ORIGINAL ARTICLE

Aquatic Diptera and their relationship with environmental variables in the lower part of the semi-arid Quilca-Chili River basin, Arequipa, Perú

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ABSTRACT

Aquatic Diptera are a diverse and widely distributed group of insects globally. In Perú, knowledge about this group is limited, with existing studies focusing mainly on aquatic community ecology, water quality, and heavy metal pollution. This study aimed to analyze the composition and structure of aquatic Diptera and their relationship with environmental variables in the lower Quilca-Chili River Basin in southern Perú. Environmental variables were measured and Diptera samples were collected from 16 stations during June and October 2022. Community structure and its relationship with environmental parameters were analyzed under conditions of high and low river flow. The results revealed 13 families and 29 genera, with Chironomidae, Simuliidae, Empididae, Ceratopogonidae, Dolichopodidae, and Muscidae being the most abundant. The analysis of similarity and the non-metric multidimensional showed clear separation in dipteran composition and structure among rivers in June, while in October, only Quilca River differed significantly. The greatest variation in taxon richness between low and high flow seasons was observed in the Vitor and Quilca rivers. Diversity indices were compared across rivers and seasons using Kruskal-Wallis and Mann-Whitney tests ($p<0.05$). Significant differences occurred in evenness (June) and all indices (October). Among the physicochemical parameters, temperature and pH remained relatively stable across all rivers, while conductivity and total dissolved solids were consistently high. The canonical correspondence analysis indicated that in June, the abundance of *Polypedilum* and *Forcipomyia* was associated with organic matter. The genera *Tabanus*, *Holorusia*, *Podonomus*, *Paltostoma*, and *Simulium* were associated with dissolved oxygen. In October, *Polypedilum* abundance was positively related to turbidity, dissolved oxygen, salinity, and electrical conductivity, while *Podonomus*, *Paltostoma*, *Tabanus*, *Bezzia*, and *Simulium* were associated with river flow. These findings demonstrate that environmental variables significantly influence river conditions and determine the distribution of Diptera. This study contributes valuable insights into the aquatic Diptera communities of semi-arid river systems.

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Key words: rivers; macroinvertebrates; benthos; bioindicators; insects; Diptera.

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INTRODUCTION

Arid and semi-arid regions are characterized by a negative water balance due to stressful climatic conditions (Vidal-Abarca *et al*., 2004). The southwestern region of Perú exhibits arid and semi-arid characteristics and is particularly vulnerable to climatic variability, such as El Niño events. Therefore, water availability in rivers depends on the spatial and temporal variability of annual precipitation patterns. Both physicochemical conditions and biological communities respond to the hydrological variability of these rivers (Gómez *et al*., 2001; Vidal-Abarca *et al*., 2004). Human activities, such as agricultural practices and intensive, unsustainable use of water resources, generate negative impacts on water quality and modify the river's environmental conditions (Reyes-Palomino and Cano, 2022).

Among aquatic macroinvertebrates, Diptera are the best-adapted group to such stressful conditions (Mosquera and Sánchez, 2019). They are highly diverse insects with a wide global distribution (Castillo-Velásquez *et al*., 2021). Their high colonization capacity is attributed to their morphological variability (Courtney *et al*., 2009; Rojas-Sandino *et al*., 2018; Mosquera and Sánchez, 2019), which enables them to inhabit a wide range of aquatic environments (Roldán and Ramírez, 2008; Mosquera and Sánchez, 2019). Some genera have been reported in heavily polluted waters (Contreras *et al*., 2021), such as members of the Chironomini tribe (Chironomidae), which are widely used as bioindicators of water quality (Serra *et al*., 2016) and are typically abundant in eutrophic environments (Rodríguez *et al*., 2021). This highlights the ecological importance of Diptera in continental aquatic ecosystems (Rodríguez *et al*., 2021).

In South America, knowledge of the taxonomy, biology, and ecology of Diptera is scarce (Rojas-Sandino *et al*., 2018; Rodríguez *et al*, 2021). There is an urgent need to expand studies on this group, particularly to better understand their relationship with environmental variables and the distribution of specific genera in freshwater systems (Rodríguez *et al*., 2021). Additionally, immature stages of Diptera play important roles in aquatic food webs (Rodríguez *et al*., 2021), and some adults are known vectors of diseases (Lotta *et al*., 2016; Rodríguez *et al*., 2021). In Perú, specific studies on aquatic Diptera are lacking. The current knowledge is very limited, with most research focused on aquatic community ecology, water quality (Carrasco *et al*., 2020; Castillo-Velásquez and Huamantinco-Araujo, 2020; Arana *et al*., 2021; Castillo *et al*., 2021; Quispe *et al*., 2021; Coayla-Peñaloza *et al*., 2024), and heavy metal contamination (Pinto *et al*., 2017; Tejada-Meza *et al*., 2023).

However, it is important to understand the ecology of Diptera and their relationship with environmental variables, especially in rivers located in arid and semi-arid areas such as the southern coast of Perú. These river systems are fragile, subject to anthropogenic pressures and high climatic variability. Therefore, the aim of this study was to analyze the community structure of aquatic Diptera larvae and their relationship with environmental variables. This research provides a contribution to the ecological knowledge of aquatic Diptera in the region. The information generated is essential for future research and provides a foundation for conservation planning focused on the aquatic biota of the Quilca-Chili basin in semi-arid river ecosystems.

METHODS

Study area

The study area is located in the lower section of the Quilca-Chili River basin, within the Arequipa region in southern Perú (Fig. 1). The basin covers an area of 13 529.88 km², with rivers

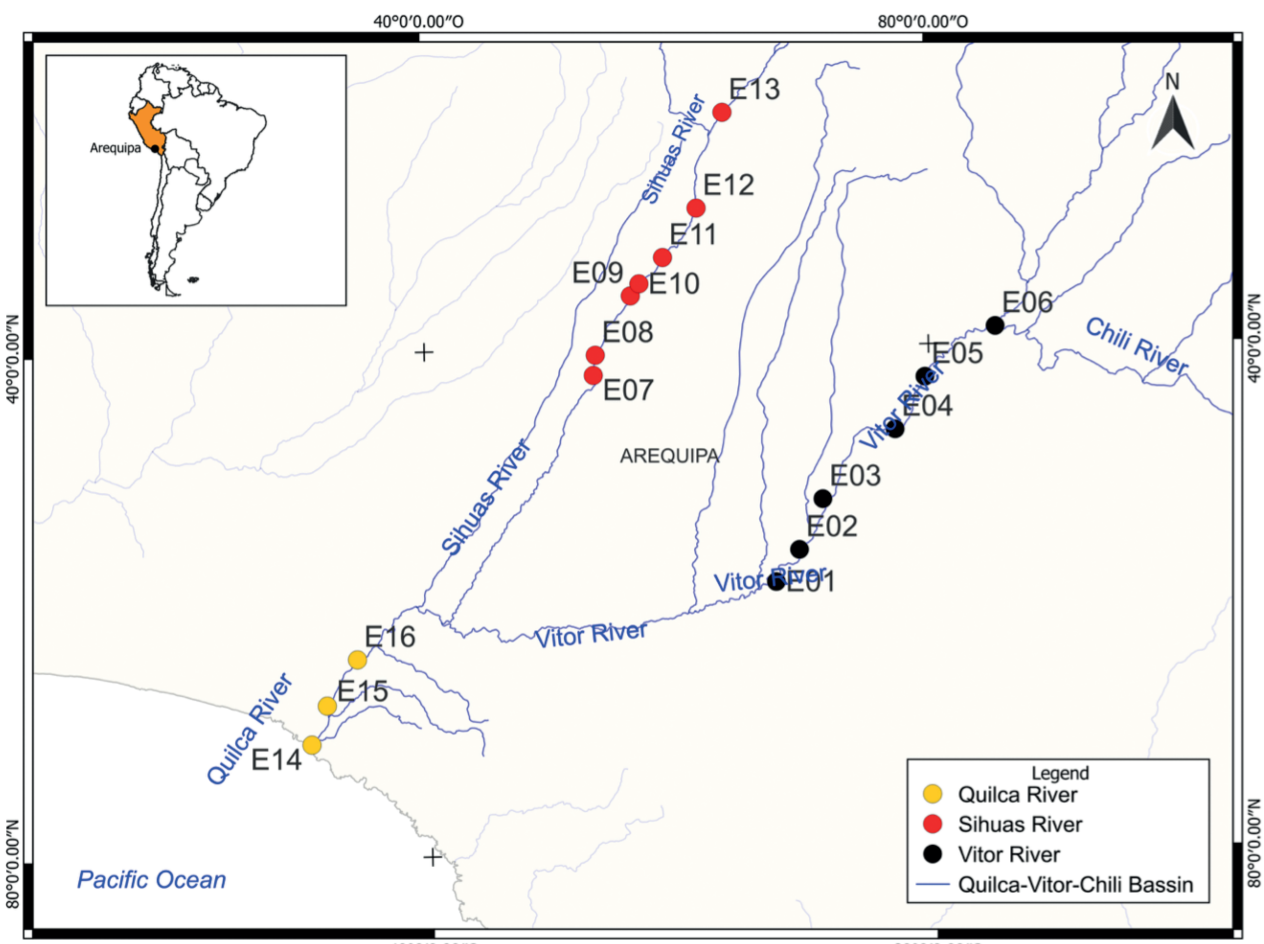

Fig. 1. Study area in the Quilca-Chili basin, Arequipa, Perú.

that drain into the Pacific Ocean along the western slope of the Andes. These rivers exhibit high discharge and torrential flow during the rainy season (December to March), particularly in the middle and upper parts of the basin due to the steep topography. The climate within the basin is variable, influenced by altitude, length, and the geometry of the basin itself. Temperature varies along the altitudinal gradient (Carpio *et al*., 2022). Surface water is regulated by reservoirs located in the upper part of the basin. Water availability primarily depends on rainfall and glacial melt originating above 6000 m asl. The main economic activities in the basin include agriculture, livestock, industry, and mining (Carpio *et al*., 2022). The lower part of the basin is mainly characterized by intensive agricultural activity. In the case of the Sihuas River, water is diverted for the irrigation of crops in adjacent arid areas, leaving only an ecological flow from station 13 onward (Fig. 1). Upstream from the Vitor River lies the densely populated city of Arequipa, where industrial activities, traditional agriculture, and growing urban expansion predominate. Along the Quilca River, agricultural activity is very limited.

Sampling methods

Sampling was conducted during two field campaigns in 2022 (June and October) at 16 stations distributed across the lower basin. At each station, three biological samples were collected using a 500 µm Surber net, covering an area of 0.09 m². The samples were stored in 500 ml plastic jars and fixed with 10% formalin. In the laboratory, the samples were separated on a 500 µm sieve. Organisms were identified to genus level using the identification keys and descriptions of Domínguez and Fernández (2009), Merritt *et al*. (2008), Thorp and Rogers (2015). After analysis, the samples were preserved in 70% ethanol and deposited in the macroinvertebrate collection of the Hydrobiology Section at the Universidad Nacional de San Agustín de Arequipa.

Simultaneously, physicochemical parameters were measured at each sampling site using a Hanna HI 9829 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. In addition, water and sediment samples were collected for the determination of organic matter (OM), which was analysed in an accredited laboratory following the ASTM D2974-20e1 method (Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils).

Data analysis

Descriptive statistics (mean and standard deviation) were applied to the environmental data. To identify the environmental variables with the greatest influence across the rivers in the lower basin, a principal component analysis (PCA) was conducted after logarithmic transformation of the data [Ln(x+1)] to reduce variance. The structure of the aquatic dipteran community was characterized by calculating abundance and diversity indices: Shannon-Wiener (H'), Simpson dominance (D), and Pielou's evenness (J') (Moreno, 2001). To evaluate significant differences ($p<0.05$) in these indices across rivers, non-parametric Kruskal-Wallis tests were performed, followed by pairwise Mann-Whitney post hoc comparisons. These analyses were conducted separately for each diversity metric (Shannon, Dominance, and Pielou's Evenness) during the June and October sampling campaigns. Non-metric multidimensional scaling (NMDS) based on Bray Curtis was used to observe variations in dipteran community composition among the three rivers. An analysis of similarity (ANOSIM) with 9,999 permutations was conducted to evaluate differences in dipteran community structure between rivers across both sampling periods. A canonical correspondence analysis (CCA) was conducted to assess the relationship between environmental variables and dipteran abundance during each sampling period. All analyses were carried out using EXCEL® and PAST software version 4.13 (Hammer *et al*., 2001).

RESULTS

Environmental variables

Tab. 1 summarizes the environmental variables recorded in the rivers of the lower Quilca-Chili basin. Temperature showed similar trends across all three rivers, with lower values in June and higher in October. In all rivers, the pH was slightly alkaline (ranging from 8.21 to 8.65), with little variation between months. Electrical conductivity and total dissolved solids were high in all rivers, increasing further during the dry season (October). Salinity was highest in the Quilca River, located at the end of the basin,

Tab. 1. Mean and standard deviations of environmental variables for each river in the Quilca-Chili Basin.

Parameter	Vitor River		Sihuas River		Quilca River	
	June	October	June	October	June	October
Temperature (°C)	17.56±2.62	22.21±2.99	15.16±3.90	21.35±4.55	16.86±0.94	22.62±2.10
pH	8.36±0.20	8.45±0.18	8.40±0.11	8.55±0.21	8.21±0.17	8.65±0.15
EC (µS cm^{-1})	1017.00±322.87	1857.31±1109.19	1745.54±1357.24	2435.09±2264.71	2447.67±926.35	3373.89±1067.92
TDS (mg L^{-1})	508.50±161.25	928.77±554.61	872.79±678.66	1582.30±1472.08	1223.67±463.39	1687.00±534.08
Sal. (psu)	0.51±0.17	0.95±0.60	0.90±0.75	1.25±1.27	1.27±0.51	1.78±0.59
DO (mg L^{-1})	4.08±1.28	8.88±1.33	7.13±1.01	8.55±0.91	6.87±0.18	13.68±0.38
Turb. (FNU)	10.62±8.49	5.24±3.45	21.35±22.24	-	62.83±104.07	8.39±1.76
OM (%)	3.46±2.83	1.91±0.86	1.51±0.61	2.40±0.88	2.07±1.36	3.60±1.30
Q (m3 s^{-1})	2.60±1.57	1.43±0.76	1.21±0.97	0.37±0.51	3.66±0.93	2.77±0.35

EC, electrical conductivity; TDS, total dissolved solids; Sal, salinity; DO, dissolved oxygen; Turb, turbidity; OM, organic matter; F, flow rate.

which receives runoff from agricultural areas. Dissolved oxygen levels were characteristic of well-oxygenated environments (>6.5 mg L^{-1}), except in the Vitor River during June. The organic matter content was below 3.6% in all three rivers. River discharge was generally low in this section of the basin (average 2.0 $m^3 s^{-1}$), with a significant reduction during the dry season: 55% in the Vitor River, 30% in the Sihuas River, and 75.7% in the Quilca River compared to the high-flow period (June). Regarding turbidity, an average of 21.7 FNU was recorded, with the highest value in the Quilca River (62.83 FNU), followed by the Sihuas River during the high-flow season, averaging 21.35 FNU.

For both sampling periods, the first two axes of PCA explained 89.6% of the total variance (Fig. 2). The variable with the highest contribution to the first component was turbidity. In the second component, total dissolved solids, electrical conductivity, and to a lesser extent, salinity, contributed the most. The PCA did not reveal a clear separation of variables by river, except for discharge in relation to the Quilca River. This behavior was observed during the high-flow (June) and low-flow (October) seasons.

Community structure

A total of 16270 individuals were collected during the study period, belonging to 13 families and 29 genera. The most abundant families were Chironomidae, Simuliidae, Empididae, Ceratopogonidae, Dolichopodidae, and Muscidae. Sixteen genera were recorded in the Quilca River, 23 in the Vitor River, and 28 in the Sihuas River (Tab. 2). Of these, 14 genera (48.3%) were present in all three rivers. The genera *Bezzia* (Ceratopogonidae), *Podonomus* (Chironomidae), *Tabanus* (Tabanidae), *Brachydeutera* (Ephydridae), and *Holorusia* (Tipulidae) were found only in the Sihuas River. During the high-flow season (June), 15 genera were found in the Quilca River, 20 in Vitor, and 26 in Sihuas. In the dry season (October), 11, 16, and 25 genera were recorded in the Quilca, Vitor, and Sihuas rivers, respectively. The average taxon richness in this part of the basin was 18.8%. The most notable differences in taxon richness between June and October were observed in the Quilca and Vitor rivers. In contrast, richness in the Sihuas River remained relatively stable across both hydrological periods.

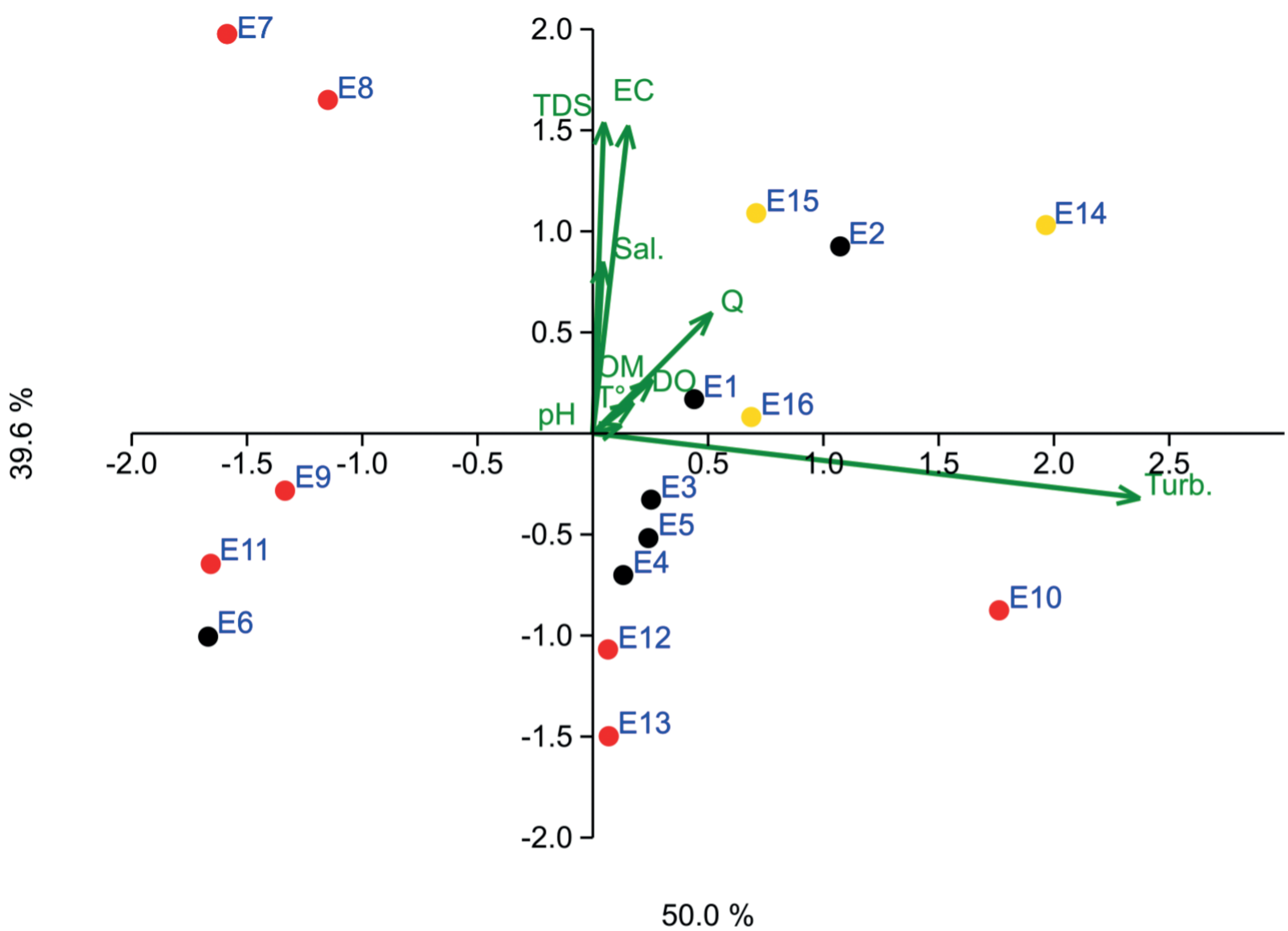

Fig. 2. Principal component analysis of environmental variables in the lower Quilca-Chili basin for both sampling periods. Red dots for the Sihuas River, yellow for the Quilca River, and black for the Vitor River.

The number of individuals increased upstream from the final section of the Quilca River during both the high- and low-flow periods. Based on total abundance, Chironomidae was the most abundant family (12044 individuals, 74%), followed by Simuliidae (3014 individuals, 18.5%) (Tab. 2). The remaining 11 families accounted for 7.5% of all individuals recorded in the lower Quilca-Chili basin. The most abundant genera were *Polypedilum* (Chironomidae) with 5683 individuals (34.9%), *Simulium* (Simuliidae) with 3014 individuals (18.5%), and *Onconeura* (Chironomidae) with 2136 individuals (13%). A total of 7965 individuals (48.9%) were recorded during the high-flow period, and 8305 individuals (51.1%) during the dry season. The analysis of similarity (ANOSIM) revealed that dipteran community composition differed significantly among the three rivers in June ($R = 0.67$, $p<0.05$), whereas in October, a significant difference was observed only between the Quilca and Sihuas rivers ($R = 0.16$, $p < 0.05$). In the Vitor and Quilca rivers, fewer organisms were observed during high flow, with numbers increasing during the dry season. In contrast, the Sihuas River had slightly fewer individuals during the dry season (Tab. 2). The sampling stations

Tab. 2. Total abundance of aquatic Diptera by genus and family (individuals per 0.09 m^2) in each river of the Quilca-Chili Basin.

	Code	Vitor River		Sihuas River		Quilca River		Total	Percentage
		June	October	June	October	June	October		
Blephariceridae		2	0	42	31	0	0	75	0.46
Paltostoma	Pal	2	0	42	31	0	0	75	0.46
Ceratopogonidae		30	3	34	171	6	4	248	1.52
Bezzia	Bez	0	0	15	70	0	0	85	0.52
Culicoides	Cul	12	3	19	101	4	4	143	0.88
Forcipomyia	Foc	18	0	0	0	2	0	20	0.12
Chironomidae		2755	3194	2625	2612	133	725	12,044	74.03
Aedokritus	Aeo	186	81	414	350	12	21	1064	6.54
Alotanypus	Alo	75	21	70	146	3	2	317	1.95
Cricotopus	Cric	69	293	788	314	4	1	1469	9.03
Larsia	Lar	24	6	31	28	0	0	89	0.55
Onconeura	Onc	88	461	977	533	38	39	2136	13.13
Paratrichocladius	Par	186	122	48	222	51	10	639	3.93
Podonomus	Pod	0	0	6	1	0	0	7	0.04
Polypedilum	Pol	2097	2034	274	611	15	652	5683	34.93
Tanytarsus	Tan	30	176	17	407	10	0	640	3.93
Culicidae		1	0	3	0	1	0	5	0.03
Aedes	Aed	1	0	1	0	0	0	2	0.01
Anopheles	Ano	0	0	2	0	1	0	3	0.02
Dolichopodidae		15	7	63	131	2	2	220	1.35
Genus 1	Gen1	15	5	61	125	2	1	209	1.28
Genus 2	Gen2	0	1	2	2	0	0	5	0.03
Genus 3	Gen3	0	1	0	4	0	1	6	0.04
Empididae		6	7	266	213	1	1	494	3.04
Neoplasta	Neo	6	7	266	213	1	1	494	3.04
Ephydridae		2	0	10	3	1	0	16	0.10
Brachydeutera	Bra	0	0	1	2	0	0	3	0.02
Ephydra	Eph	1	0	1	0	0	0	2	0.01
Scatella	Sca	1	0	8	1	1	0	11	0.07
Muscidae		20	8	25	55	1	0	109	0.67
Limnophora	Lim	20	8	25	55	1	0	109	0.67
Psychodidae		1	0	2	10	1	3	17	0.10
Pericoma	Per	1	0	2	10	1	3	17	0.10
Simuliidae		103	72	1808	1031	0	0	3014	18.52
Simulium	Sim	103	72	1808	1031	0	0	3014	18.52
Tabanidae		0	0	1	17	0	0	18	0.11
Tabanus	Tab	0	0	1	17	0	0	18	0.11
Tipulidae		0	0	1	1	0	0	2	0.01
Holorusia	Hol	0	0	1	1	0	0	2	0.01
Stratiomyidae		2	1	2	3	0	0	8	0.05
Nemotelus	Nem	0	1	0	2	0	0	3	0.02
Stratiomys	Str	2	0	2	1	0	0	5	0.03
Total								16,270	100.00

of the three rivers were distributed along the two axes of the NMDS analysis based on dipteran community structure (Fig. 3). In June, three distinct clusters were observed, corresponding to each river (stress = 0.18; R axis 1 = 0.43, R axis 2 = 0.12). In October, the Quilca River formed a separate cluster, while the Sihuas and Vitor rivers showed overlap (stress = 0.16; R axis 1 = 0.50, R axis 2 = 0.29).

Diversity indices for the dipteran community are presented in Tab. 3. June showed significant evenness differences between Quilca-Vitor rivers (p=0.028) and Quilca-Sihuas rivers (p=0.040). October revealed differences in Shannon between Sihuas-Vitor rivers (p = 0.038), Sihuas-Quilca rivers (p=0.023), Dominance between Quilca-Sihuas (p=0.023), and Evenness between Quilca-Sihuas (p=0.038).

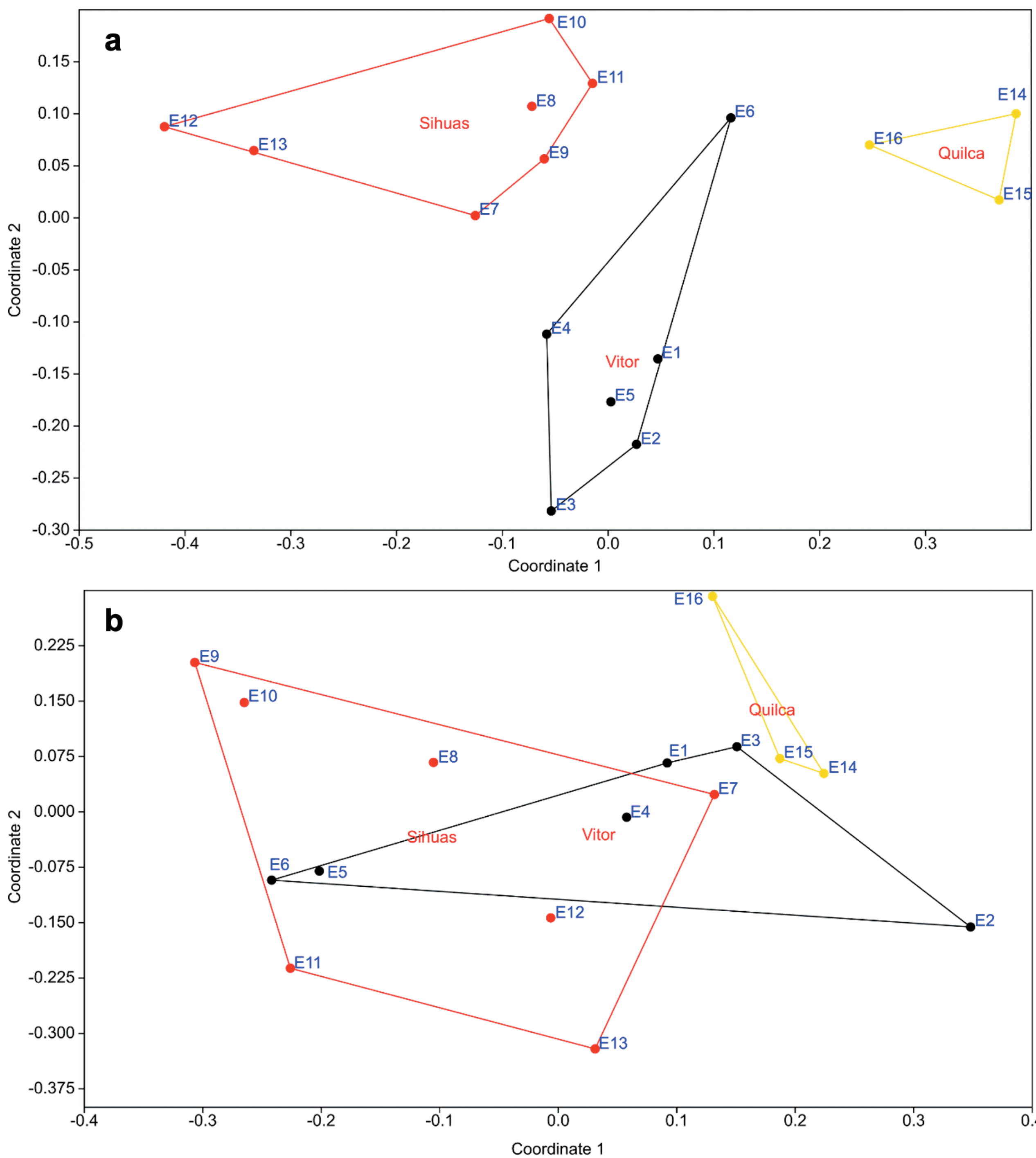

Fig. 3. Non-metric multidimensional scaling (NMDS) of dipteran community composition by river and sampling station in the Quilca-Chili Basin. **a)** High-flow period in June. **b)** Dry season in October. Vitor River (black), Sihuas River (red), and Quilca River (yellow).

Tab. 3. Shannon diversity, dominance, and Pielou's evenness values in rivers of the lower Quilca-Chili basin.

River	Station	Shannon		Dominance		Evenness	
		June	October	June	October	June	October
Vitor	E1	1.19	1.22	0.49	0.4	0.54	0.55
	E2	0.88	0.45	0.67	0.79	0.35	0.2
	E3	0.62	1.02	0.78	0.61	0.22	0.44
	E4	1.52	1.48	0.27	0.34	0.69	0.6
	E5	1.25	2.09	0.51	0.16	0.49	0.87
	E6	1.76	1.61	0.33	0.23	0.69	0.77
	Mean	1.2	1.31	0.51	0.42	0.5	0.57
	SD	0.41	0.56	0.19	0.24	0.19	0.24
Sihuas	E7	1.61	1.75	0.27	0.29	0.65	0.63
	E8	1.94	2.29	0.22	0.13	0.72	0.89
	E9	1.93	2.02	0.2	0.19	0.73	0.84
	E10	1.41	1.91	0.42	0.22	0.53	0.74
	E11	2.13	2.06	0.2	0.16	0.77	0.74
	E12	0.82	2.15	0.68	0.15	0.28	0.74
	E13	1.12	1.58	0.62	0.39	0.37	0.56
	Mean	1.57	1.97	0.37	0.22	0.58	0.73
	SD	0.44	0.22	0.19	0.09	0.18	0.1
Quilca	E14	2.47	0.59	0.05	0.78	1.13	0.27
	E15	1.47	0.76	0.35	0.7	0.75	0.36
	E16	2.59	1.11	0.08	0.5	1.01	0.62
	Mean	2.18	0.82	0.16	0.66	0.96	0.42
	SD	0.61	0.27	0.17	0.14	0.19	0.18

SD, standard deviation.

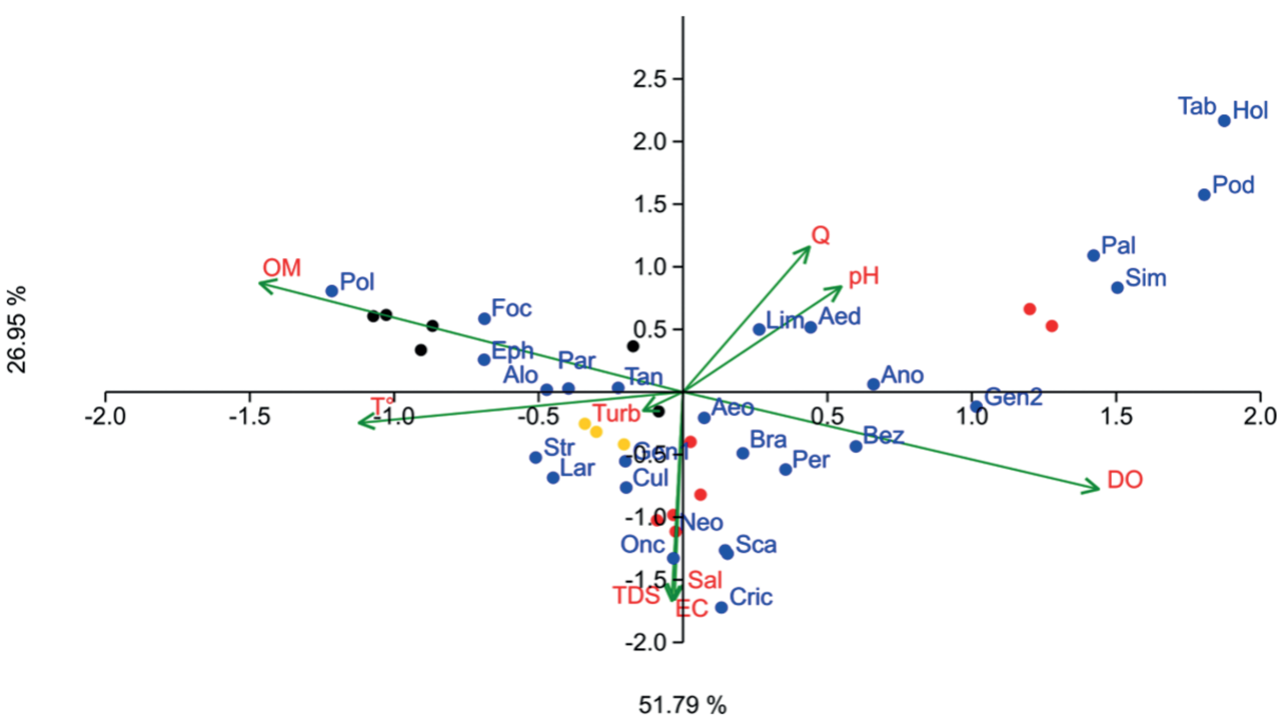

Fig. 4. Canonical correspondence analysis of Diptera genera in the lower Quilca-Chili basin during the high-flow period. Red dots for the Sihuas River, yellow for the Quilca River, and black for the Vitor River. Pal, *Paltostoma*; Bez, *Bezzia*; Cul, *Culicoides*; Foc, *Forcipomyia*; Aeo, *Aedokritus*; Alo, *Alotanypus*; Cric, *Cricotopus*; Lar, *Larsia*; Onc, *Oconeura*; Par, *Paratrichocladius*; Pod, *Podonomus*; Pol, *Polypedilum*; Tan, *Tanytarsus*; Aed, *Aedes*; Ano, *Anopheles*; Gen 1, *Genus 1*; Gen 2, *Genus 2*; Gen 3, *Genus 3*; Neo, *Neoplasta*; Bra, *Brachydeutera*; Eph, *Ephydra*; Sca, *Scatella*; Lim, *Limnophora*; Per, *Pericoma*; Sim, *Simulium*; Tab, *Tabanus*; Hol, *Holorusia*; Nem, *Nemotelus*; Str, *Stratiomys*.

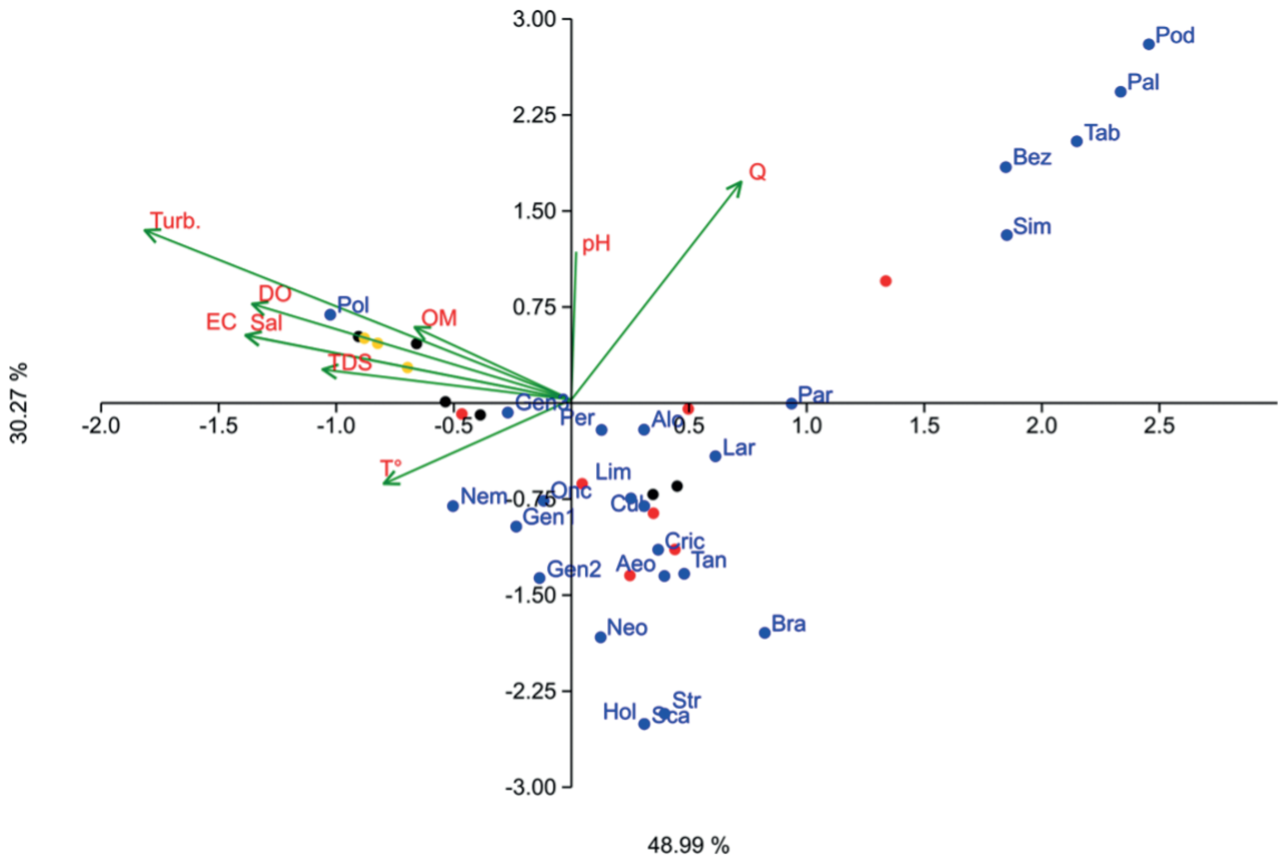

Fig. 5. Canonical correspondence analysis of Diptera genera in the lower Quilca-Chili basin during the dry season. Red dots for the Sihuas River, yellow for the Quilca River, and black for the Vitor River. Pal, *Paltostoma*, Bez, *Bezzia*, Cul, *Culicoides*, Foc, *Forcipomyia*, Aeo, *Aedokritus*, Alo, *Alotanypus*, Cric, *Cricotopus*, Lar, *Larsia*, Onc, *Oconeura*, Par, *Paratrichocladius*, Pod, *Podonomus*, Pol, *Polypedilum*, Tan, *Tanytarsus*, Aed, *Aedes*, Ano, *Anopheles*, Gen 1, *Genus 1*, Gen 2, *Genus 2*, Gen 3, *Genus 3*, Neo, *Neoplasta*, Bra, *Brachydeutera*, Eph, *Ephydra*, Sca, *Scatella*, Lim, *Limnophora*, Per, *Pericoma*, Sim, *Simulium*, Tab, *Tabanus*, Hol, *Holorusia*, Nem, *Nemotelus*, Str, *Stratiomys*.

Relationship between dipterans and environmental variables

Fig. 4 presents the canonical correspondence analysis (CCA) for the high-flow period (June). The first two axes explained 78.74% of the data variability. The variables contributing most to the first component were dissolved oxygen and, to a lesser extent pH. In the second axis, discharge and organic matter were the most influential variables. The CCA showed that in June, the Vitor River was negatively associated with organic matter and positively associated with the abundance of *Polypedilum* and *Forcipomyia*. The Sihuas River was positively associated with dissolved oxygen and the abundance of the genera *Tabanus*, *Holorusia*, *Podonomus*, *Paltostoma*, and *Simulium*. In contrast, the Quilca River showed no clear separation, with points clustering near the origin of the ordination.

During the dry season (October), the first two axes of the CCA explained 79.26% of the data variability (Fig. 5). Discharge was the main contributor to both the first and second components on the positive axis. In contrast, turbidity, dissolved oxygen, salinity, and electrical conductivity were negatively associated with the first component and correlated with *Polypedilum* in the Quilca River. Most genera were associated with the Sihuas River, with positive correlations between discharge and *Podonomus*, *Paltostoma*, *Tabanus*, *Bezzia*, and *Simulium*, and a slight correlation between temperature and the genera *Holorusia*, *Scatella*, *Stratiomys*, *Neoplasta*, and *Brachydeutera* (Fig. 5).

DISCUSSION

The high values of conductivity, salinity, and total dissolved solids observed during the dry season (October) at the Quilca River stations are likely associated with the presence of inorganic materials from nearby agricultural activities, transported via runoff and inputs from the Sihuas and Vitor rivers. Tectonic activity (Zavala *et al*., 2022), erosion and mineralization processes are also believed to contribute to the elevated electrical conductivity.

According to Morelli and Verdi (2014), in the Neotropical region, dissolved oxygen is one of the variables that best explains the functioning of lotic systems. The high levels of this parameter in the three rivers studied indicate suitable conditions for macroinvertebrate communities. However, the low percentages of organic matter recorded may be due to the sparse riparian vegetation throughout the basin, a common feature of coastal rivers in Perú. The reduction in flow reported in some rivers in Colombia has been associated with the dominance of certain Diptera genera (Ríos-Pulgarín *et al*., 2016; Rodríguez *et al*., 2021). In our case, the decrease in flow observed in the Vitor, Quilca, and Sihuas rivers does not appear to be a determining factor in the structure of aquatic Diptera communities. This is likely due to the adaptation of species to water-scarce conditions typical of these rivers in arid systems.

PCA revealed that the most influential parameters contributing to environmental variability in the rivers of the lower Quilca-Chili basin are turbidity, total dissolved solids, and electrical conductivity. These factors appear to be related to the structure of the aquatic dipteran community. In the case of the Sihuas River, from station 13 downstream, the flow is regulated to maintain an ecological discharge, as water is diverted for local agricultural irrigation. However, this regulation is not upheld during drought conditions in the basin. In contrast, the Vitor River is located downstream of the city of Arequipa, and therefore receives a higher load of both organic and inorganic materials, not only from agricultural areas but also from population-related water use. This could explain the increase in total dissolved solids and electrical conductivity observed in the Quilca River. On the other hand, discharge variations appear to be related to the climatic variability of the region (Vidal-Abarca *et al*., 2004; Rojas-Sandino *et al*., 2018; Arana *et al*., 2021; Coayla-P *et al*., 2022), which in turn influences the development of aquatic communities (Rojas-Sandino *et al*., 2018).

The families Chironomidae and Simuliidae have been reported as abundant in Neotropical rivers (Scheibler *et al*., 2014; Mosquera and Sánchez, 2019; Rodríguez *et al*., 2021), with a feeding preference for fine particulate organic matter (Rojas-Sandino *et al*., 2018). Chironomidae, in particular, exhibits a high degree of ecological plasticity (Zanotto-Arpellino *et al*., 2015) and can inhabit diverse habitats (Caleño *et al*., 2018). In this study, Chironomidae was found in all three rivers during both sampling periods, although its abundance varied between rivers, possibly due to its higher tolerance to environmental fluctuations and specific microhabitat or feeding preferences (Vásquez-Ramos and Reinoso-Flórez, 2012). Simuliidae was more abundant in the Sihuas River and absent downstream in the Quilca River during both periods, possibly due to its lower tolerance to environmental variability. The families Ceratopogonidae, Stratiomyidae, Tipulidae, and Tabanidae showed low abundance, likely due to the low organic matter content in these rivers, as these taxa generally prefer coarse particulate organic matter, detritus and other organisms (Rojas-Sandino *et al*., 2018; Mullens, 2019).

Polypedilum has been reported in both fast- and slow-flowing waters and at different elevations (Tejerina and Molineri, 2007). It reaches high densities in river mouths when waters are warm, highly mineralized, and have elevated sulfate concentrations (Scheibler *et al*., 2008). The high abundances of *Polypedilum* recorded in the Vitor and Sihuas rivers are likely due to similar environmental characteristics occurring during the spring season, as mentioned by Scheibler *et al*. (2008). *Simulium* is abundant in Andean Mountain rivers, and is considered rheophilic, with strong substrate adherence capabilities (Díaz-Rojas *et al*., 2020). Its abundance has been associated with the dry season in Colombian rivers (Rodríguez *et al*., 2021; Buitrago-Guacaneme *et al*., 2018). In the present study, it was recorded with high abundance in both high- and low-flow seasons in the Sihuas River. *Onconeura* has been reported in Ecuadorian Andean rivers (Villamarín *et al*., 2021), associated with high dissolved oxygen concentrations and low conductivity values. In our study, this genus was abundant in both seasons in the Sihuas River, which had dissolved oxygen concentrations 7 mg L^{-1}, though with high electrical conductivity values.

The diversity and richness of aquatic dipterans in Neotropical rivers have been attributed to their ability to colonize various habitats, endure drought and rainfall conditions, and inhabit a wide altitudinal range (Kikuchi and Uieda, 2005; Merritt *et al*., 2009; Rojas-Sandino *et al*., 2018). The variations in diversity, dominance, and evenness indices recorded in the Vitor, Sihuas, and Quilca rivers during both seasons suggest that dipterans can adapt to the physical and chemical changes in water caused by climatic variability (Arana *et al*., 2021; Rodríguez *et al*., 2021; Coayla-Peñaloza *et al*., 2024), which determines the hydrological precipitation regime in the basin.

In the CCA for the high-flow season in the lower Quilca-Chili basin, the genera *Tabanus*, *Holorusia*, *Podonomus*, *Paltostoma*, and *Simulium* were associated with higher dissolved oxygen levels recorded in the Sihuas River. This may be due to low organic matter input, which limits oxygen consumption during oxidation processes, and also to high epilithic diatom concentrations previously reported in this river (Coayla *et al*., 2025), which increase oxygen availability in the water. *Polypedilum* is known to be dominant in lower elevation rivers (Villamarín *et al*., 2021) and tolerant to low oxygen concentrations (López and Talero, 2015). Its abundance, along with *Forcipomyia* (to a lesser extent) in the Vitor River, may be attributed to these factors, especially since June had the lowest dissolved oxygen concentrations (4.08 mg L^{-1}) of the study period. In contrast, in the Quilca River, environmental variables appeared to have little influence on dipteran community structure during this season.

In the CCA for October, corresponding to the dry season in the basin, a clearer response was observed in the Quilca River compared to the high-flow season. Notably, turbidity, dissolved oxygen, salinity, and electrical conductivity were associated with *Polypedilum*, suggesting that this genus is more tolerant of variations in physicochemical variables and discharge during the dry season in the Quilca River. The observed association of genera with the Sihuas River does not appear to be influenced by physicochemical conditions, indicating less disturbance, likely due to the maintenance of ecological flow throughout the year, as this is a regulated river. It is important to note that the results are based on only two months of sampling; nevertheless, the analysis shows clear trends that should be corroborated through more intensive temporal and spatial studies.

CONCLUSIONS

The results of this study indicate that the community of aquatic dipterans is associated with environmental variables such as electrical conductivity, dissolved solids, and turbidity. The families Chironomidae and Simuliidae were the most abundant in the study area. However, the correlation between genus abundance and environmental variables showed that *Polypedilum* was the most representative genus in the study and exhibited a significant preference for high levels of organic matter. In contrast, the genera *Podonomus*, *Paltostoma*, *Tabanus*, *Bezzia*, and *Simulium* were closely associated with streamflow. On the other hand, the remaining genera did not show a clear association with the variables analyzed. This study constitutes an important contribution to the understanding of aquatic dipteran communities in rivers of semi-arid basins and provides baseline information for future research on the order Diptera, as well as for the conservation of local biota.

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