The sampling method was stratified by sectors, and within the stations, a targeted random sampling was conducted (Maroñas et al., 2010), considering the location and 0.

Sampling and data processing: Biological sampling and physicochemical data collection were conducted between June and October 2022. At each sampling station, three replicates were taken using a Surber net (0.09 m^2) with a 500 μm mesh size. The samples were fixed with 4 % formaldehyde and transported to the laboratory for separation and identification under a stereomicroscope, using the taxonomic keys and descriptions of Cummins et al. (2008); Domínguez & Fernández (2009); Huamantinco & Ortiz (2010); Thorp & Rogers (2014). Simultaneously, physicochemical parameters were measured at each sampling site using a Hanna HI 9 829 multiparameter probe. In situ measurements included water temperature (T °), dissolved oxygen (DO), electrical conductivity (EC), pH, salinity (Sal), total dissolved solids (TDS), and turbidity (Turb). Water velocity and depth were measured using a Global Water FP111 flowmeter to calculate the flow rate (Q) in cubic meters per second.

Macroinvertebrates were grouped into five functional feeding groups: collector-gatherers (DF), predators (P), shredders (SH), scrapers (SC), and filterers (FF), according to Cummins (1973); Baptista et al. (2006); Tomanova et al. (2006); Domínguez & Fernández (2009); Chará-Serna et al. (2010); Rodríguez-Barrios et al. (2011); and Chará-Serna et al. (2012). For specimens with poor information for the Neotropics areas, they were assigned to a functional feeding group based on the classification proposed by Cummins et al. (2008) for North America.

Data analysis: Average abundances per taxon were used to normalize the data and standardize the variance. The number of individuals per taxon was transformed using the square root to reduce the effects of dominant taxa, allowing intermediate and rare taxa to contribute to potential differences between sampling stations before conducting tests. To determine the differences in community composition between sampling sectors, an analysis of similarity (ANOSIM) was performed ($p < 0.05$), creating a matrix using the Bray-Curtis index, which was complemented by a similarity percentage analysis (SIMPER) to identify the taxa that most influence community patterns. To analyze spatial distribution patterns among the sampling stations, the non-parametric Multidimensional Scaling (nMDS) method was applied. These analyses were conducted using the statistical software PRIMER v7 (Clarke & Gorley, 2006).

The evaluation of community structure was carried out using ecological indices analyzed with the software PAST 4.03 (Hammer et al., 2001). Macroinvertebrate abundance data were not standardized before analysis. The indices included species richness (S), Pielou's evenness (J'), Shannon-Wiener diversity index (H'), Simpson's dominance index (D), and were subjected to an ANOVA test to identify significant differences ($p < 0.05$) between sectors.

Canonical Correspondence Analysis (CCA) was applied to establish the relationship between physicochemical parameters and functional feeding groups. Previously, functional feeding groups data were transformed using the square root. This process was carried out using the software PAST 4.03 (Hammer et al., 2001). The relative abundance of functional feeding groups was also subjected to an ANOVA test to identify significant differences between sectors ($p < 0.05$).

RESULTS

Aquatic macroinvertebrates: A total of 20 450 aquatic macroinvertebrate individuals belonging to 79 taxa, distributed across five phylum, 21 orders, and 51 families were collected (Table 1). The highest diversity and abundance corresponded to the class Insecta, with the orders Diptera (37.97 %), Coleoptera (13.92 %), Hemiptera (6.33 %), Trichoptera (6.33 %), Ephemeroptera (6.33 %), and Odonata (5.06 %)

Table 1
Average abundance of aquatic macroinvertebrates by sampling sector in the Quilca-Chili watershed.

Orden	Familia	*Taxa*	GF	Vitor	Sihuas	Quilca	Chili	Lluta	Sumbay
Tricladida	Dugesiidae	*Girardia*	P	28.5	2.83	0	119.33	3.33	12
Triplonchida	Tripylidae	*Tripyla*	P	1.67	1.67	0	0.67	1	6
Rhynchobdellida	Glossiphoniidae	*Helobdella*	SH	1.83	3.5	0	36	0	0.33
Arhynchobdellida	Erpobdellidae	*Nephelopsis*	P	1	0	0	0	0	0
Haplotaxida	Naididae	*Pristina*	CG	9	4.67	4	3	0.67	15
Lumbriculida	Lumbriculidae	*Lumbriculus*	CG	3.17	11.67	1.83	72	117	20.67
Basommatophora	Planorbidae	*Acrorbis*	S	2	0	1	1	0	1
	Physidae	*Physa*	S	43.17	195	2.33	22.33	0	2
Littorinimorpha	Hydrobiidae	*Heleobia*	S	10.33	6	2.17	3 983.67	2.33	1.33
Veneroida	Sphaeriidae	*Pisidium*	F	0	0	0	0.33	0	0
Amphipoda	Hyalellidae	*Hyalella*	CG	4.5	5.5	3	4.67	330	33.33
Podocopida	Cyprididae	*Isocypris*	F	23	197.83	3.33	4.667	5	2.33
Sarcoptiformes	Limnozetidae	*Limnozetes*	P	1.17	1	0	0	0	0
Trombidiformes	Limnesiidae	*Tyrrellia*	P	32.83	148.33	2	5.33	1	19.33
	Hygrobatoidea	Hygrobatoidea1	P	0	0.83	0	0	0	0
Ephemeroptera	Leptohyphidae	*Thicorythodes*	SH	0.17	0.17	0	0	0	0
	Baetidae	*Callibaetis*	CG	0.83	1.17	1.17	0	0	0
		Cryptonympha	CG	23.5	211.33	1.17	115.67	1 638.67	22
		Camelobaetidius	CG	2.33	509.17	0.5	0	0	0
	Oligoneuriidae	*Lachlania*	F	0	8.5	0	0	0	0
Plecoptera	Gripopterygidae	*Falklandoperla*	SH	0	0.67	0	0	5.33	74.33
		Notoperla	CG	0	0	0	0	1	3
Odonata	Aeshnidae	*Aeshna*	P	3	4.67	1	0	2	1
	Libellulidae	*Sympetrum*	P	1.17	4.83	0	0	0	1
	Coenagrionidae	*Argia*	P	3.17	6.17	1	0	0	0
		Ischnura	P	2.17	5	2.5	0	0	0
Trichoptera	Glossosomatidae	Glossosomatidae1	S	0	0.17	0	0	0	0
	Hydrobiosidae	*Cailloma*	P	0	6	0	1	5.67	1.33
	Hydroptilidae	*Metrichia*	S	223.33	442.17	7.17	411	349.33	492
		Neotrichia	S	0	4.17	0	0	0	0
	Leptoceridae	*Nectopsyche*	SH	2.33	0.33	0	1.67	0	0
		Leptoceridae1	CG	1	0	0	0	0	0
Lepidoptera	Crambidae	Crambidae1	SH	1	0	0	0	1	0
Hemiptera	Mesoveliidae	*Mesovelia*	P	0	1	0	0	0	0
	Veliidae	*Microvelia*	P	2.67	4.67	2.17	1.33	0	0.67
		Rhagovelia	P	1	2	0	0	0	0
	Notonectidae	*Notonecta*	P	0	1	0	0	0	0
	Corixidae	*Trichocorixa*	P	0	1	0	0	0	4.67
Coleoptera	Dytiscidae	*Meridiorhantus*	P	0	1.17	1	0	0	0
		Leuronectes	P	0	3.5	0	0	0.33	0
	Hydrophilidae	*Tropisternus*	SH	1	4.67	2	1	0	1
	Staphylinidae	*Thinobius*	P	2.17	2.17	1	0	0.33	0
	Elmidae	*Austrelmis*	P	53.5	166	0.5	1	87	22
		Microcylloepus	S	829.33	679.83	35.83	1.67	7	33.33
		Heterelmis	S	0	1	0	0	0	0

Orden	Familia	*Taxa*	GF	Vitor	Sihuas	Quilca	Chili	Lluta	Sumbay
		Luchoelmis	S	0	0	1	0	0	0
	Limnichidae	Limnichidae1	CG	0	3	3	0	0	0
	Chrysomelidae	Chrysomelidae1	S	0	0.17	0	0	0	0
	Curculionidae	Curculionidae1	SH	0	1	0	0	0	0
Diptera	Blephariceridae	*Paltostoma*	S	1.17	12.17	0	5.67	0.33	0
	Psychodidae	*Pericoma*	CG	1	4.17	3	1	1	1
	Culicidae	*Anopheles*	F	0	2	1	0	0	0
		Aedes	CG	1	1	0	0	0	0
	Simuliidae	*Simulium*	F	29.67	473.17	0	836	1 142.33	46.33
	Ceratopogonidae	*Culicoides*	CG	2.33	20	1.17	1.33	1.33	4.33
		Bezzia	P	0	15	0	0	5.33	0
		Forcipomyia	P	3	0	0.33	0	0	0
	Chironomidae	*Podonomus*	S	0	2	0	0	0.67	5.33
		Tanytarsus	F	34.17	70	1.67	968.67	3.67	8.33
		Aedokritus	CG	44.17	127.17	5.5	88.67	2.67	7.67
		Polypedilum	SH	688.5	147.5	111	55	19.67	7.33
		Larsia	P	5.83	9.5	0	0	9.33	1.33
		Alotanypus	P	16	36	0.5	3.67	3.33	2.67
		Onconeura	F	91.33	251.67	12.83	339.33	1	0
		Cricotopus	CG	60	183.67	1.67	493	194.67	263.33
		Paratrichocladius	CG	51	44.83	10.17	304	537	90
		Corynoneura	F	0	0	0	1	0	0
	Tabanidae	*Tabanus*	F	0	3.67	0	0	1	2.67
	Stratiomyidae	*Stratiomys*	CG	2	2	0	0	0	0
		Nemotelus	CG	1	1.33	0	0	0	0
	Dolichopodidae	Dolichopodidae1	P	4.17	31.83	1.33	26.33	4	2.67
		Dolichopodidae2	P	1	2.17	0	0	1	0
		Dolichopodidae3	P	1	1.5	1	0	0	0.33
	Tipulidae	*Holorusia*	CG	0	2	0	0	1	0
	Empididae	*Neoplasta*	P	3.83	79.83	1.17	2.67	5.33	0.67
	Ephydridae	*Brachydeutera*	CG	0	1.33	0	0	0	2.67
		Ephydra	CG	1	2	0	0	4.67	2
		Scatella	CG	1	3	1	0	0	1
	Muscidae	*Limnophora*	P	6.17	14.83	1	5.33	10.33	2

Functional feeding group al (FG): P = Predator; SH= Shredder; CG= Collector-gatherer; S= Scraper; F= Filterer.

of the total taxa. Twenty-one taxa were shared among the studied sectors of the basin, with the most abundant families being Chironomidae (26.49 %), Cochliopidae (19.59 %), Simuliidae (12.36 %), Baetidae (12.36 %), Hydroptilidae (9.43 %), and Elmidae (9.38 %) of the total number of individuals. The most abundant taxa were *Polypedilum* in the Quilca and Sihuas sectors; meanwhile *Microcylloepus, Heleobia, Simulium, Cryptonympha*, and *Metrichia* in the Vítor, Chili, Lluta, and Sumbay sectors, respectively. SIMPER analysis indicated a global dissimilarity of 60.7 % between all sectors of the basin regarding macroinvertebrate composition, with 16 macroinvertebrate taxa being the most influential in this dissimilarity (Table 2).

The nMDS analysis showed four groups with a 40 % similarity and a stress factor of 0.14 (Fig. 2). The first group consisted of stations in the Quilca sector, located in the lower part

Table 2
SIMPER Analysis of benthic macroinvertebrates in comparing the six sectors.

Sector	Overall average dissimilarity (%)	Taxa	Contribution (%)	Cumulate (%)
Vitor	60.71%	*Simulium*	6.95	6.95
Sihuas		*Heleobia*	6.84	13.79
Quilca		*Microcylloepus*	6.31	20.09
Chili		*Cryptonympha*	6.01	26.10
Lluta		*Metrichia*	5.78	31.88
Sumbay		*Cricotopus*	5.17	37.05
		Polypedilum	4.81	41.87
		Paratrichocladius	4.81	46.68
		Tanytarsus	4.07	50.75
		Onconeura	3.88	54.63
		Camelobaetidius	3.20	57.83
		Austrelmis	2.67	60.50
		Hyalella	2.58	63.08
		Physa	2.41	65.49
		Lumbriculus	2.34	67.83
		Aedokritus	2.28	70.12

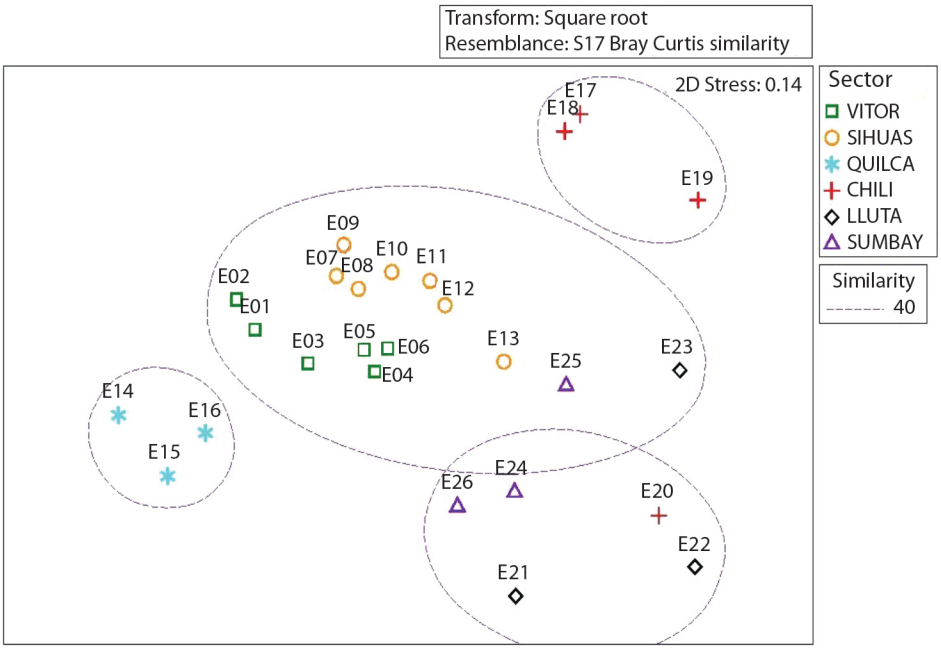

Fig. 2. nMDS of aquatic macroinvertebrate abundances by sampling station.

of the basin (E14, E15, E16), where the most abundant taxa were *Polypedilum* (47.23 %), *Microcylloepus* (15.25 %), and *Onconeura* (5.46 %). The second group included stations from the Vítor and Sihuas sectors (E01 to E13) and two stations from the Lluta and Sumbay sectors (E23, E25), where the most abundant taxa were *Simulium* (16.88 %), *Cryptonympha* (16.17 %), and *Microcylloepus* (15.34 %). The third group comprised stations from the Chili sector (E17,

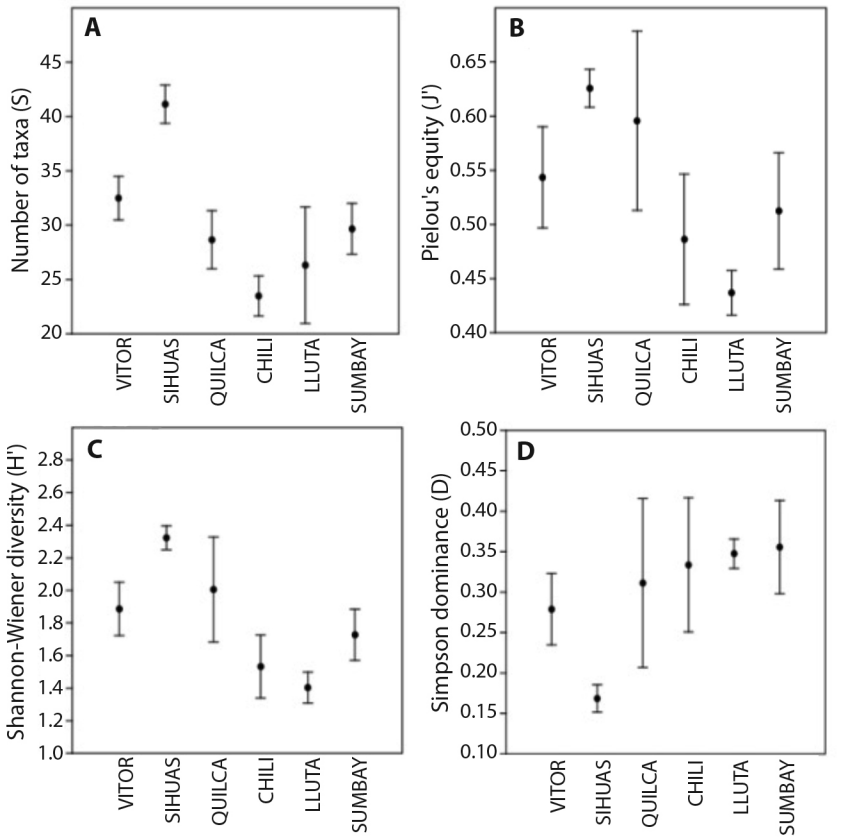

Fig. 3. Macroinvertebrate community structure in the Quilca-Chili watershed. **A.** Number of taxa (S). **B.** Pielou's equity (J'). **C.** Shannon-Wiener diversity (H'). **D.** Simpson dominance (D).

E18, E19), where the most abundant taxa were *Heleobia* (55.13 %), *Tanytarsus* (13.40 %), and *Simulium* (11.48 %). The fourth group was formed by the station located upstream from the city of Arequipa, in the Chili sector (E20), and stations from the Lluta and Sumbay sectors (E21, E22, E24, E26), which are at higher altitudes. The most abundant taxa in these stations were *Metrichia* (31.97 %), *Paratrichocladius* (22.71 %), and *Cryptonympha* (13.24 %). ANOSIM indicated that these groups were statistically significant (R = 0.7621, p = 0.0001).

Species richness (40 taxa) (Fig. 3A), Pielou's evenness (J' = 0.63) and Shannon-Wiener diversity index values (H' = 2.32) (Fig. 3B, Fig. 3C) were highest in the Sihuas sector. Dominance index values (Fig. 3D) were low across all sectors (D < 0.5). Significant differences were found in species richness and diversity, across the river sectors (Table 3).

Functional feeding groups: Of the 79 identified taxa, 29 were predators, 21 collector-gatherers, 12 scrapers, nine filterers, and eight shredders. Scrapers were the most abundant

Table 3
ANOVA test for community structure indices among zones of the watershed. Significant values are highlighted in bold.

	DF	F	*p*
Richness (S)	5	7.548	**0.0004001**
Shannon Diversity Index (H')	5	4.607	**0.0058610**
Pielou's Evenness Index (J')	5	2.299	**0.0835900**
Simpson's Dominance Index (D)	5	2.199	**0.0949500**

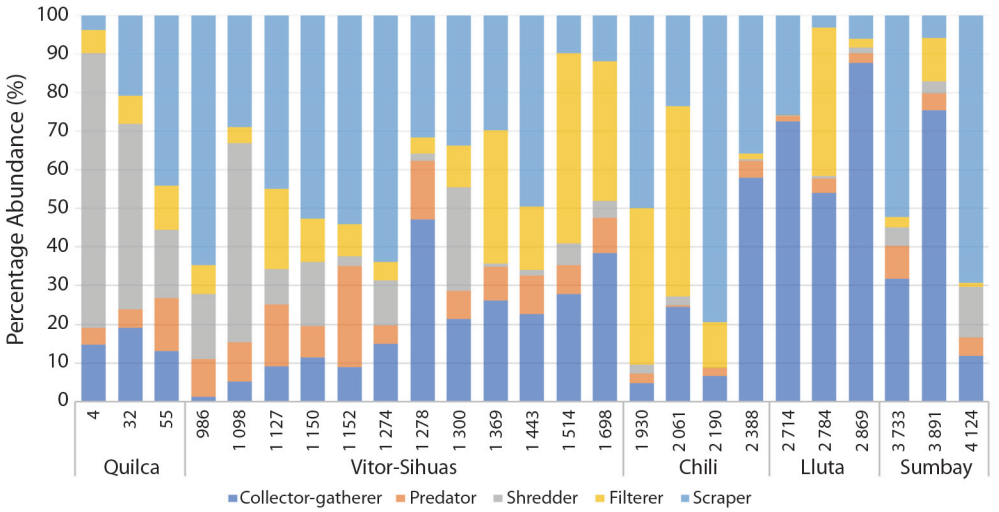

Fig. 4. Relative abundance of aquatic macroinvertebrates by functional feeding groups in the Quilca-Chili basin. The numbers on the x-axis correspond to altitudinal levels.

functional feeding group, accounting for 38 % (7 821 individuals), followed by collector-gatherers with 28 % (5 764) and filterers with 22 % (4 567). Shredders represented 6 % of the total (1 179 individuals), while predators accounted for 6 % as well (1 119 individuals).-

Fig. 4 shows the variation in the relative abundance of aquatic macroinvertebrates by functional feeding group. Collector-gatherers increase upstream, while predators decrease. Shredders increase downstream, being underrepresented in the Chili, Lluta, and Sumbay sectors. Filterers had the highest number of individuals in the middle part of the basin, especially in the Sihuas and Chili sectors. The most abundant filterers families were Simuliidae (12.36 %), Chironomidae (8.72 %), and Cyprididae (1.15 %). Scrapers showed fluctuating values throughout the basin (3.15 to 79.39 %), with the most abundant representatives being the families Cochliopidae (19.59 %), Hydroptilidae (9.43 %), and Elmidae (7.77 %). Significant differences were found between the abundance of functional feeding groups ($F = 3.413$, $p = 0.00594$).

The first two components of the CCA together explained 90.48 % of the accumulated variance in the association between physicochemical variables (Table 4) and functional feeding groups composition. Shredders and collector-gatherers were associated with high dissolved oxygen values, with the highest values in the Quilca sector (E15 and E16). Predators were associated with high total dissolved solids (TDS) values, and scrapers were related to pH, with both groups prevalent at stations E07 and E08. Meanwhile, filterers were associated with lower pH, electrical conductivity, salinity, TDS, and temperature values. High flow rates were inversely associated with filterers and collector-gatherers. In general, stations in the Chili, Sihuas, Lluta, and Sumbay sectors had lower values for the studied physicochemical variables, while the Vítor and Quilca sectors recorded the highest values for these parameters (Fig. 5).

DISCUSSION

The results confirm the presence of a diverse and abundant aquatic macroinvertebrate fauna in the Quilca-Chili basin in the department of Arequipa, which is characterized by arid and semi-arid conditions. In this study,

Table 4
Physicochemical parameters recorded in the sectors of the Quilca-Chili basin during the study period.

Est.	Sector	Temp.[°C]	pH	EC[µS/cm]	TDS [mg/L]	Sal. [psu]	D.O.[mg/L]	Turb.FNU
E01	Vitor	25.72 ± 0	8.45 ± 0	2231.5 ± 266.64	1 120 ± 1.87	1.14 ± 0	8.23 ± 0.02	6.52 ± 0.5
E02	Vitor	22.71 ± 0	8.16 ± 0	3 873 ± 832.67	1 194 ± 1.91	2.05 ± 0	7.26 ± 0.03	11.02 ± 1.21
E03	Vitor	23.86 ± 0	8.65 ± 0	1 579.67 ± 844	790 ± 1.67	0.8 ± 0	9.82 ± 0.13	3.45 ± 0.4
E04	Vitor	23.89 ± 0	8.64 ± 0	1 254 ± 120.28	630 ± 1.57	0.62 ± 0.01	11.1 ± 0.15	4.22 ± 0.32
E05	Vitor	20.44 ± 0.01	8.51 ± 0.01	1 327.33 ± 237.16	660 ± 1.59	0.67 ± 0	9.18 ± 0.26	6.05 ± 1.45
E06	Vitor	16.64 ± 0.12	8.29 ± 0.01	878.33 ± 67.19	440 ± 1.46	0.43 ± 0	7.71 ± 0.03	0.2 ± 0
E07	Sihuas	15.5 ± 0	8.82 ± 0	6 796 ± 4.05	4 417 ± 2.68	3.71 ± 0	9.2 ± 0.03	0 ± 0
E08	Sihuas	18.6 ± 0	8.67 ± 0.01	5 207.83 ± 7.08	3 384.5 ± 4.59	2.79 ± 0.01	8.48 ± 0.01	1.3 ± 1.31
E09	Sihuas	25.8 ± 0	8.36 ± 0	1 482.13 ± 4.97	962.88 ± 3.09	0.7 ± 0	8.8 ± 0.52	1.8 ± 0.29
E10	Sihuas	25.5 ± 0	8.37 ± 0	1 326.2 ± 1.92	861.4 ± 1.14	0.63 ± 0	10.39 ± 0.01	51.79 ± 0.63
E11	Sihuas	26.34 ± 0.05	8.32 ± 0.01	1 112.43 ± 3.26	722.57 ± 2.23	0.53 ± 0	7.47 ± 0.02	0.63 ± 0.17
E12	Sihuas	20.8 ± 0	8.58 ± 0	803.83 ± 1.17	522 ± 0.89	0.34 ± 0	7.69 ± 0.01	15.8 ± 1.66
E13	Sihuas	15.3 ± 0	8.84 ± 0	670.5 ± 0.84	435.33 ± 0.52	0.28 ± 0	8.2 ± 0.01	10.3 ± 1.92
E14	Quilca	25.28 ± 0.01	8.73 ± 0	4 226.5 ± 173.25	2 110 ± 86.84	2.24 ± 0.1	14.2 ± 0.05	7.2 ± 0.49
E15	Quilca	20.32 ± 0.01	8.45 ± 0.01	3 967 ± 167.36	1 980 ± 83.61	2.11 ± 0.09	13.41 ± 0.05	8.6 ± 2.25
E16	Quilca	22.28 ± 0.01	8.78 ± 0	1 928.17 ± 130.02	960 ± 65.11	0.98 ± 0.07	13.45 ± 0.06	9.37 ± 1.52
E17	Chili	9.42 ± 0	8.14 ± 0	754.25 ± 0.5	377 ± 0	0.37 ± 0	7.38 ± 0.02	6.9 ± 0.12
E18	Chili	11.37 ± 0.01	8.09 ± 0	685.5 ± 0.58	343 ± 0	0.34 ± 0	7.09 ± 0.11	5.35 ± 1.17
E19	Chili	10.72 ± 0.01	7.61 ± 0.01	526.25 ± 0.5	263 ± 0	0.26 ± 0	7.1 ± 0.03	1.7 ± 0.22
E20	Chili	8.13 ± 0.01	8.41 ± 0.01	325 ± 0	162.4 ± 0.11	0.16 ± 0	11.14 ± 0.66	58.1 ± 7.62
E21	Lluta	13.59 ± 0.024	8.93 ± 0	1 051.29 ± 1.7	682.71 ± 0.95	0.5 ± 0	7.3 ± 0.01	ND
E22	Lluta	15.56 ± 0.04	8.83 ± 0.01	580.13 ± 1.89	376.63 ± 1.06	0.24 ± 0	7.42 ± 0.01	ND
E23	Lluta	15.55 ± 0.051	8.84 ± 0	1 251.87 ± 1.55	813.25 ± 1.16	0.59 ± 0	7.6 ± 0.02	ND
E24	Sumbay	13.89 ± 0.02	8.83 ± 0	234 ± 0	120 ± 1.05	0.11 ± 0	1.26 ± 0.1	2.97 ± 0.3
E25	Sumbay	11.04 ± 0.01	8.06 ± 0.02	122.83 ± 0.02	60 ± 0.9	0.06 ± 0.1	2.32 ± 0.05	11.08 ± 1.5
E26	Sumbay	9.23 ± 0.07	8.34 ± 0.01	506.67 ± 0.01	250 ± 1.02	0.25 ± 0	1.96 ± 0.1	18.9 ± 1.76

79 taxa conformed the diversity in these basins. These results are similar to those reported (77 taxa) for the Damas River watershed (Figueroa et al., 2003) as well as for the Lluta River (Ferru & Fierro, 2015) in Chile. This similarity most likely due to these are desert ecosystem rivers, which exhibit similar characteristics. However, the diversity found in this study is lower than reported for the Burkina Faso basin in West Africa (Kabore et al., 2016), which shows variability determined by fluvial factors and human activity.

It has been reported that aquatic macroinvertebrate communities are primarily composed of Diptera (Ferru & Fierro, 2015; Hankel et al., 2018; Kabore et al., 2016; Leal-Bastidas et al., 2021), Plecoptera (Figueroa et al., 2003), and Coleoptera (Nieto et al., 2016). Also, a greater richness of families from the order Diptera was found, followed by Coleoptera and Ephemeroptera. This responds by the wide distribution and adaptability of Diptera to different environmental conditions (Gutiérrez-Garaviz et al., 2014), even in areas with varying levels of disturbance. This is the case with many members of the family Chironomidae, known for their high tolerance to pollution, which were found to be most abundant in the Quilca sector (the lower part of the basin), where an increase in mud or fine particulate matter likely promotes their development.

The differences in groupings between zones found in the multidimensional scaling analysis (nMDS) can be attributed to local

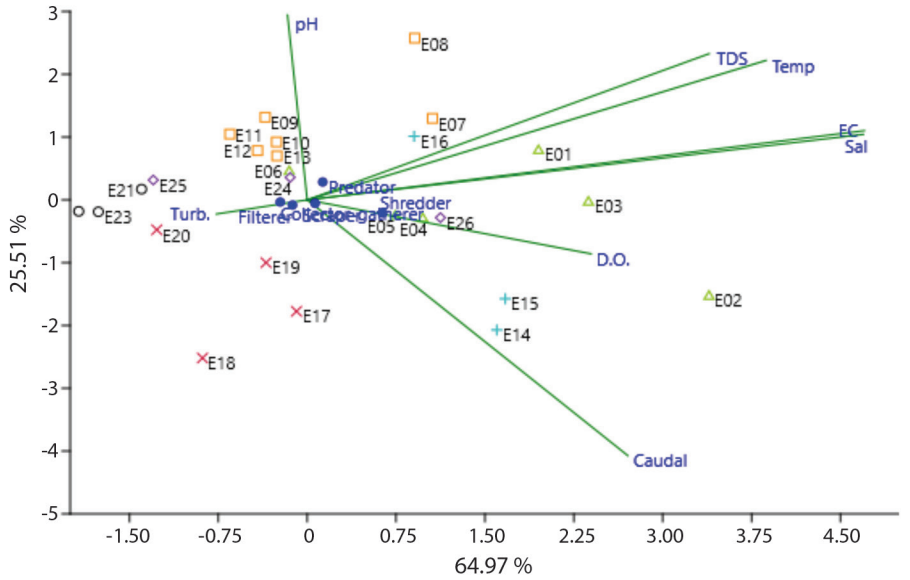

Fig. 5. Canonical Correspondence Analysis (CCA) between trophic functional groups and physicochemical variables.

factors such as the presence of urban areas (Carrasco-Badajoz et al., 2022) and intense agricultural activity, particularly in the middle and lower parts of the basin. These factors influence the distribution and composition of aquatic macroinvertebrates.

Species richness is influenced by both local and regional factors, such as dispersal and historical events (Rodrigues-Capítulo et al., 2020). Phenomena such as "El Niño" and "La Niña" are of great importance in the basin, as they affect climate variability and the annual rainfall pattern, ultimately determining water availability. These events shape the environmental and substrate characteristics of all rivers in the region, which are important factors in species distribution (Schenková et al., 2016), as well as in the development of aquatic vegetation (Lin & Yo, 2008). Macroinvertebrates have been reported to be associated with specific substrates; for example, collectors prefer gravel sediments, while predators favor macrophytes (Rodrigues-Capítulo et al., 2020). This likely occurs in all sectors of the basin.

Significant differences in species richness and diversity were found among the river sectors in this study. Richness and diversity were highest in the Sihuas sector, which may be related to specific factors such as reduced flow and the presence of emergent plants. These macrophytes provide a stable habitat (Habib & Yousuf, 2015), offering shelter and protection from predation (Bendary et al., 2023; Gallardo et al., 2017). Diversity indices have also been used to assess rivers with declining water quality (Zhang et al., 2021), where lower values are linked to human-induced disturbances. It is likely that the low values found in the Chili sector are due to it being the most populated area of the basin. In contrast, the low diversity values found in the Lluta sector may be related to the shape of the river, which is canyon-like, torrential, and lacks vegetation, along with other geological factors (Rodríguez-Barrios et al., 2011).

In this study, the most abundant functional feeding groups was the scrapers, followed by collector-gatherers, filterers, shredders, and predators. These results differ from those reported for regions with similar characteristics, where collector-gatherers are the most abundant functional feeding groups (Ferru & Fierro, 2015; Mangadze et al., 2019). The

abundance of scrapers is related to the type of substrate, such as stones, wood, or submerged macrophytes in aquatic environments (Li et al., 2023), where they find their food. These characteristics are present throughout the basin, suggesting a greater availability of periphyton, which promotes the growth of organisms that feed on this resource.

Differences were found in the abundance of functional feeding groups across the sectors of the basin. The most abundant groups throughout the basin were scrapers and collector-gatherers, which replace the dominance that shredders would typically have in tropical rivers (Chará-Serna et al., 2010; Rodríguez-Barrios et al., 2011), as arid and semi-arid basins lack significant amounts of coarse organic matter, which is the primary food source for shredders (Shredder). The feeding habits of scrapers are related to the availability of periphyton (Moyo & Richoux, 2017), while the abundance of collector-gatherers is associated with their ability to acquire any food in the form of fine organic matter (Demars et al., 2021).

Filterers are more abundant in lotic systems (Hanson et al., 2010) due to their unique adaptation to environmental conditions, an adaptive advantage that other groups. In this study, filterers were abundant in sectors with strong currents and higher flow rates, such as in the Sihuas, Chili, and Lluta sectors. Additionally, the presence of filterers is associated with an increase in fine particulate organic matter (FPOM) transport, a common phenomenon during the rainy seasons in such systems (Cummins, 2021; Tamaris-Turizo & Rodríguez-Barrios, 2015; Uieda & Motta, 2007; Wantzen et al., 2008).

Shredders were found to be less abundant in this study, especially in Quilca sector, which is consistent with findings from other rivers in arid zones (Ferru & Fierro, 2015). This is likely due to the scarcity of coarse allochthonous organic matter, as riparian vegetation is sparse or absent in many parts of the basin.

The abundance of predators in the different sectors did not show significant differences and remained constant throughout the basin. Predator abundance depends on the abundance of other functional feeding groups that serve as their prey (Moyo & Richoux, 2017) and remains constant due to their ability to switch prey based on availability (Vannote et al., 1980). This would explain the distribution pattern of predators recorded in the different sectors of this study (Fig. 4), in which functional feeding such as scrapers, collector-gatherers, and shredders are well represented across the basin. A similar pattern was observed by Carrasco-Badajoz et al. (2022) in the Alameda River (Ayacucho, Peru), where predator abundance remained relatively stable along an urban gradient despite marked changes in environmental quality. This suggests that trophic dynamics of predator groups can be resilient to certain types of disturbance, as long as prey availability remains sufficient.

The CCA analysis revealed associations between functional feeding groups and physicochemical variables that were not particularly strong. We found that pH values were associated with scrapers, consistent with reports for Andean zones (Carrasco-Badajoz et al., 2022), where a strong association between pH and this functional feeding groups. Also, we found that predators were associated with high dissolved oxygen levels, as also reported in the works of Moyo & Richoux (2017) and Mangadze et al. (2019), where a positive relationship was found between these functional feeding groups and dissolved oxygen. Additionally, the proportion of predators and collector-gatherers was related to total dissolved solids, consistent with findings from other studies (Mangadze et al., 2019; Moyo & Richoux, 2017).

These findings highlight the complexity and variability of relationships between physicochemical parameters and functional feeding groups in aquatic ecosystems. It is essential to consider these relationships when designing management and conservation strategies for aquatic resources in the Quilca-Chili basin, underscoring the importance of specific research in this region for effective resource management and biodiversity conservation.

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REFERENCES

Arana-Maestre, J., Carrasco-Badajoz, C., Coayla-Peñaloza, P., Rayme-Chalco, C., & Sánchez-Peña, M. (2021). Aquatic macroinvertebrates of arid and semi-arid ecosystems of Peru. *Frontiers in Environmental Science, 9*, 658940. https://doi.org/10.3389/fenvs.2021.658940

Autoridad Nacional del Agua. (2013). *Plan nacional de recursos hídricos del Perú*. https://hdl.handle.net/20.500.12543/224

Autoridad Nacional del Agua. (2023). *Plan de gestión de recursos hídricos en la cuenca Quilca Chili*. Consejo de Recursos Hídricos de Cuenca Quilca Chili. https://cdn.www.gob.pe/uploads/document/file/5436512/4856491-r-j-340-plan-de-gestion-de-recursos-hidricos-en-la-cuenca-quilca-chili.pdf?v=1700234382

Baptista, D. F., Buss, D. F., Dias, L. G., Nessimian, J. L., da Silva, E. R., de Moraes-Neto, A. H. A., de Carvalho, S. N., de Oliveira, M. A., & Andrade, L. R. (2006). Functional feeding groups of Brazilian *Ephemeroptera* nymphs: Ultrastructure of mouthparts. *Annales de Limnologie - International Journal of Limnology, 42*(2), 87–96. https://doi.org/10.1051/limn/2006013

Bendary, R. E., Goher, M. E., & El-Shamy, A. S. (2023). Taxonomic and functional diversity of macroinvertebrates in sediment and macrophyte habitats: A case study, the Ibrahimia Canal, Nile River, Egypt. *The Egyptian Journal of Aquatic Research, 49*(2), 129–135. https://doi.org/10.1016/j.ejar.2023.05.001

Carpio-Fernández, J., Quispe-Yanapa, B., Peña-Laureano, F., & Sulca-Ortiz, P. (2022). *Hidrogeología de la cuenca del río Quilca—Vitor—Chili* (Boletín Serie H: Hidrogeología, N.º 132). Instituto Geológico, Minero y Metalúrgico – INGEMMET. https://hdl.handle.net/20.500.12544/3885

Carrasco-Badajoz, C., Rayme-Chalco, C., Arana-Maestre, J., Álvarez-Tolentino, D., Ayala-Sulca, Y., & Sánchez-Peña, M. (2022). Aquatic macroinvertebrate trophic guilds, functional feeding groups, and water quality of an Andean urban river. *Frontiers in Environmental Science, 10*, 1003207. https://doi.org/10.3389/fenvs.2022.1003207

Chará-Serna, A. M., Chará, J. D., Zúñiga, M. del C., Pearson, R. G., & Boyero, L. (2012). Diets of leaf litter-associated invertebrates in three tropical streams. *Annales de Limnologie - International Journal of Limnology*, *48*(2), 139–144. https://doi.org/10.1051/limn/2012013

Chará-Serna, A. M., Chará, J. D., Zúñiga, M. del C., Pedraza, G. X., & Giraldo, L. P. (2010). Clasificación trófica de insectos acuáticos en ocho quebradas protegidas de la ecorregión cafetera colombiana. *Universitas Scientiarum*, *15*(1), 27–36. https://doi.org/10.11144/javeriana.SC15-1.tcoa

Clarke, K. R., & Gorley, R. N. (2006). *PRIMER v6: User manual/tutorial (Plymouth Routines in Multivariate Ecological Research)*. PRIMER-E Ltd.

Cummins, K. W. (1973). Trophic relations of aquatic insects. *Annual Review of Entomology, 18*, 183–206.

Cummins, K. W. (1995). Invertebrates. In P. Calow, & G. E. Petts (Eds.), *The rivers handbook: Hydrological and ecological principles* (Vol. 1, pp. 234–250). Blackwell Scientific.

Cummins, K. W. (2021). The use of macroinvertebrate functional feeding group analysis to evaluate, monitor and restore stream ecosystem condition. *Reports on Global Health Research*, *4*, 129.

Cummins, K. W., Merritt, R. W., & Berg, M. B. (2008). Ecology and distribution of aquatic insects. In R. W. Merritt, K. W. Cummins, & M. B. Berg (Eds.), *An introduction to the aquatic insects of North America* (4th ed., pp. 105–122). Kendall/Hunt.

Demars, B. O. L., Kemp, J. L., Marteau, B., Friberg, N., & Thornton, B. (2021). Stream macroinvertebrates and carbon cycling in tangled food webs. *Ecosystems*, *24*(8), 1944–1961. https://doi.org/10.1007/s10021-021-00626-8

Domínguez, E., & Fernández, H. R. (2009). *Macroinvertebrados bentónicos sudamericanos: Sistemática y biología*. Fundación Miguel Lillo.

Ferru, M., & Fierro, P. (2015). Estructura de macroinvertebrados acuáticos y grupos funcionales tróficos en la cuenca del río Lluta, desierto de Atacama, Arica y Parinacota, Chile. *Idesia (Arica)*, *33*(4), 47–54. https://doi.org/10.4067/S0718-34292015000400007

Figueroa, R., Valdovinos, C., Araya, E., & Parra, O. (2003). Macroinvertebrados bentónicos como indicadores de calidad de agua de ríos del sur de Chile. *Revista Chilena de Historia Natural*, *76*(2), 275–285. https://doi.org/10.4067/S0716-078X2003000200012

Gallardo, L., Carnevali, R., Porcel, E. A., & Poi, A. S. G. (2017). Does the effect of aquatic plant types on invertebrate assemblages change across seasons in a subtropical wetland? *Limnetica, 36*(1), 87–98. https://doi.org/10.23818/limn.36.07

Gómez, R., Vidal-Abarca, M. R., & Suárez, M. L. (2001). Importance of the subsurface–surface water interaction in the wetland structure and dynamic in arid and semiarid areas. In C. Griebler, D. L. Danielopol, J. Gibert, H. P. Nachtnebel, & J. Notenboom (Eds.), *Groundwater ecology: A tool for management of water resources* (pp. 317–322). European Commission – Environment and Climate Programme.

Gutiérrez-Garaviz, J., Zamora-González, H., & Andrade-Sossa, C. (2014). Efecto de la actividad antrópica sobre la composición y diversidad de macroinvertebrados acuáticos en el río Cofre (sistema lótico andino colombiano). *Revista Biodiversidad Neotropical*, *4*, 113. https://doi.org/10.18636/bioneotropical.v4i2.137

Habib, S., & Yousuf, A. R. (2015). Effect of macrophytes on Phytophilous macroinvertebrate community: A review. *Journal of Entomology and Zoology Studies*, *3*(6), 377–384.

Hammer, O., Harper, D. A. T., & Ryan, P. D. (2001). PAST: Paleontological Statistics Software for education and data analysis. *Paleontologia Electronica, 4*, 1–9.

Hankel, G. E., Emmerich, D., & Molineri, C. (2018). Macroinvertebrados bentónicos de ríos de zonas áridas del noroeste argentino. *Ecología Austral*, *28*(2), 435–445.

Hanson, P., Springer, M., & Ramirez, A. (2010). Capítulo 1: Introducción a los grupos de macroinvertebrados acuáticos. *Revista de Biología Tropical*, *58*(4), 3–37. https://doi.org/10.15517/rbt.v58i4.20080

Huamantinco, A. A., & Ortiz, W. (2010). Clave de géneros de larvas de Trichoptera (Insecta) de la Vertiente Occidental de los Andes, Lima, Perú. *Revista Peruana de Biología*, *17*(1), 75–80. https://doi.org/10.15381/rpb.v17i1.54

Kabore, I., Ouédraogo, I., Tampo, L., Ouéda, A., Moog, O., Guenda, W., & Melcher, A. H. (2016). Composition and dynamic of benthic macroinvertebrates community in semi-arid area rivers of Burkina Faso (West Africa). *International Journal of Biological and Chemical Sciences*, *10*(4), 1542–1561. https://doi.org/10.4314/ijbcs.v10i4.8

Leal-Bastidas, C., Vargas-Chacoff, L., Sandoval, N., & Fierro, P. (2021). Variabilidad temporal y espacial de los macroinvertebrados acuáticos y la calidad del agua en el río Palena, Patagonia Chilena. *Gayana (Concepción)*, *85*(2), 132–145. https://doi.org/10.4067/S0717-65382021000200132

Li, Y., He, Y., Liu, M., Uddin, K. B., Zhao, Y., Wang, H., Cui, Y., & Wang, H. (2023). Benthic macroinvertebrate assemblages in relation to high ammonia loading: A 5-year fertilization experiment in 5 subtropical ponds. *Environmental Pollution*, *337*, 122587. https://doi.org/10.1016/j.envpol.2023.122587

Likens, G. E. (1999). Afterword: Reflections and needs. In T. W. Hoekstra, & M. Shachak (Eds.), *Arid lands management. Toward ecological sustainability* (pp. 269–272). University of Illinois Press.

Lin, K. J., & Yo, S. P. (2008). The effect of organic pollution on the abundance and distribution of aquatic oligochaetes in an urban water basin, Taiwan. *Hydrobiologia*, *596*(1), 213–223. https://doi.org/10.1007/s10750-007-9098-x

Mangadze, T., Wasserman, R. J., Froneman, P. W., & Dalu, T. (2019). Macroinvertebrate functional feeding group alterations in response to habitat degradation of headwater Austral streams. *Science of The Total Environment*, *695*, 133910. https://doi.org/10.1016/j.scitotenv.2019.133910

Maroñas, M. E., Marzoratti, G., Vilches, A., Legarralde, T., & Darrigran, G. (2010). *Guía para el estudio de macroinvertebrados. II. Introducción a la metodología de muestreo y análisis de datos* (Vol. 12). ProBiota, Facultad de Ciencias Naturales y Museo (FCNyM), Universidad Nacional de La Plata (UNLP). http://hdl.handle.net/1834/23510

Moyo, S., & Richoux, N. B. (2017). Macroinvertebrate functional organisation along the longitudinal gradient of an Austral Temperate River. *African Zoology*, *52*(3), 125–136. https://doi.org/10.1080/15627020.2017.1354721

Nieto, C., Malizia, A., Carilla, J., Izquierdo, A., Rodríguez, J., Cuello, S., Zannier, M., & Grau, H. R. (2016). Patrones espaciales en comunidades de macroinvertebrados acuáticos de la Puna Argentina. *Revista de Biología Tropical, 64*(2), 747–762. https://doi.org/10.15517/rbt.v64i2.18801

Rodrigues-Capítulo, A., Armendáriz, L., Siri, A., Altieri, P., Ocon, C., Cortese, B., Rodríguez-Catanzaro, L., Zanotto-Arpellino, J. P., Rodríguez, M., & Donato, M. (2020). Caracterización estructural y funcional de los macroinvertebrados en los bañados de desborde fluvial del área pampeana. *Biología Acuática, 35*, 015. https://doi.org/10.24215/16684869e015

Rodríguez-Barrios, J., Ospina-Tórres, R., & Turizo-Correa, R. (2011). Grupos funcionales alimentarios de macroinvertebrados acuáticos en el río Gaira, Colombia. *Revista de Biología Tropical, 59*(4), 1537–1552. https://doi.org/10.15517/rbt.v59i4.3418

Schenková, J., Bílková, M., & Horsák, M. (2016). The response of Clitellata (Annelida) to environmental gradients in spring fens. *Limnologica, 57*, 73–82. https://doi.org/10.1016/j.limno.2016.01.004

Statzner, B., Hildrew, A. G., & Resh, V. H. (2001). Species traits and environmental constraints: Entomological research and the history of ecological theory. *Annual Review of Entomology, 46*(1), 291–316. https://doi.org/10.1146/annurev.ento.46.1.291

Tamaris-Turizo, C. E., & Rodríguez-Barrios, J. (2015). Transporte de materia orgánica a lo largo de un río tropical de montaña en la Sierra Nevada de Santa Marta (Colombia). *Acta Biológica Colombiana*, *20*(3), 209–216. https://doi.org/10.15446/abc.v20n3.45421

Thorp, J. H., & Rogers, D. C. (Eds.). (2014). *Ecology and general biology* (4th ed., Vol. 1). Elsevier.

Tomanova, S., Goitia, E., & Helešic, J. (2006). Trophic levels and functional feeding groups of macroinvertebrates in Neotropical streams. *Hydrobiologia, 556*(1), 251–264. https://doi.org/10.1007/s10750-005-1255-5

Uieda, V. S., & Motta, R. L. (2007). Trophic organization and food web structure of southeastern Brazilian streams: A review. *Acta Limnologica Brasiliensia, 19*, 15–30.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, *37*(1), 130–137. https://doi.org/10.1139/f80-017

Vidal-Abarca, M. R., Gómez, R., & Suárez, M. L. (2004). Los ríos de las regiones semiáridas. *Ecosistemas: Revista Científica y Técnica de Ecología y Medio Ambiente*, *13*(1), 16–28.

Wantzen, K. M., Yule, C. M., Mathooko, J. M., & Pringle, C. M. (2008). Organic matter processing in tropical streams. In D. Dudgeon (Ed.), *Tropical stream ecology* (pp. 43–64). Academic Press. https://doi.org/10.1016/B978-012088449-0.50005-4

Zhang, Q., Yang, T., Wan, X., Wang, Y., & Wang, W. (2021). Community characteristics of benthic macroinvertebrates and identification of environmental driving factors in rivers in semi-arid areas – A case study of Wei River Basin, China. *Ecological Indicators, 121*, 107153. https://doi.org/10.1016/j.ecolind.2020.107153