ORIGINAL ARTICLE

Abundance and diversity of black flies (Diptera: Simuliidae) in rivers of the Andean Eastern Hills of Bogotá (Colombia), and its relationship with water stream physicochemical variables

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Abstract

Black flies are abundant benthic organisms in well-oxygenated running water and are considered effective bioindicators of water quality. Information on the ecology of these organisms at the species level is important, since up to now information has mainly been available on a family level. The aim of this study was to evaluate the composition of black flies and their relationships to a group of physical and chemical factors in four small rivers of the Eastern Hills around Bogotá, Colombia. These headwaters are protected by the Empresa de Acueducto y Alcantarillado de Bogotá. Black fly larvae and pupae were collected during four sampling periods during the dry season to the early rainy season of 2012. Multivariate methods were used to determine the presence of each species in relation to dissolved oxygen, nitrates, pH, temperature, and water velocity. PCA ordination revealed a physicochemical environment with a tendency towards a certain homogeneity in the four rivers studied. The DCA ordination confirmed that in La Vieja River the *G. ortizi* complex dominated while *S. muiscorum* was dominant in the other three rivers. Similarly, according to the NMDS, the composition of black flies in Arzobispo and Chorro de Padilla rivers was similar, while that of El Delirio and La Vieja rivers were different, especially in this last river. The rivers had low species richness (four species and one species complex). *Simulium muiscorum* was negatively correlated with dissolved oxygen, temperature and current velocity while *S. ignescens* was associated with slightly more oxygenated waters and *S. furcilatum* with faster currents. The low species diversity and richness for the four rivers is consistent with previous reports of low Neotropical diversity of black flies. Results showed that simuliid species could possibly be good indicators of the environmental conditions of Eastern Hills rivers around Bogotá.

Keywords: bioindicators; black flies; macroinvertebrates; rivers; water quality.

Introduction

Simuliids, known generally as "black flies" in English and "jejenes" in Spanish, are widely distributed in streams and rivers worldwide from sea level to altitudes of 5 000 m (Coscarón & Coscarón-Arias 1995, Adler *et al.* 2004,

Adler & Crosskey 2017). A total of 2 204 extant species of black flies are known to science (Adler & Crosskey 2017) of which 74 have been recorded in Colombia (Moncada-Álvarez *et al.* 2017). Black flies are often the dominant form of secondary productivity in boreal lotic ecosystems (Malmqvist *et al.* 2004, Currie & Adler 2008). Due to their activity as filter feeders, these aquatic dipterans play a fundamental role in the transfer of energy from fine particulate organic matter to predators, represented by other macroinvertebrates and fish. They also are important in the supply of larger particles via their feces to a broad spectrum of deposit-feeding detritivores (Wallace & Webster 1996). Simuliid larvae typically are associated with well-oxygenated waters, although certain species can be found at low concentrations of dissolved oxygen (Welch & Tindell 1992). Consequently, the immature stages can be useful bioindicators of water quality (Martínez & Portillo 1999, Carle *et al.* 2015). However, few ecological studies of black flies have addressed taxonomic resolution to the species level (McCreadie & Adler 2008), and this has hindered a more accurate use of these organisms as bioindicators.

Most ecological studies of black flies have been conducted in Nearctic and Palearctic regions (Figueiró & Gil-Azevedo 2010, Figueiró *et al.* 2014). In the Neotropical region, ecological studies have mostly been carried out in Brazil, especially at low elevations (Hamada & McCreadie 1999, Hamada *et al.* 2002, McCreadie *et al.* 2005, Figueiró *et al.* 2006, 2008, 2012, Landeiro *et al.* 2009, Dos Santos *et al.* 2010, Couceiro *et al.* 2014, Docile *et al.* 2015), with some studies in Venezuela (Grillet & Barrera 1997). In Ecuadorian highland Andean streams the simuliids are one of the four most abundant families during both the wet and dry season (Jacobsen *et al.* 1997, Jacobsen & Encalada 1998), and one of the most abundant groups when riparian coverings are forests and pastures (Iñiguez-Armijos *et al.* 2016). These studies and other published on macroinvertebrates in Neotropical high mountain rivers only refer to the simuliids as a family without sufficient ecological information on the species.

In Colombia most simuliid literature is taxonomic (Adler & Crosskey 2017). Early ecological notes were recorded for Colombian black fly species in the Sierra Nevada de Santa Marta (Lewis & Lee-Potter 1964). Bueno *et al.* (1979) published some ecological annotations for *Simulium (Hemicnetha) muiscorium*. An analysis of historical ecology of the Central and Eastern Cordilleras in Colombia revealed an elevational species gradient in which the lower areas correspond to the oldest regions with the most primitive species (Muñoz & Miranda-Esquivel 1997). Reports of the presence and abundance of black flies in the Fucha River (a stream of the Eastern Hills of Bogotá) were based on limited environmental observations (Restrepo & Rincón 2009), while a few ecological notes were presented for oviposition behavior of

Simulium dinellii (Mantilla *et al.* 2015). Some studies have addressed the medical importance of simuliids as vectors of onchocerciasis in Colombia (Tidwell *et al.* 1980, Corredor *et al.* 1998), the transmission of which is currently eradicated from Colombia (WHO 2013). Other reports have dealt with the role of these dipterans in bird diseases (Lotta *et al.* 2016).

Simuliid species of the temperate zones, as well as species from lower elevations in Neotropical regions are different from those reported in the Colombian Andean region (Moncada-Álvarez *et al.* 2017). Therefore, one would expect that on a species level, ecological responses of high mountain river taxa in Colombia are different. A study of bioindication in Brazil showed that Simuliidae species were present in streams with intermediate urban pollution impacts, but absent in heavily impacted sites (Docile *et al.* 2015). These authors suggested that some species were associated with more pristine breeding sites, while others might be good bioindicators of moderately impacted streams. However, the Brazilian species are different from those found in Colombian waters, so it is necessary to study the native Colombian black fly fauna to know their responses to environmental variables.

The majority of the watercourses in the upper basin of the Bogotá River are used for agricultural, domestic, and industrial purposes. The Arzobispo, Chorro de Padilla (also known as San Francisco), La Vieja, and El Delirio (also known as La Osa) rivers have their upriver areas protected by the Empresa de Acueducto y Alcantarillado de Bogotá (EAAB), and these rivers eventually feed into the Bogotá River. Since, small, highland streams and rivers can influence limnological processes in lower reaches of the Andean basins (Allan *et al.* 2006), a long-term biomonitoring and environmental assessment of these watercourses is required to account for the impact imposed by anthropic practices. Given the potential value of black flies as bioindicators of water quality, knowledge about their biodiversity and relative abundance could facilitate the conservation of riverine ecosystems, essential for the maintenance of the urban lotic environment and water reserves for cities like Bogotá. Therefore, in the present study the relationship between water stream physical and chemical factors and the presence of black fly species was investigated in four streams of the Bogotá River watershed. This allows to explore the capability of simuliids as indicators of water quality.

Methods

Study area

The study area lies within the watershed of the Bogotá River, which has four sub-basins: Teusacá, Juan Amarillo (Salitre), Fucha, and Tunjuelito. The streams and rivers of these sub-basins run through the Eastern Hills

around Bogotá before entering the urban area, which lies in an extensive, high montane valley at about 2 600 m above sea level. Sampling sites were in three rivers of the Juan Amarillo river basin-Arzobispo, Chorro de Padilla (San Francisco), and La Vieja-and one river of the Fucha river Basin-El Delirio (La Osa) (**Fig. 1**). The list of environmental features of each sampled river is presented in **Table. 1**.

Sampling

Each river was sampled four times, twice during the rainy season (March and April) and twice during the beginning of the dry season (May and June) in 2012. A total of 16 samples per river were taken during the study. In each river a sampling section of 30 m including a combination of pools and riffles was randomly established. The same sampling section of each river was visited during the dry and rainy seasons. In each of these sections two people collected simuliid immature states during two hours of effort for a total of four hours per sampling. Abundance data were reported as number of individuals captured during these four hours. Forceps were used to manually collect simulliid larvae and pupae from available substrates (stones, rocks, pieces of wood, leaves, cloths, plastics) along the established sampling section of each river. No adults were collected because they were absent during the sampling periods.
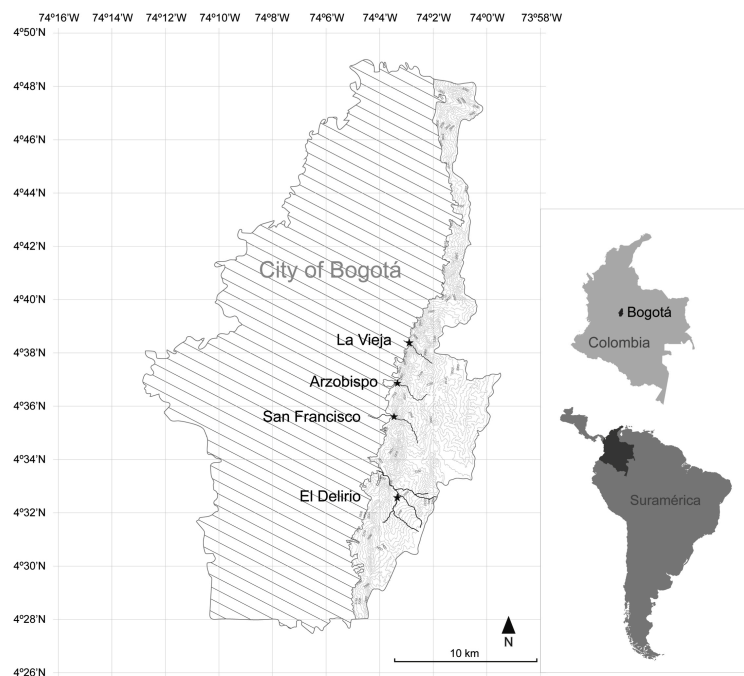

Figure 1. Location of the sampling points in the rivers studied in the Eastern Hills of the city of Bogotá.

Table 1. General characteristics of the sites in the rivers studied at the Eastern Hills of the Andes around Bogotá, Colombia, 2012.

River	Geographical coordinates	Elevation (masl)	River order (Horton 1945)	Type of substrate	Riparian vegetation	General conservation status
El Delirio	4°32'58"N 74°3'19"W	2971	2	Rocks of different size, predominantly boulders and bedrock	Andean forest vegetation with dominance of introduced pine trees (*Pinus patula*)	Area under conservation, without agricultural or urban activities
Arzobispo	4°37'27"N 74°3'19"W	2788	1	Large rocks (boulders) and some wooden logs	Andean forest vegetation and introduced trees of eucalyptus (*Euclaliptus globulus*)	Area under conservation, without agricultural or urban activities
Chorro de Padilla (San Francisco River)	4°36'04"N 74°3'30"W	2735	1	Rocks of middle sizes (gravel and cobbles), wood and litter	Andean arboreal vegetation, with dominant species such as *Symplocos, Weinmannia, Clusia, Prunus and Oreopanax,* among others.	Area under conservation, without agricultural activities but with eco-tourist hiking and close to roads influence
La Vieja	4°39'02"N 74°2'53"W	2705	1	Rocks of different sizes, predominantly cobbles and boulders	Andean forest vegetation with mixture of native (*Symphytum officinale, Sambucus nigra, Fuchsia boliviana*) and exotic species (*Acacia melanoxylon*)	Area under conservation, without agricultural activities but with eco-tourist hiking and near to urban influence

Specimens were fixed in 70 % alcohol and transported to the Medical Entomology Laboratory at Universidad Nacional de Colombia (LEMUN) for identification using taxonomic keys by Muñoz *et al*. (1984), Muñoz & Coscarón (1999), Hamada & Grillet (2001), Shelley *et al*. (2004), and Coscarón & Coscarón-Arias (2007). Species identification was completed shortly after collection. The following physicochemical variables were measured in situ with a water sample from the stream surface: water temperature and pH were recorded with a potentiometer Schott® HandyLab; and nitrates and dissolved oxygen were assessed with Aqua-Merck® kits. In addition, water velocity was determined following the floating-object method reported by Hauer & Lamberti (2007).

Data analysis

The following ecological indices were calculated: the Shannon-Weaver diversity (natural logarithm), Simpson dominance, and Pielou's equitability (i.e. evenness) indices. To examine the differences of the physical, chemical and biotic variables between the rivers, the nonparametric variance analysis of Kruskal-Wallis was applied to the data. Subsequently, post-hoc pairwise comparisons, based on the Tukey-Kramer test, were performed to establish the set of data that produced the differences. A principal component analysis (PCA) was then performed to inspect the relation among physicochemical variables coupled to a detrended correspondence analysis (DCA) to explore the spatial-temporal organization of species. Two nonmetric multidimensional scaling (NMDS) analyses were performed, one for species and another for environmental variables. For all these ordination procedures, data were square root-transformed due to small sample sizes and to reduce statistical biases. Non-parametric Spearman correlations were calculated to examine the statistical relationship between abiotic factors and taxon abundance using data of the 16 sampling cases. The similarity of the sampling sites was determined based on simuliid composition, using a Bray-Curtis similarity cluster analysis. All statistical analyses were conducted with the PAST program, version 3.18 (Hammer *et al*. 2001), and species accumulation curves were computed with the EstimateS program (Colwell & Elsensohn 2014), using the nonparametric estimators Chao1 (abundance) and Chao2 (incidence).

Results

A total of 1 492 larvae and pupae of five t axa a cross fi ve species/species complexes were collected (**Fig. 2**): *Simulium muiscorum* (Bueno, Moncada & Muñoz), *Simulium furcillatum* (Wygodzinsky & Coscarón), *Simulium ignescens* (Wygodzinsky), *Gigantodax cervicornis* (Wygodzinsky), and the *Gigantodax ortizi* complex. The *G. ortizi* complex as treated here includes at least the following species: *Gigantodax chilensis* (Philippi), *Gigantodax paramorum* (Wygodzinsky & Coscarón), and *Gigantodax multituberculatus* (Wygodzinsky & Coscarón). Diagnostic characters for these three species of *Gigantodax* are equivocal, hence, until their taxonomy is clarified through molecular studies or capture of adult forms these three species were recognized as a single taxonomic entity.

Simulium muiscorum was the most abundant taxon in all rivers (68.6 % of the total relative abundance) excluding La Vieja, where it was absent in all sampled months but May. *Gigantodax cervicornis* was the least abundant species (0.13 %) and was found only in La Vieja in June (Fig. 2). According
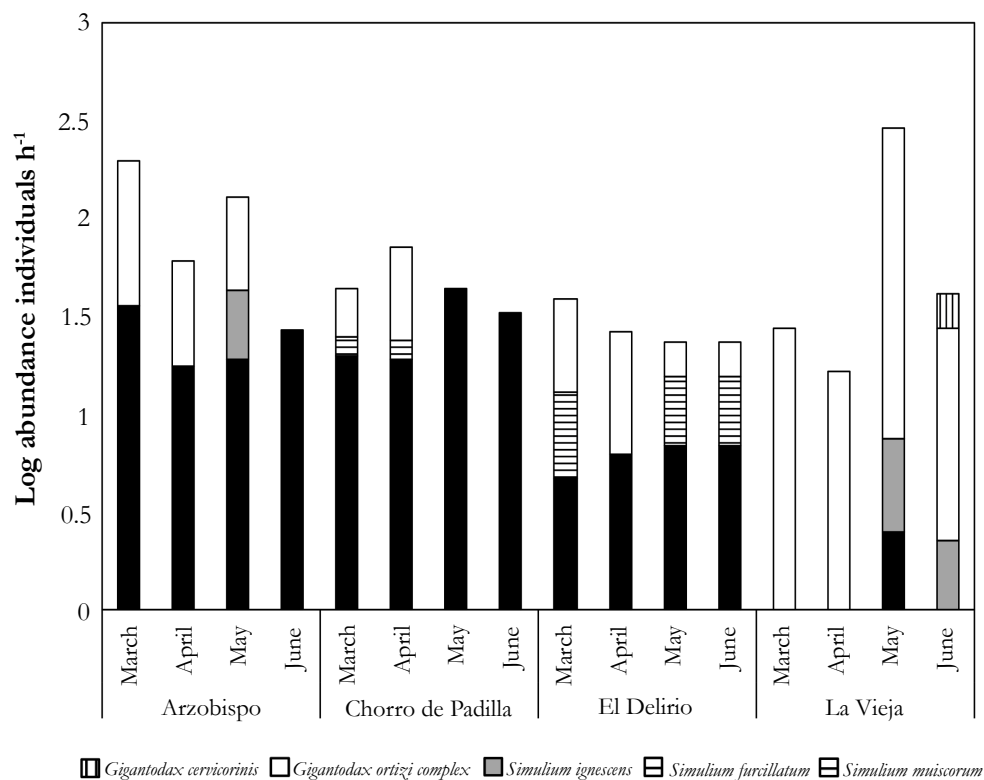
Figure 2. Logarithm of the abundance of simuliids (individuals . h^{-1}) collected in four rivers of the Andean Eastern Hills around Bogotá, Colombia (March, April, May and June of 2012).

to the Kruskal-Wallis analysis the abundances of *S. muiscorum* and the *G. ortizi* complex were significantly different between rivers (H = 10.3, p = 0.02, H = 9.7, p = 0.02). The Tukey-Kramer test indicated that La Vieja River was the stream that accounted for this difference. There were no significant differences in the abundances of simuliid species between climatic seasons (H = 1.9, p = 0.2).

The obtained species accumulation curves, based on 16 samples and 5 taxa, were asymptotic for the Chao 1 and 2 estimators (**Fig. 3**), showing that all species of black flies present probably were collected. Thus, the estimators suggested that the sampling program had 100 % efficiency, both in numbers of individuals of each taxon (Chao 1) and as species richness (Chao 2).

The four rivers were acidic with high dissolved oxygen levels (> 5.9 mg L^{-1}), cool temperatures (< 12 °C), moderately high mean stream velocities (1.3 - 1.4 m s^{-1}), and appreciable nitrate concentrations ($\geq$ 13.8 mg L^{-1}) (**Table 2**). Dissolved oxygen and pH were higher in Chorro de Padilla. Arzobispo had larger amounts of nitrates and, together with La Vieja, had
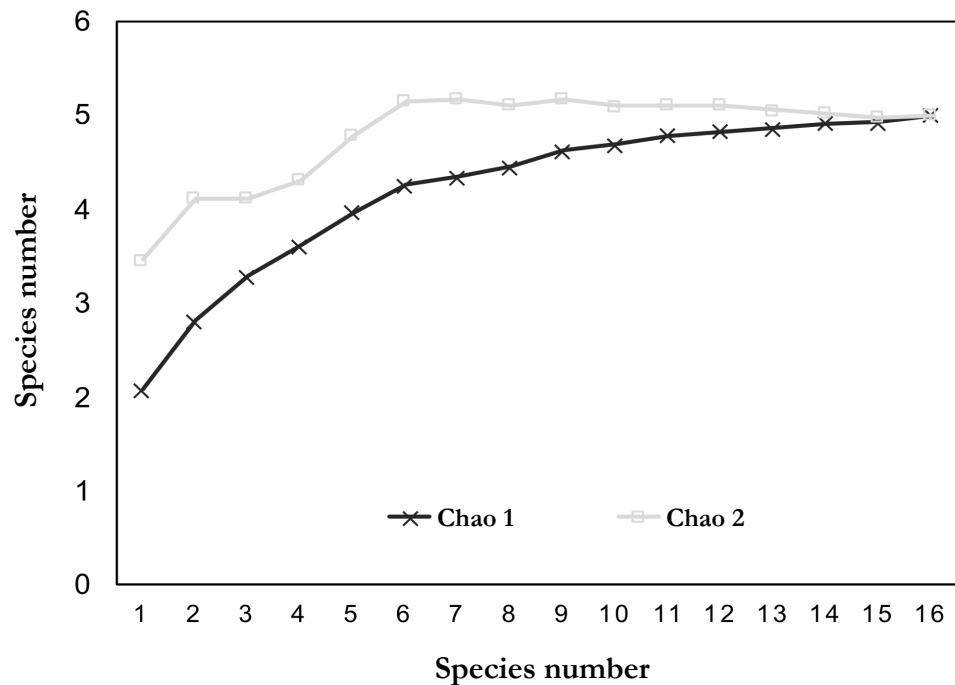
Figure 3. Species accumulation curves for simuliids in four rivers of the Andean Eastern Hills around Bogotá, Colombia, 2012.

a slightly faster water velocity. El Delirio had the lowest pH and nitrates. Abiotic variables had values with no significant differences between the rivers, but during the dry period temperature was statistically higher ($H = 5.1$, $p = 0.02$) (11.5 °C in dryness vs. 10.4 °C in rains) and water velocity faster ($H = 6.1$, $p = 0.01$) (1.65 m s^{-1} in dryness vs. 1.07 m s^{-1} in rains).

PCA analysis on abiotic variables showed that principal component (PC) axis 1 explained 41.98 % of the total variability and PC axis 2 explained 27.53 % (**Fig. 4**). The cumulative explanation for the two components was near 70 % of all variation among physicochemical data. The PC axis 1 was associated mainly with pH and dissolved oxygen and the PC axis 2 with nitrates. Arzobispo river in May and June was related with stream velocity and temperature, parameters that had high scores with axis 1 (0.41 and 0.46, respectively). Oxygen and pH were associated with El Delirio river in June (scores with axis 1: 0.55 and 0.57 respectively) and nitrates with La Vieja and Chorro de Padilla rivers in May (score with axis 2: 0.6). The other sites and samples did not show a clear relation with the physicochemical variables.

Table 2. Means (and standard deviations in parentheses) of the measurements of physical and chemical variables of the studied rivers in the Andean Eastern Hills around Bogotá, Colombia (March, April, May and June of 2012) ($n = 4$ for each variable in each river).

River	pH	Dissolved oxygen (mg L^{-1} O^2)	Water temperature (ºC)	Nitrates (mg L^{-1} NO^3)	Water velocity (m s^{-1})
El Delirio	5.6 (1.15)	6.08 (0.89)	10.0 (1.17)	13.8 (7.5)	1.3 (0.47)
Arzobispo	6.1 (1.19)	5.92 (0.46)	11.4 (0.64)	23.7 (18.8)	1.4 (0.22)
Chorro de Padilla (San Francisco River)	6.3 (1.10)	6.52 (0.83)	10.7 (0.48)	16.8 (13.5)	1.3 (0.80)
La Vieja	5.8 (1.22)	6.07 (1.12)	11.6 (0.85)	17.5 (8.7)	1.4 (0.41)

The DCA (**Fig. 5**) with a high eigenvalue of 0.532 on the first axis and a minor value of 0.147 on the second axis, indicated that La Vieja was characterized by the presence of the *G. ortizi* complex and that Arzobispo and Chorro de Padilla shared a predominance of *S. muiscorum*. The NMDS analysis for species with a stress value of 0.08, indicated that the composition of black flies in Arzobispo and Chorro de Padilla was similar (**Fig. 6A**). In contrast, the simuliid fauna of La Vieja was distinct, and in El Delirio simuliids also showed some degree of segregation (except in June). The NMDS analysis for environmental variables (with a stress value of 0.03) split data into two groups. One such group encompassed all April samplings with a handful of samplings across sites and months (**Fig. 6B**, right hand side cluster). The other group included all March samples in El Delirio and La Vieja; May samples in Chorro de Padilla, La Vieja and Arzobispo; and June samples in Arzobispo (Fig. 6B, left hand side cluster). All sites falling into the second group featured the highest levels of nitrates.
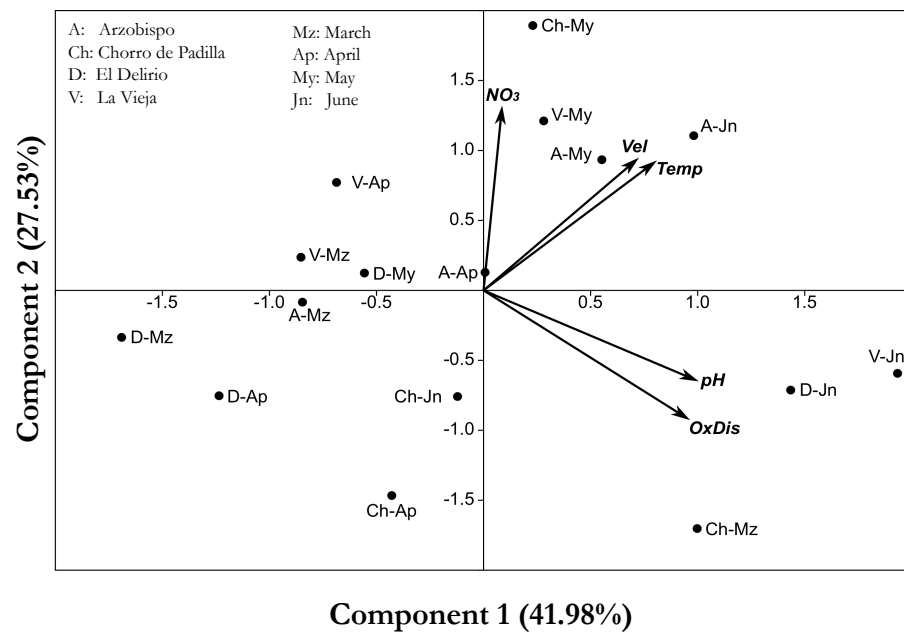
Figure 4. PCA biplot of the physicochemical data for four rivers in the Andean Eastern Hills around Bogotá, Colombia, in 2012.

The abundance of *S. muiscorum* was negatively correlated with dissolved oxygen ($r = -0.6$, $p = 0.02$, $n = 16$), suggesting an increase in abundance in less oxygenated waters. In contrast, *S. ignescens* abundance correlated positively with oxygen ($r = 0.6$, $p = 0.02$, $n = 16$); *S. ignescens* tended to be slightly more abundant in more oxygenated waters. *S. muiscorum* also correlated negatively both with temperature ($r = -0.5$, $p = 0.04$, $n = 16$) and stream velocity ($r = -0.6$, $p = 0.02$, $n = 16$). Abundance of *S. furcilatum* was directly correlated with stream velocity ($r = 0.5$, $p = 0.04$, $n = 16$), but the correlation between abundance of the entire simuliid community and water velocity was negative ($r = -0.8$, $p < 0.05$, $n = 16$). The mean species number per river on each sampling date was 1.8 - 2.5. The low equitability (< 0.5) of the sampled rivers confirmed the dominance of some taxa (*S. muiscorum* and *G. ortizi* complex) over others. Shannon-Weaver diversity index had in general low values and was highest in El Delirio (0.86 nats) and lowest in Chorro de Padilla (0.14 nats) (**Fig. 7A**). In El Delirio, Simpson's dominance index was low, and equitability was high, whereas in La Vieja, the converse was observed (**Figs. 7B** and **7C**).
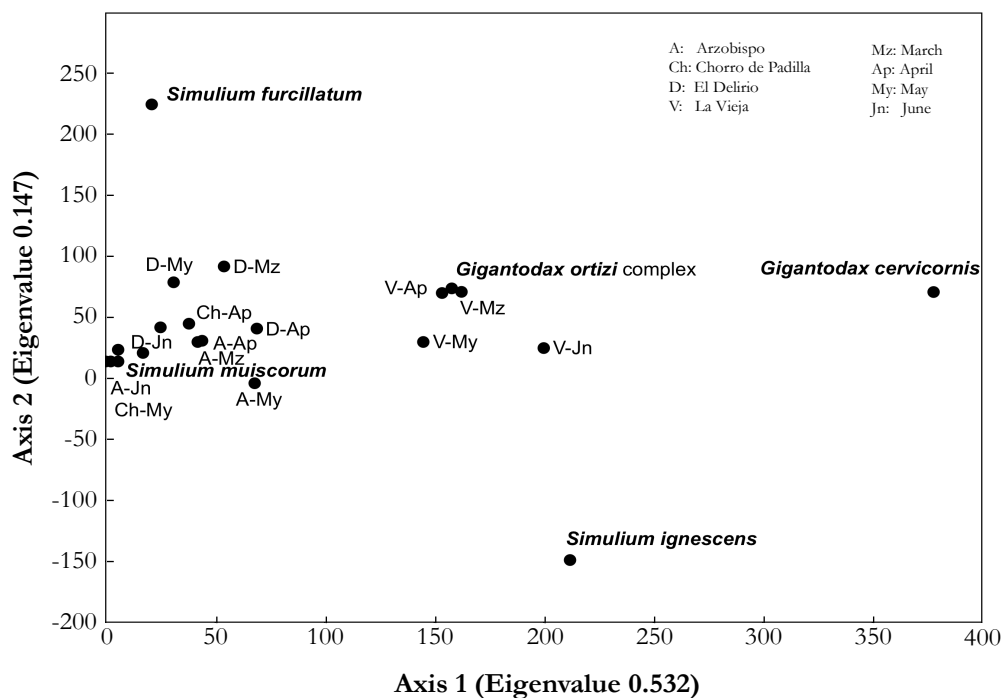
Figure 5. DCA analysis of samples from four rivers in the Andean Eastern Hills around Bogotá, Colombia, in 2012, based on species abundance.

As indicated by the cluster in **Fig. 8**, Arzobispo and Chorro de Padilla were virtually identical in their simuliid composition; the composition of El Delirio resembled that of Arzobispo and Chorro de Padilla; and that of La Vieja was the most different.
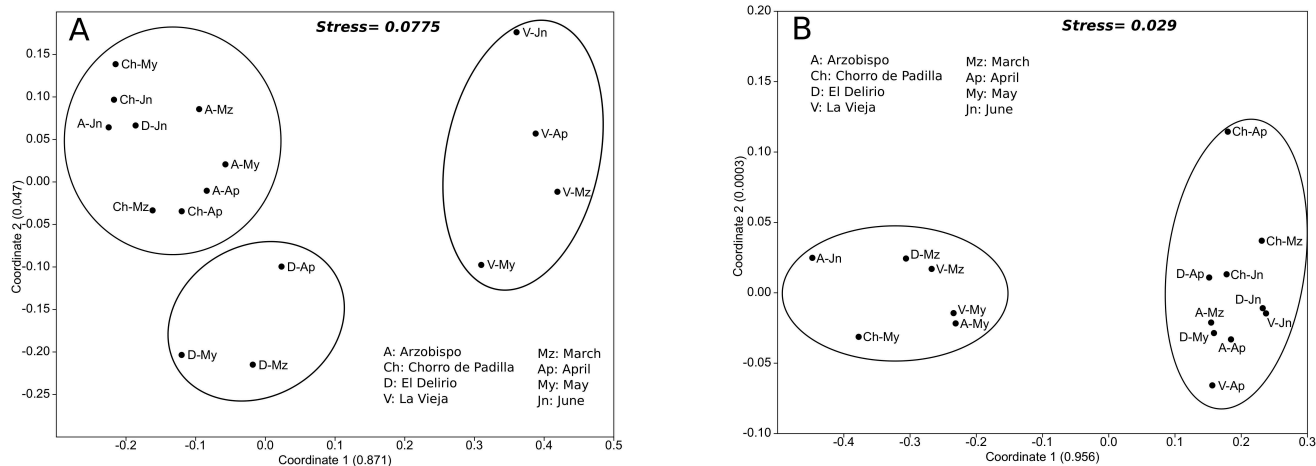

Figure 6. NMDS analysis of samples from four rivers in the Andean Eastern Hills around Bogotá, Colombia, in 2012, based on species abundance (A) and abiotic variables (B).
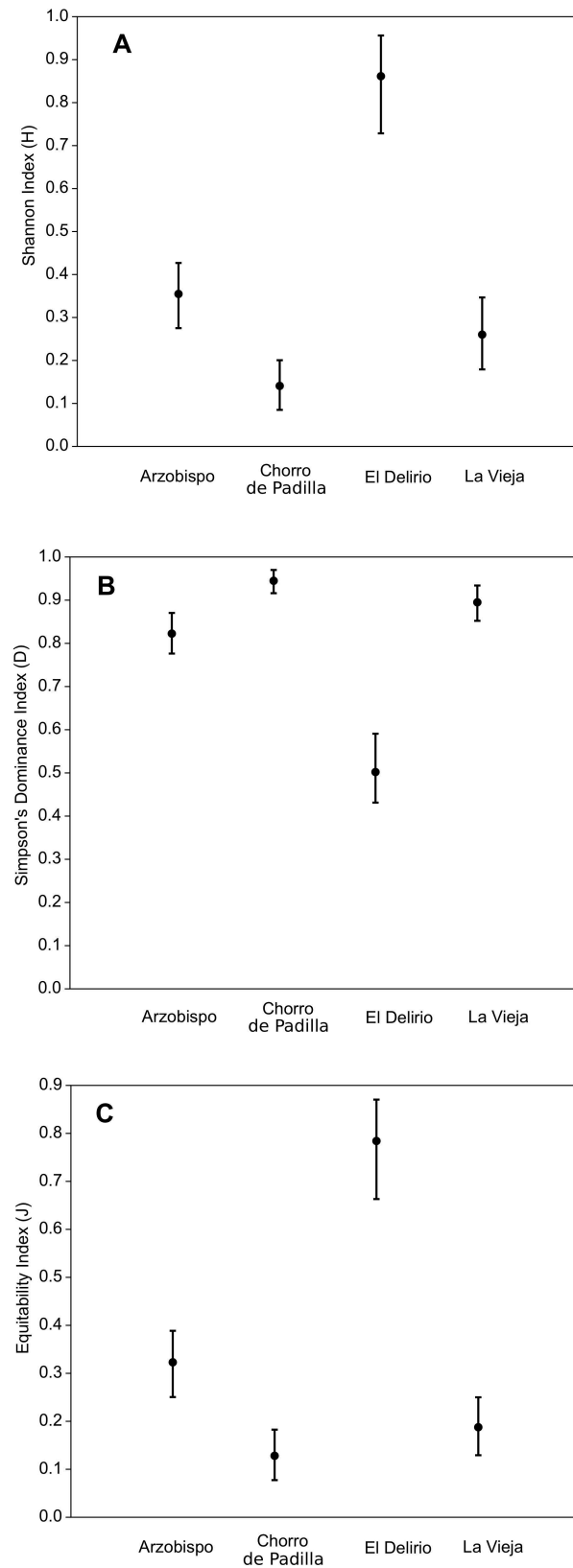
Figure 7. Indices of Shannon-Weaver diversity (A), Simpson dominance (B), and Pielou equitability (C) of the simuliid community for four rivers in the Andean Eastern Hills around Bogotá, Colombia, in 2012. Bars indicate the maximum, mean and minimum values.
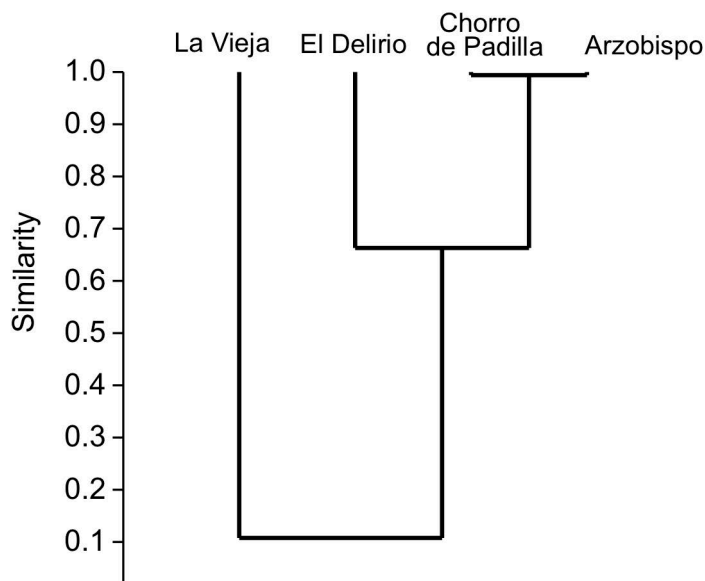
Figure 8. Cluster of similarity (Bray-Curtis index) for four rivers in the Andean Eastern Hills around Bogotá, Colombia, in 2012, based on the composition of the simuliid species.

Discussion

Ecological studies of black flies in much of the Neotropical Region are scarce, often addressing these dipterans at the family level and occasionally at the genus level (Prat *et al*. 2009). Ecological responses, however, are typically species-specific or even population-specific. The family Simuliidae is well known for its cryptic species (Adler *et al*. 2010, Conflitti *et al*. 2015). The inability to reliably distinguish nominal species of the *G. ortizi* complex potentially limits not only high values of diversity, but also it limits the possibility of establishing the responses of each species to environmental variations. We suggest the capture of adults or raising pupae to improve taxonomic identification. Other tools, such as molecular and cytogenetic techniques, and obtaining pharate adults should be used to correctly identify the species from the *G. ortizi* complex.

The rivers of the Eastern Hills of Bogotá have few simuliid species (a total of 5), with *Simulium* species being more abundant in the central (Arzobispo) and southern (Chorro de Padilla, El Delirio) rivers, and the *Gigantodax* species

predominating to the north (La Vieja river). Also, a low number of simuliid taxa (7) have been recorded in watercourses of the municipality of La Calera (Muñoz *et al.* 1984) near the rivers of the current study. For other territories of Colombia (Departments of Cundinamarca and Tolima, located in the central Andean region of the country), Muñoz & Miranda-Esquivel (1997) recorded 38 species (15 species of *Gigantodax* and 23 species of *Simulium*). The mean number (1.8 - 2.5) of simuliid species in each of our rivers is lower than the typical number (2.3 - 4.7) in Nearctic and Neotropical streams and rivers (McCreadie *et al.* 2005). This lower number of species in the rivers of the Eastern Hills around Bogotá may be due mainly to the fact that the *G. ortizi* complex includes at least three cryptic species. It is probable that once the taxonomic difficulties of this complex are solved the species richness in the area will increase.

Dissolved oxygen, pH, and temperature are physicochemical parameters to which aquatic organisms are sensitive (Roldán & Ramírez 2008). Changes in these parameters in the four rivers of this study are mainly influenced by climatic variation. No industrial pollutants or household wastes are released into these rivers. Rain, however, can carry eroded sediments into the rivers, increasing substances such as nitrates (Roldán & Ramírez 2008). The high prevalence of *Gigantodax* in La Vieja could indicate that species of this taxon have some preference for the slightly more acidic waters of this river. This assumption, however, requires further testing, both in the field and in the laboratory. Also, it is likely that the characteristics of the substrate in La Vieja (cobbles and boulders) favor the establishment of species of this genus. This hypothesis, like the previous assumption, should be studied in future research.

Given the appropriate range of physicochemical factors, biotic factors (e.g., competition) and stochastic factors can also influence species assemblage at a given site (McCreadie *et al.* 1997). One of the factors influencing black fly diversity is elevation, which is associated with temperature (Srisuka *et al.* 2015, Ya'cob *et al.* 2016). The maximum difference in elevation among sampling sites was only 266 m, and it was coupled to a temperature difference of ca. 2 °C. This temperature difference was able to differentiate samples in May and June, during the transition from the rainy to the dry season, when waters were slightly warmer (as the Kruskal-Wallis analysis seems to confirm).

Water velocity influences the abundance of Diptera in Andean rivers (Donato 2008), and often it is correlated with simuliid distribution at various spatial scales (Orth & Maughan 1983, Morin *et al.* 1986, McCreadie & Colbo 1993). Although stream velocity was uniform across the rivers in this study (Table 2), the differences reflected in the standard deviation were sufficient to cause a reduction in the abundance of the total simuliid

community when stream velocity was higher. Remarkably, *S. furcilatum* seemed to prefer swifter waters, which means that a greater speed seems to favor its abundance. Either way, water velocity can have an important effect on the abundance of these dipterans. *S. muiscorum*, which predominated in three of the four rivers (Chorro de Padilla, Arzobispo, and El Delirio), tends to have a clumped larval distribution. The individuals' aggregations might allow the larvae to optimize filtering of particulate matter when water velocity increases (Eymann 1991), and perhaps a clumped population offers some protection from predators. However, the negative relationship between the total simuliid abundance and water velocity could mean that not all species are favored by the increase in water velocity. The influence of other physical and chemical variables was weak or not correlated with species abundance, perhaps due to the moderate degree of uniformity in the environmental conditions of all rivers. As previously mentioned, temporal variations in environmental conditions were restricted to temperature and stream velocity and did not significantly influence short-term faunal composition or species distribution.

Diversity indices were low. This is partly due to cryptic speciation in the Simuliidae (Adler *et al.* 2010; Conflitti *et al.* 2015). An example of this phenomenon is the *G. ortizii* complex, which could include three species of this genus in the studied rivers. Another reason for the low diversity values is that only Simuliid taxa were considered. The inclusion of other invertebrate groups would have increased diversity index values. All sampled streams had low equitability (that is, the distribution of individuals between populations was uneven), a clear indication of the trend of dominance of some taxa (mainly *S. muiscorum*). Research on the Simuliidae by Dos Santos *et al.* (2010) shows that the dominance in a given region (like the Guaravera river, Paraná State, Brazil) is common. In that basin the authors observed that some simuliids species were much more dominant than others. The Simpson index for El Delirio revealed that in this river species predominance was lowest and at the same time, it was the river with greater equitability, possibly because this is a second-order river (Table. 1), namely, with contributions from other streams, that could favor a slightly greater diversity. When observing the physicochemical variables of this river (Table 2), it is feasible to think that its colder, more uniform temperatures (from May-June), more oxygenated and nitrate-low environment could lead to a richer and more diverse assemblage of black flies. Furthermore, it can be hypothesized that the greater richness and diversity observed in El Delirio river is also a reflection of the intense competition for niches and habitats taking place in this river, and this prevents dominance of a single species.

The four rivers are geographically close to one another, and all are located in the same cool temperature zone, with similar elevation, flow, and slope. The rivers in the southern and central sectors of the study area (Arzobispo,

Chorro de Padilla, and El Delirio) are more similar to one-another than to La Vieja, which is located in the north section, where the *G. ortizi* complex predominated. The clustering of Arzobispo and Chorro de Padilla probably reflects their physical proximity (2.4 k m). Despite the apparent environmental homogeneity in the studied rivers, the current results reveal that there is some variation in the black fly species assemblages among sites. Whether this is significant or not, this variation is clearly shown by the differences between black fly species correlations to different habitats or environmental variables. Thus, some simuliids species (e.g. *S. ignescens*) could be suitable indicators of good water quality, and some taxa (e.g. *S. muiscorum*) might be more tolerant to lower oxygen levels in slightly polluted rivers.

In conclusion, the results of this study show that the species of simuliids in the rivers of the Eastern Hills around Bogotá can be potential indicators of the environmental conditions of these lotic ecosystems. In this way, the presence of different black fly taxa of could indicate the conditions of each river. The present study is preliminary and exploratory, so it would be necessary in future studies to increase the number of river ecosystems and deepen the biota-environmental relationships, including many more variables, especially relating to those of sanitation, such as coliform bacteria, chemical and biological oxygen demands, phosphorus and electrical conductivity, among others.

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Conflicts of interests

No potential conflict of interest was reported by the authors.

References

Adler PH, Cheke RA, Post RJ, Evolution, epidemiology, and population genetics of black flies (Diptera: Simuliidae), *Infection, Genetics and Evolution*, 10: 846-865, 2010.

doi: 10.1016/j.meegid.2010.07.003

Adler PH, Crosskey RW. World blackflies (Diptera: Simuliidae): a comprehensive revision on the taxonomic and geographical inventory, Clemson University, Clemson, USA. 131 p. 2017.

Retrieved from: http://www.clemson.edu/cafls/biomia/pdfs/blackflyinventory.pdf

Adler PH, Currie DC, Wood DM. The black flies (Simuliidae) of North America, Cornell University Press, New York. 941 p. 2004.

Allan JD, Flecker AS, Segnini S, Taphorn DC, Sokal E, Kling GW. Limnology of Andean piedmont rivers of Venezuela, *Journal of the North American Benthological Society*, 25: 66-81, 2006.

doi: 10.1899/0887-3593(2006)25[66:LOAPRO]2.0.CO;2

Bueno M, Moncada L, Muñoz P. Simuliidae (Insecta: Diptera) de Colombia I-Nueva especie de *Simulium (Hemicnetha), Caldasia*, 12: 581-594, 1979.

Carle DM, Adler PH, Robson MG. Pollution tolerance values for predicting the spread of black flies (Diptera: Simuliidae) in New Jersey, with implications for control, *Human and Ecological Risk Assessment*, 21: 2273-2291, 2015.

doi: 10.1080/10807039.2015.1052960

Colwell RK, Elsensohn JE. EstimateS turns 20: statistical estimation of species richness and shared species from samples, with non-parametric extrapolation, *Ecography*, 7: 609-613, 2014.

doi: 10.1111/ecog.00814

Conflitti IM, Shields GF, Murphy RW, Currie DC. The speciation continuum: ecological and chromosomal divergence in the *Simulium arcticum* complex (Diptera: Simuliidae), *Biological Journal of the Linnean Society*, 115: 13-27, 2015.

doi: 10.1111/bij.12480

Corredor A, Nicholls RS, Duque S, Munoz de Hoyos P, Alvarez CA, Guderian RH, López HH, Palma GI. Current status of onchocerciasis in Colombia, *The American Journal of Tropical Medicine and Hygiene*, 58(5): 594-8, 1998.

doi: 10.4269/ajtmh.1998.58.594

Coscarón S, Coscarón-Arias CL. Distribution of Neotropical Simuliidae (Insecta, Diptera) and its areas of endemism, *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales*, 19: 717-732, 1995.

Coscarón S, Coscarón-Arias CL. Neotropical Simuliidae (Diptera: Insecta). Aquatic Biodiversity in Latin America. 3, Pensoft, Sofia, UDA 685 p. 2007.

Couceiro SR, Hamada N, Sagot LB, Pepinelli M. Black-fly assemblage distribution patterns in streams in disturbed areas in southern Brazil, *Acta Tropica*, 140: 26-33, 2014.

doi: 10.1016/j.actatropica.2014.07.018

Currie DC, Adler PH. Global diversity of black flies (Diptera: Simuliidae) in freshwater, *Hydrobiologia*, 595: 469-475, 2008.

doi: 10.1007/s10750-007-9114-1

Docile TN, Figueiró R, Gil-Azevedo LH, Nessimian JL. Water pollution and distribution of the black fly (Diptera: Simuliidae) in the Atlantic Forest, Brazil, *Revista de Biología Tropical*, 63: 683-693, 2015.

doi: 10.15517/rbt.v63i3.16195

Donato RC (ed). Ecología de un río de montaña de los Andes Colombianos (Río Tota, Boyacá), Universidad Nacional de Colombia, Facultad de Ciencias, Bogotá, Colombia. 231 p. 2008.

Dos Santos RB, Lopes J, Dos Santos BK. Distribuição espacial e variação temporal da composição de espécies de borrachudos (Diptera: Simuliidae) em uma microbacia situada no norte do Paraná, *Neotropical Entomology*, 39: 289-298, 2010.

doi: 10.1590/S1519-566X2010000200022

Eymann M. Dispersion patterns exhibited by larvae of the black flies *Cnephia dacotensis* and *Simulium rostratum* (Diptera: Simuliidae), *Aquatic Insects*, 13: 99-106, 1991.

doi: 10.1080/01650429109361429

Figueiró R, Araújo-Coutinho CJ, Gil-Azevedo LH, Nascimento ES, Monteiro RF. Spatial and temporal distribution of blackflies (Diptera: Simuliidae) in the Itatiaia National Park, Brazil, *Neotropical Entomology*, 35: 542-550, 2006.

doi: 10.1590/S1519-566X2006000400018

Figueiró R, Nascimento ES, Gil-Azevedo LH, Maia-Herzog M, Monteiro RF. Local distribution of blackfly (Diptera, Simuliidae) larvae in two adjacent streams: the role of water current velocity in the diversity of blackfly larvae, *Revista Brasileira de Entomologia*, 52: 452-454, 2008.

doi: 10.1590/S0085-56262008000300020

Figueiró R, Gil-Azevedo LH. The role of neotropical blackflies (Diptera: Simuliidae) as vectors of the onchocerciasis: a short overview of the ecology behind the disease, *Oecologia Australis*, 14: 745-755, 2010.

doi: 10.4257/oeco.2010.1403.10

Figueiró R, Gil-Azevedo LE, Maia-Herzog M, Monteiro RF. Diversity and microdistribution of black fly (Diptera: Simuliidae) assemblages in the tropical savanna streams of the Brazilian cerrado, *Memorias do Instituto Oswaldo Cruz*, 107: 362-369, 2012.

doi: 10.1590/S0074-02762012000300011

Figueiró R, Maia-Herzog M, Gil-Azevedo LH, Monteiro RF. Seasonal variation in black fly (Diptera: Simuliidae) taxocenoses from the Brazilian Savannah (Tocantins, Brazil), *Journal of Vector Ecology*, 39(2): 321-7.

doi: 10.1111/jvec.12107

Grillet ME, Barrera R. Spatial and temporal abundance substrate partitioning and species co-occurrence in a guild of Neotropical blackflies (Diptera: Simuliidae), *Hydrobiologia*, 345: 197-208, 1997.

doi: 10.1023/A:1002901612957

Hamada N, Grillet ME. Blackflies (Diptera: Simuliidae) of the Gran Sabana (Venezuela) and Pacaraima region (Brazil): distributional and identification keys for larvae and pupae, *Entomotropica*, 16: 29-49, 2001.

Hamada N, McCreadie JW. Environmental factors associated with the distribution of *Simulium perflavum* (Diptera: Simuliidae) among streams in Brazilian Amazonia, *Hydrobiologia*, 397: 71-78, 1999.

doi: 10.1023/A:1003642430681

Hamada N, McCreadie JW, Adler PH. Species richness and spatial distribution of black flies (Diptera: Simuliidae) in streams of central Amazonia, Brazil, *Freshwater Biology*, 47: 31-40, 2002.

doi: 10.1046/j.1365-2427.2002.00778.x

Hammer Ø, Harper DAT, Ryan PD. PAST: Paleontological statistics software package for education and data analysis, *Paleontologia Electronica*, 4: 1-9, 2001.

Retrieved from http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Hauer FR, Lamberti GA. Methods in stream ecology, 2nd ed, Academic Press, Burlington, USA. 877 p. 2007.

Horton RE. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology, *Geological Society of America Bulletin*, 56: 275-370, 1945.

doi: 10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Iñiguez-Armijos C, Rausche S, Cueva A, Sánchez-Rodríguez A, Espinosa C, Breue L. Shifts in leaf litter breakdown along a forest-pasture- urban gradient in Andean streams, *Ecology and Evolution*, 6(14): 4849-4865, 2016.

doi: 10.1002/ece3.2257

Jacobsen D, Schultz R, Encalada A. Structure and diversity of stream invertebrate assemblages: the influence of temperature with altitude and latitude. *Freshwater Biology*. 38: 247-261, 1997.

doi: 10.1046/j.1365-2427.1997.00210.x

Jacobsen D, Encalada A. The macroinvertebrate fauna of Ecuadorian highland streams in the wet and dry season, *Fundamental and Applied LimnologyArchiv für Hydrobiologie*, 142: 53-70, 1998.

doi: 10.1127/archiv-hydrobiol/142/1998/53

Landeiro VL, Pepinelli M, Hamada N. Species richness and distribution of blackflies (Diptera: Simuliidae) in the Chapada Diamantina region, Bahia, Brazil, *Neotropical Entomology*, 38: 332-339, 2009.

doi: 10.1590/S1519-566X2009000300006

Lewis DJ, Lee-Potter J. Simuliidae (Diptera) from the Sierra Nevada de Santa Marta, Colombia. *Annals and Magazine of Natural Sistory, Series 13*, 7: 95-100, 1964.

doi: 10.1080/00222936408651444

Lotta IA, Pacheco MA, Escalante AA, González AD, Mantilla JS, Moncada LI, Adler P, Matta NE. *Leucocytozoon* diversity and possible vectors in the Neotropical highlands of Colombia, *Protist*, 167(2): 185-204, 2016.

doi: 10.1016/j.protis.2016.02.002

Malmqvist B, Adler PH, Kuusela K, Merritt RW, Wotton RS. Black flies in the boreal biome, key organisms in both terrestrial and aquatic environments: a review, *Ecoscience*, 11: 187-200, 2004.

doi: 10.1080/11956860.2004.11682824

Mantilla JS, Moncada LI, Matta NE, Adler PH. Oviposition behavior and microstructure of the eggs of *Simulium dinellii* (Joan) (Diptera: Simuliidae), *Acta Biológica Colombiana*, 20: 217-220, 2015.

doi: 10.15446/abc.v20n1.43149

Martínez RE, Portillo M. Estudio faunístico y ecológico de los simúlidos (Diptera, Simuliidae) del río Cidacos a su paso por la Rioja, *Zubía Monográfico*, 11: 61-80, 1999.

McCreadie JW, Adler PH. Spatial distributions of rare species in lotic habitats, *Insect Conservation and Diversity*, 1: 127-134, 2008.

doi: 10.1111/j.1752-4598.2008.00017.x

McCreadie JW, Colbo MH. Larval and pupal microhabitat selection by *Simulium truncatum* Lundström, *S. rostratum* Lundström, and *S. verecundum* AA (Diptera: Simuliidae), *Canadian Journal of Zoology*, 71: 358-367, 1993.

doi: 10.1139/z93-050

McCreadie JW, Adler PH, Burger JF. Species assemblages of larval black flies (Diptera: Simuliidae): random or predictable?, *Journal of the North American Benthological Society*, 16: 760-770, 1997.

doi: 10.2307/1468169

McCreadie JW, Adler PH, Hamada N. Patterns of species richness for blackflies (Diptera: Simuliidae) in the Nearctic and Neotropical regions, *Ecological Entomology*, 30: 201-209, 2005.

doi: 10.1111/j.0307-6946.2005.00681.x

Moncada-Álvarez LI, Cuadrado-Argel LA, Pinilla-Agudelo GA. Biodiversidad de simúlidos (Diptera: Simuliidae) de Colombia: estado del conocimiento, *Biota Colombiana*, 18(2): 164-179. 2017.

doi: 10.21068/c2017.v18n02a10

Morin A, Harper P, Peters RH. Microhabitat-preference curves of blackfly larvae (Diptera: Simuliidae): a comparison of three estimation methods, *Canadian Journal of Fisheries and Aquatic Sciences*, 43: 1235-1241, 1986.

doi: 10.1139/f86-153

Muñoz P, Bueno M, Moncada L. Simuliidae (Insecta: Diptera) de Colombia. IV-Clave gráfica para la identificación de los simúlidos de la región de La Calera, Cundinamarca, *Biomedica*, 4: 14-24, 1984.

doi: 10.7705/biomedica.v4i1.1877

Muñoz P, Miranda-Esquivel DR. Simúlidos (Diptera: Simuliidae) presentes entre las vertientes magdalenense y orinocense, en un sector al centro de Colombia, *Caldasia*, 19: 297-310, 1997.

doi: 10.15446/caldasia

Muñoz P, Coscarón S. Claves para la identificación de simúlidos (Diptera: Simuliidae) presentes entre las vertientes magdalenense y orinocense, en un sector al centro de Colombia, *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales*, 23: 181-214, 1999.

Orth DJ, Maughan OE. Microhabitat preferences of benthic fauna in a woodland stream, *Hydrobiologia*, 106: 157-168, 1983.

doi: 10.1007/BF00006748

Prat N, Ríos B, Acosta R, Rieradevall M. Los macroinvertebrados como indicadores de calidad de las aguas, p. 631-654. In: E. Domínguez and H.R. Fernández (eds), Macroinvertebrados bentónicos sudamericanos. Sistemática y biología, Fundación Miguel Lillo, San Miguel de Tucumán, Argentina. 2009.

Restrepo M, Rincón CM. Aproximación a la caracterización ecológica de la quebrada Fucha en la Reserva Forestal de los Cerros Orientales en la localidad de San Cristóbal. (Bogotá, Colombia), *Bio-grafía: Escritos sobre la Biología y su Enseñanza*, 2: 1-18, 2009.

Roldán G, Ramírez J. Fundamentos de limnología neotropical, 2nd ed, Universidad de Antioquia, Universidad Católica de Oriente, ACCEFYN, Medellín, Colombia. 440 p. 2008.

Shelley AJ, Hernández LM, Davies JB. Blackflies (Diptera: Simuliidae) of Southern Guyana with keys for the identification of adults and pupae - a review, *Memorias do Instituto Oswaldo Cruz*, 99: 443-470, 2004.

doi: 10.1590/S0074-02762004000500001

Srisuka W, Takaoka H, Otsuka Y, Fukuda M, Thongsahuan S, Taai K, Choochote W, Saeung A. Seasonal biodiversity of black flies (Diptera: Simuliidae) and evaluation of ecological factors influencing species distribution at Doi Pha Hom Pok National Park, Thailand, *Acta Tropica*, 149: 212-219, 2015.

doi: 10.1016/j.actatropica.2015.05.024

Tidwell MA, Tidwell M, Muñoz de Hoyos P, Corredor A. *Simulium exiguum*, the vector of Onchocerca volvulus on the Río Micay, Colombia, *The American Journal of Tropical Medicine and Hygiene*, 29(3): 377-381, 1980.

doi: 10.4269/ajtmh.1980.29.377

Wallace JB, Webster JR. The role of macroinvertebrates in stream ecosystem function, *Annual Review of Entomology*, 41: 115-139, 1996.

doi: 10.1146/annurev.en.41.010196.000555

Welch EB, Tindell T. Ecological effects of waste water: applied limnology and pollutant effects, 2nd ed, E & F N Spon, London. 425 p. 1992.

World Health Organization (WHO). Progress towards eliminating onchocerciasis in the WHO Region of the Americas: verification by WHO of elimination of transmission in Colombia, *Weekly Epidemiological Record*, 88(36): 381-388, 2013.

Retrieved from http://www.who.int/onchocerciasis/resources/who_wer8836/en/

Ya'cob Z, Takaoka H, Pramual P, Low VL, Sofian-Azirun M. Distribution pattern of black fly (Diptera: Simuliidae) assemblages along an altitudinal gradient in Peninsular Malaysia, *Parasites & Vectors*, 9: 219, 2016.

doi: 10.1186/s13071-016-1492-7

Abundancia y diversidad de moscas negras (Diptera: Simuliidae) en ríos de los Cerros Orientales Andinos de Bogotá (Colombia), y su relación con variables fisicoquímicas de las corrientes de agua

Resumen. Las moscas negras son organismos bénticos abundantes en corrientes de agua bien oxigenadas y se consideran bioindicadores efectivos de la calidad de agua. La información sobre la ecología de estos organismos a nivel de especie es importante, ya que hasta el momento, ha estado disponible principalmente solo a nivel de familia. El objetivo de este estudio fue evaluar la composición de moscas negras y sus relaciones con un grupo de factores físicos y químicos en cuatro ríos pequeños de los Cerros Orientales alrededor de Bogotá, Colombia. Estos nacimientos están protegidos por la Empresa de Acueducto y Alcantarillado de Bogotá, Colombia. Se colectaron larvas y pupas de moscas negras a lo largo de cuatro períodos de muestreo, desde la estación seca hasta la estación lluviosa de 2012. Se utilizaron métodos multivariados para determinar la presencia de cada especie en relación con: oxígeno disuelto, nitratos, pH, temperatura y velocidad del agua. La ordenación por PCA reveló un ambiente fisicoquímico con tendencia hacia la homogeneidad en los cuatro ríos estudiados. La ordenación por DCA confirmó que en el río La Vieja dominó el complejo *G. ortizi*, mientras que *S. muiscorum* fue dominante en los otros tres. De igual forma de acuerdo con el análisis NMDS, la composición de moscas negras en los ríos Arzobispo y Chorro de Padilla fue similar, mientras que en los ríos El Delirio y La Vieja fue diferente, especialmente en este último. Los ríos presentaron baja riqueza de especies (cuatro especies y un complejo de especies). *Simulium muiscorum* se correlacionó negativamente con el oxígeno disuelto, temperatura y velocidad de la corriente, mientras que *S. ignescens* estuvo asociado con aguas ligeramente más oxigendas y *S. furcilatum*, con corrientes más rápidas. La baja diversidad y riqueza para los cuatro ríos es consistente con reportes previos de baja diversidad neotropical de moscas negras. Los resultados muestran que las especies de simúlidos podrían ser buenos indicadores de las condiciones ambientales de los ríos de los Cerros Orientales de Bogotá.

Palabras clave: bioindicadores; moscas negras; macroinvertebrados; ríos; calidad de agua.

Abundancia e diversidade de moscas negras (Diptera: Simuliidae) em rios dos Cerros Orientais Andinos de Bogotá (Colômbia), e sua relação com variáveis físico-químicas das correntes de água

Resumo As moscas negras são organismos bentônicos abundantes em correntes de água bem oxigenadas e se consideram bioindicadores efetivos da calidade de água. A informação sobre a ecologia de estes organismos quanto a espécie é importante, pois até o momento, há informação somente em nível de família. O objetivo de este estudo foi avaliar a composição de moscas negras e suas relações com um grupo de fatores físicos e químicos em quatro rios pequenos dos Cerros Orientais nas redondezas de Bogotá, Colômbia. As nascentes estão protegidas pela Empresa de Acueducto y Alcantarillado de Bogotá, Colômbia. Foram coletadas larvas e poupas de moscas negras ao longo de quatro períodos de amostragem, desde a estação seca até a estação chuvosa de 2012. Foram utilizados métodos multivariados para determinar a presença de cada espécie em relação com: oxigênio dissolvido, nitratos, pH, temperatura e velocidade da água. A ordenação por PCA revelou um ambiente físico-químico com tendência à homogeneidade nos quatro rios estudados. A ordenação por DCS confirmou que no rio La Vieja dominou o complexo *G. ortizi*, enquanto que *S. muiscorum* foi dominante nos outros três rios. Igualmente, de acordo com a análise NMDS, a composição de moscas negras nos rios Arzobispo e Chorro de Padilla foi similar, enquanto que nos rios El delírio e La Vieja foi diferente, em especial neste último. Os rios apresentaram baixa riqueza de espécies (quatro espécies e um complexo de espécies). *S. muiscorum* se correlacionou negativamente com o oxigênio dissolvido, temperatura e velocidades da corrente, enquanto que *S. ignescens* foi associado com águas ligeiramente mais oxigenadas e *S. furcilatum*, com correntes mais rápidas. A baixa diversidade e riqueza para os quatro rios é consistente com reportes prévios de baixa diversidade neotropical de moscas negras. Os resultados mostram que espécies de Simulium poderiam ser boas indicadoras das condições ambientais dos rios dos Cerros Orientais de Bogotá.

Palabras clave: bioindicadores; moscas negras; macroinvertebrados; rios; qualidade da água.

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