UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias Biológicas y Ambientales

On the verge of resilience in the Andean Chocó: mayfly diversity response to seasonality and intermittency in streams

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Biología

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Quito, 19 de diciembre de 2022

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RESUMEN

Los ríos intermitentes son ecosistemas que se secan o desconectan en algún momento del tiempo. En el Neotrópico los ríos intermitentes no han recibido toda la atención como ha ocurrido con los ríos del Trópico y la zona Templada. La biorregión del Chocó en el Neotrópico es conocida como un “hot-spot” de biodiversidad y es uno de los biomas que recibe más precipitación durante el año (>4500 mm). A pesar de ello, en la biorregión del Chocó se encuentra sistemas intermitentes como la microcuenca del río Cube que pertenece a la cuenca del río Esmeraldas. En la microcuenca del río Cube se analizó la respuesta de la comunidad de efímeras a las variables ambientales en dos estaciones climáticas (lluviosa y seca). Se muestrearon 20 sitios distribuidos a lo largo de microcuenca. Al agregar todos los sitios del sistema intermitente se encontró que la comunidad de efímeras no cambia en las dos estaciones. Sin embargo, al disgregar los sitios entre intermitentes y permanentes se encontró que la diversidad de géneros de efímeras aumenta en la época seca en comparación con la época húmeda para ríos permanentes.

Palabras clave: Neotrópico, macroinvertebrados, biodiversidad, ríos, intermitencia.

ABSTRACT

Intermittent rivers and streams are ecosystems that dry during certain time of the hydrological year. In the Neotropics, intermittent rivers have not received as much attention as rivers in the Tropic and Temperate zones. The Chocó Bioregion in the Neotropics is known as a biodiversity "hot-spot" and is one of the biomes that receive records of precipitation during the year (>4500 mm). Despite this, few intermittent systems occur in the Chocó Bioregion, such as the Cube River that is part of the Esmeraldas River Basin. The Cube River was the study site to assess the response of the mayfly community to environmental variables in two seasons: dry and wet. Twenty sites distributed along the watershed were sampled in the wet and dry seasons. The diversity and other community metrics did not change between seasons when sites were aggregate. Inversely, when sites were disaggregated into intermittent and perennial, the diversity of mayflies changed between seasons showing that perennial sites had a higher mayfly diversity in the dry season compared to the wet season.

Key words: Neotropics, macroinvertebrates, biodiversity, rivers, intermittency.

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INTRODUCTION

Rivers and streams are freshwater ecosystems that connect landscapes from the headwaters to the lowlands and harbors a wide variety of living organisms performing different processes along the river continuum (Vannote et al., 1980). Rivers and streams are complex freshwater ecosystems where abiotic and biotic conditions interact to create dynamic environments that offers energy and resources to sustain aquatic biodiversity and human livelihoods. The wealth of ecosystem services that rivers and streams provide to humans (i.e., water provision, nutrient cycling, fisheries, transportation, etc.) have been a subject of extensive research globally (Abell & Harrison, 2020; Tickner et al., 2020). It is known that freshwater ecosystems are habitats for of almost 12% of all described species which are compressed in just 2% of the planet's surface area (Albert et al., 2021). Among the most biodiverse groups we find freshwater fish and aquatic invertebrates which are also important sentinels for freshwater conservation initiatives (Nicacio & Juen, 2015). Despite current efforts, only 17% of rivers and streams are located within protected areas (Abell and Harrison, 2020), and their ecological integrity is constantly under threat by pollution, damming, channelization, and nutrient loading that affects ecological processes, biodiversity, and ecosystem services (Martínez-Sanz et al., 2014). Among world rivers, Neotropical streams face not only the mentioned threats but also the conflict of providing ecosystem services while maintaining the highly variable hydrological regimes present in tropical biomes (Siddiqui et al., 2021).

Freshwater ecosystems across latitudes can be intermittent and perennial according to the degree of permanence of flow. Intermittent rivers and ephemeral streams (IRES) are considered running waters that cease flow in one point of their course and/or during a temporary period (Datry et al., 2017). IRES are cosmopolitan and are regarded as the most common type flowing waters on the planet (Datry et al., 2017) , nevertheless, due to the diverse types of IRES found in different continents a definition that englobes all the types is yet open to more research (Datry et al., 2017). In alpine and artic stream networks, intermittence is given by flow cessation due to water freezing (Robinson et al., 2016); or by flow cessation due to reduced glacial inputs (in glacier-fed streams) and the contraction of groundwater (in groundwater-fed streams), both associated with seasonal changes (Robinson et al., 2016). In other areas, such as arid and semiarid regions like Sycamore Creek in the Sonoran Desert, Arizona, intermittency has a direct relationship with precipitation and the temporal cycles of evapotranspiration (Stanley et al., 1997).

In addition to natural causes for flow cessation, intermittence can be the result of human activities like land use change that may alter flow regulation, extraction of superficial and groundwater, an increase in evaporation, and decrease of the duration of precipitation (Datry et al., 2016; Leigh et al., 2016). Large rivers have been subject to intermittence due to unnatural causes such as is the case with the Colorado River which was transformed from a perennial river to an intermittent river after the construction of Glen Canyon Dam in the 1960s (Datry et al., 2017). A similar case occurred in the Yellow River in China, in which the close-to 5500 km river became intermittent after the construction of 12 dams (Datry et al., 2017).

The main concern regarding IRES dynamics is that ecology of the aquatic ecosystem is affected by the natural fluctuation and that anthropogenic alterations can create an additive effect on the ecosystem. The most general diagnostics of this effects are an increase in water temperature and events of nutrient resuspension with presence of algal blooms that diminish the dissolved oxygen (Hamilton et al., 2005). In addition, pollutants get less diluted and increase in concentration due to a decrease in the water level, while aquatic organisms bioaccumulate these contaminants and pass it on through the trophic web (Osorio et al., 2014).

Among the most studied aquatic organisms in IRES are benthic macroinvertebrates compared to algae, microbes, plants, and fish. Macroinvertebrates are organisms lacking a backbone, are visible to the naked eye and live on the bottom of streams (Birmingham et al., 2005). Macroinvertebrates are the most diverse and abundant group within the riparian ecosystem, hyporheic and benthic habitats (Figueroa et al., 2003). Within the macroinvertebrate community, mayflies are one of the oldest groups of winged insects with 37 families composed of approximately 375 genera (Derka et al., 2019) and 3700 species(Jacobus et al., 2019). They are unique flying insects that have two stages with wings, a subimago and imago. They live most of their lives in immature stages in aquatic environments and are found in every type of freshwater ecosystem except for Antarctica.

Mayfly´s dietary diversity plays a key role in nutrient cycling. Breaking and tearing down elements make nutrients available for other groups but also, mayflies become vital food source for birds, fish, amphibians, and other invertebrates (Dominguez et al., 2006; Jacobus et al., 2019). Burrowing mayflies provide bioturbation and bioirrigation to the benthic environment which provides aeration and oxidation of elements and compounds (Chaffin & Kane, 2010). In some habitats, mayfly (i.e., *Hexagenia limbate)* contribution can be primordial as they are responsible of the movement of 90% of the sediment (i.e., Lake Saint Joseph, Canada) (Charbonneau & Hare, 1998). Bioturbation mediated by mayflies has proven to promote the flux of phosphorus in the water column (i.e., Lake Erie) caused by the emergence of 88 billon individuals in one single event (Chaffin & Kane, 2010; Stepanian et al., 2020). Such massive emergence release tons of biomass transferring substantial concentrations of phosphates and nitrates from the water to the terrestrial environment, thus removing and cleansing pollutants in freshwater systems (Dominguez et al., 2006).

Despite the ecological role of mayfly, since 2012 a decline of the 50% of the mayfly community has been reported in the Upper Mississippi River and in the Western Lake Erie Basin(Stepanian et al., 2020). This trend can be attributed to a worldwide use of pesticides to which most mayflies have proven to be sensitive (Daam et al., 2013; Lundin et al., 2015). In the Neotropics, the expansion of pastures and agricultural land suggest a potential similar threat to aquatic insects (Wassenaar et al., 2007). Therefore, most research is needed to understand diversity in intermittent rivers and ephemeral streams of the Neotropics.

The Neotropics has the highest mayfly diversity with almost 900 species, followed by the Palaearctic (830), Nearctic and Oriental (610 and 620 respectively), Afrotropical (440) Australasian (250), and Pacific (48) (Jacobus et al., 2019). The Neotropics are also the evolutionary origin of some of the major mayfly families such as Ephemeroptera: Leptophlebiidae which is the largest family in terms of number of genera and the second in terms of number of species which originated in South America to what is known as the Gondwanan origin (Mccafferty, 1998; Monjardim et al., 2020; Savage, 1987). Currently the Leptophlebiidae family is cosmopolitan and has kept a close relationship to this ancestral origin. Approximately 60% of the genera and 80% of species are endemic to the region (Pescador et al., 2001) with a total count of 150 species and 40 genera in the Neotropics (Dominguez et al., 2006). Other cosmopolitan families such as Caenidae, Baetidae and Leptophlebiidae show a high generic and specific endemicity in South America (Dominguez et al., 2006).

Current studies of mayfly in the Neotropics, have reported the diversity of the Leptophlebiidae family in Brazil (Brasil et al., 2013). However, little is known about mayfly and other aquatic invertebrates in intermittent rivers and ephemeral streams of the Neotropics, including the Andean Chocó (Molinero et al., 2019). Therefore, we propose to understand how the mayfly community assembly varies during the wet (April-May) and dry seasons (October-November). A three-fold approach to answer this question includes 1) assess the overall mayfly community assembly across the Cube River Basin, 2) evaluate environmental variables between and within seasons, and 3) compare the mayfly diversity in streams of the Cube River Basin within seasons.

METHODS

The study of intermittent rivers and ephemeral streams around the world has expanded to Neotropical biomes. The worldwide initiative for Securing biodiversity, functional integrity, and ecosystem services in DRYing riVER networks is a Horizon 2020 project designed to understand the response of IRES to climate change and the impacts on the biodiversity (Datry et al. 2021). This research is part of the DRYvER project occurring in 9 Drying River Networks between Europe, Latin America, and Caribbean countries (CELAC), China and United States. The CELAC participants are Ecuador, Bolivia, and Brazil.

Study Area

The study area is part of Esmeraldas River Basin located in the Andean Chocó bioregion that ranges from Southern Panamá to Southern Ecuador (Fagua & Ramsey, 2019). The Esmeraldas River Basin begins in the Andes at 5800 m and drains into the Pacific Ocean (Figure 1b). The Cube River feeds the Viche River, a lowland tributary of the Esmeraldas River. The Cube River Basin starts in the Coloncho Ridge at 604 m and flows North to the Viche River at 32 m, with a drainage area of 165 km². The headwaters of the Cube River Basin are located inside the Mache Chindul Ecological Reserve (REMACH) that includes the Ramsar Site Nº 1143 (Laguna de Cube)(Tosso, 2009). The Cube River Basin is composed by a mosaic of land uses including the protected area, secondary tropical forest, agricultural and pasture lands, and human settlements (Figure 1c).

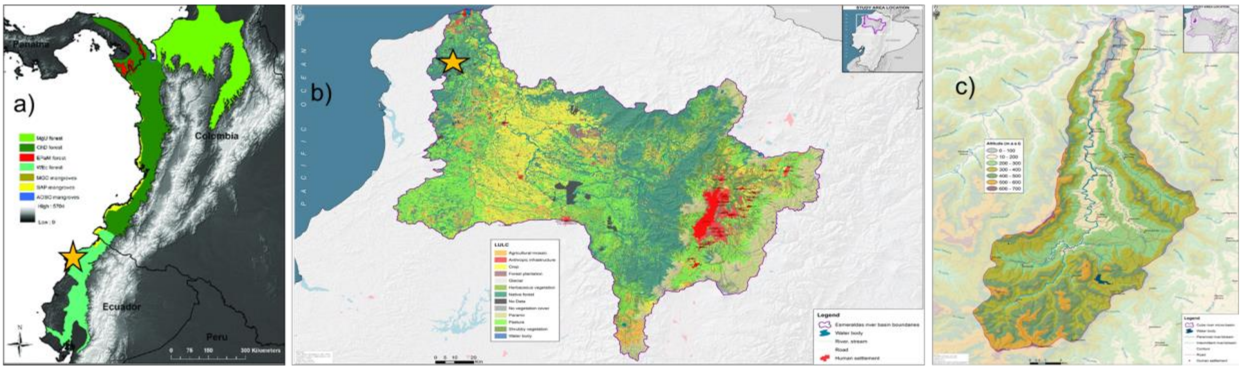

Figure 1. The Andean Chocó Bioregion extending from Dairen in Panamá to Southern Ecuador (a) source: Fagua and Ramsey 2019, the Esmeraldas River Basin (orange star) in Northern Ecuador (b) showing the main city of Quito and the Cube River Basin (orange star) (c), source: Instituto Biósfera.

Sampling design

Sampling was designed to be comparable and standard between Drying River Networks in the DRYvER project (Datry et al., 2021). To sample aquatic macroinvertebrates and environmental variables 20 localities were selected including streams that cease to flow during some part of the year and streams or rivers that remain with water during most of the year. A balance between sites included sites in headwaters or distant to the mainstem (Cube River) and streams adjacent or in the mainstem (Figure 2) Sampling was carried out six times during the year according to the DRYvER protocol, however for this analysis only two field campaigns were used: wet (April-May) and dry (October – November). The climatic patterns of northwestern Ecuador fall in what is known in Koppen's classification as a Tropical monsoon (Am) region (Toalombo Vargas et al., 2020). This type of region is characterized for having a well-defined dry season from August to November, and a well-defined rainy season from January to May (Gómez, 2018). The annual precipitation of the area varies from 2000 to 3000 mm (Gómez, 2018).

Figure 2. The Cube River Basin showing sampling sites (numbers) in the headwaters 1 – 13 distant to the mainstem, and middle and lowland sites 14 - 20 adjacent to the mainstem.

Environmental parameters

Sampling environmental parameters following the DRYvER protocol included hydrological variables (i.e., width, depth, velocity) using a doppler velocimeter (OTT ®). In situ physical and chemical parameters were measured on five transects of all reaches (i.e., pH temperature (°C), Conductivity (µS/cm), Dissolved Oxygen (mg/l), and Oxygen Saturation (%) and Specific Conductivity (µS/cm) using a multiparameter sonde (YSI PRO DSS). We collected water samples for chemical analysis in the Laboratorio of different ions, nutrients, and metals. Finally, chlorophyll-a was measured from biofilms using an extraction in the field and laboratory analysis with a spectrophotometer (Agilent®).

Macroinvertebrate sampling

As part of the DRYvER protocol, linear transects must be established on the bank of the river with the consideration that its length must account for at least 20 times the maximum mean wetted width. The minimum length should be 50m and the maximum length 150 m, these values were adjusted according to streams. The sampling effort considered at least 2.5 hours for two people. The quantitative sample device was a Surber net used for all sites. Samples were washed, and macroinvertebrates were decantated by stirring and collecting sediment which was poured with water through a set of sieves of three mesh sizes: 300 mm, 10 mm, and 2 mm was All samples were stored in containers with 96% ethanol and preserved under cool temperature (Datry et al., 2021).

Samples were labeled and brought to Laboratorio de Ecología Acuática of Universidad San Francisco de Quito (LEA-USFQ), where mayflies were identified in a Zeiss Stereo Microscope up to the genus level, using several taxonomic keys(Domínguez & Fernández, 2009; Miñano et al., 2019; Salles et al., 2018; Thorp et al., 2014) . Classified specimens from each genus were stored in 5 mL vials with 96% ethanol and stored in the collection of the Aquatic Ecology Laboratory of Universidad San Francisco de Quito (LEA-USFQ).

Data analysis

Ecological indexes to assess the community assembly and the environmental data between seasons were assessed using a Shapiro test of normality. When feasible a paired t-test was used or a Wilkinson Rank Sum test for non-parametrical data. We calculated density, richness, evenness, and diversity using the Shannon-Wiener and Simpson indexes. Indices from seasons were computed using the average of all sites. A principal component analysis was used to assess the effect of seasons on environmental variables. All analysis were run in R Studio.

RESULTS

We recorded a total of 939 mayfly larvae from wet season and a total of 1694 mayfly larvae from the dry season. In the case of the mayfly community structure and its comparison between seasons, we have found that there are no significant differences in terms of Density, Richness, Simpson's Diversity Index, and Pielou´s Evenness (Figure 3).

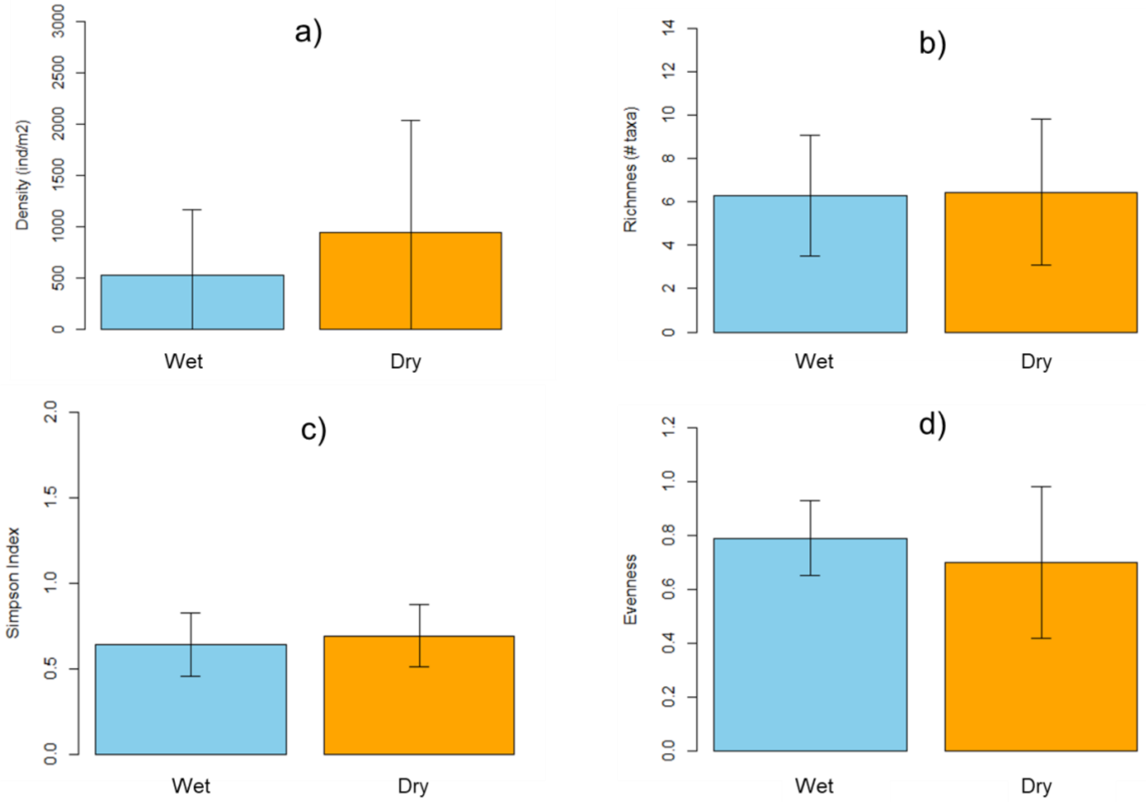

Figure 3. The mayfly community in the Cube River Basin sampled in April 2021 corresponding to the wet season (blue) and in October 2021 correspondng to the dry season (orange). Community metrics show no statistical difference for density (ind/m^2) (a), richness of taxa (b), Simpson diversity (c), and Evennes (d).

The comparison of genera found within major families, show differences by genera appearing exclusively on either season (Figure 4). In the wet season, two exclusive genera appear with one individual each: Atopophlebia and Hexagenia, while in the the dry season the genera Traverella and Latineosus appear also with one individual each.

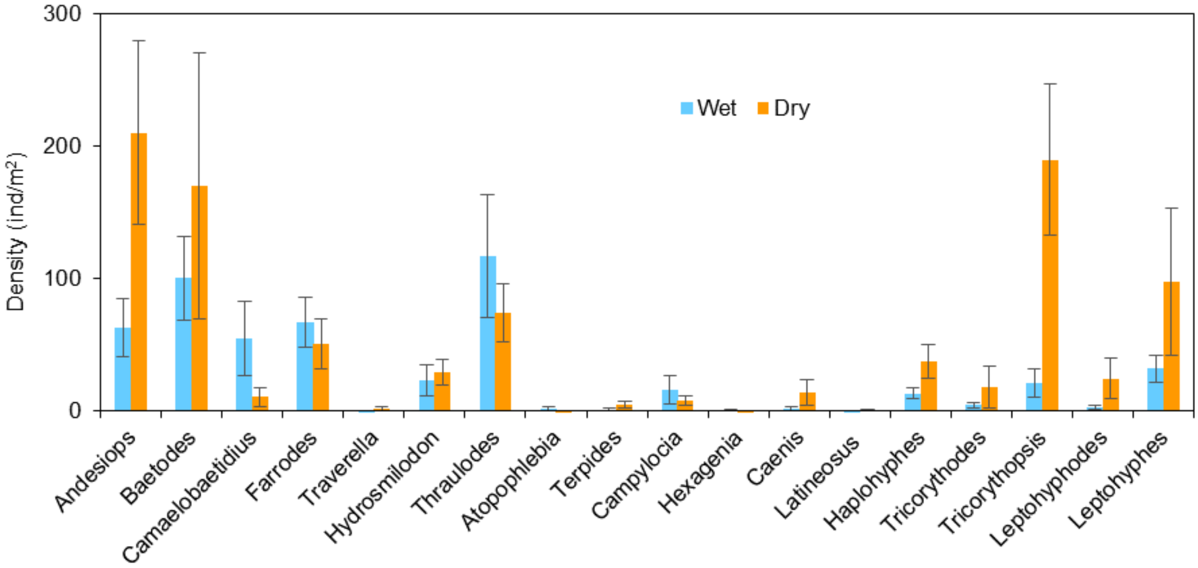

Figure 4. Mayfly genera in the Cube River Basin sampled in 2021 during the wet (blue) and dry (orange) seasons, bars correspond to averaged density (ind/m²) (n = 20) with ± standard errors.

The environmental variables analysis for both seasons show altitude explain 40% of the sites variation while flow and suspended solids explain 22% of the sites variation (Figure 5a). The biplot analysis show how sites separate according to each season (Figure 5b)

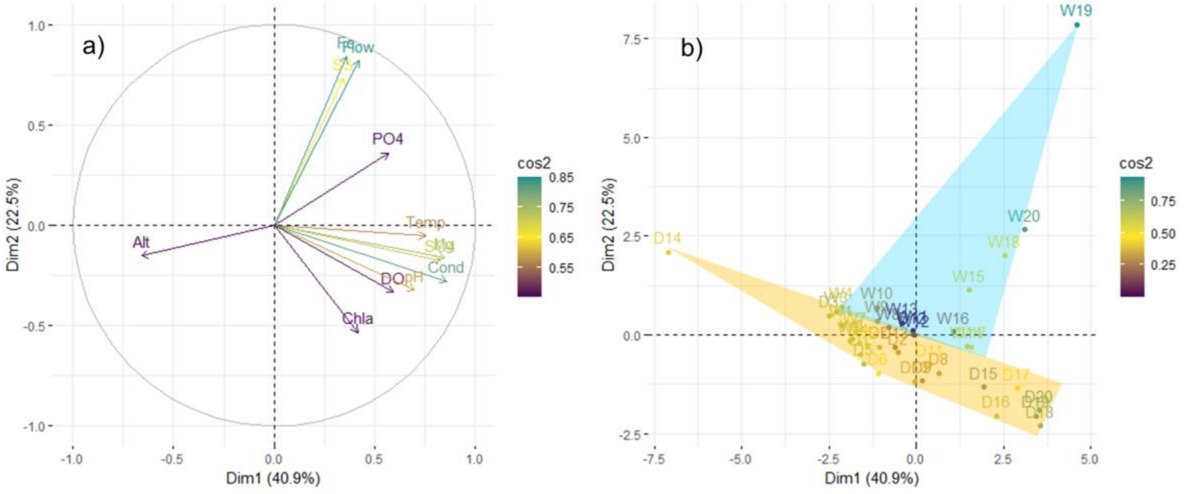

Figure 5. Principal component analysis of environmental variables measured in streams (n = 20) of the Cube River Basin during the wet (April) and dry (October) seasons of 2021, x-axis explain 40.9%

of data variation represented by altitude and dissolved ions in water (Mg+, SO4-) (a), variables in sampling sites (n=20) separate naturally (shades) in wet (blue) and dry (orange) seasons.

The analysis of the altitude´s effect on the mayfly community show that data from the wet and dry seasons are not related to altitude, for density, richness, Simpson diversity Index, and Evenness (Figure 6).

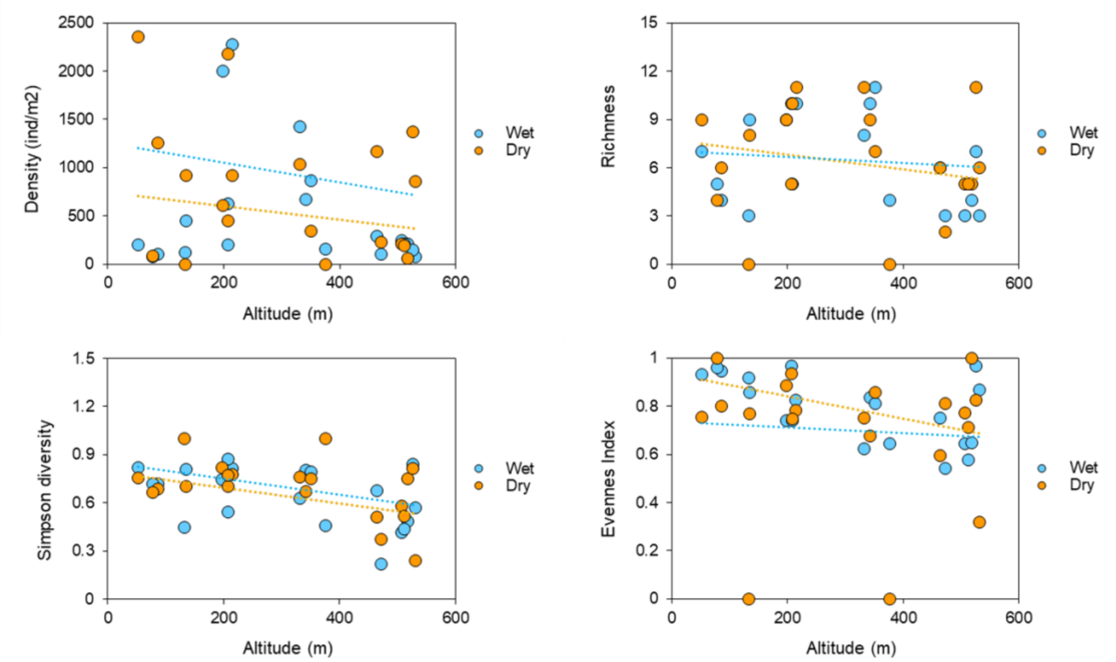

Figure 6. Mayfly community metrics along the altitudinal gradient in the Cube River Basin, showing sampled streams (n=20) during the wet (blue) and dry (orange) seasons of 2021.

The comparison of sites between seasons show how density is higher for most sites in the dry season (Figure 7), with exception of sites CuB-08, 09, 11, 12, and 13.

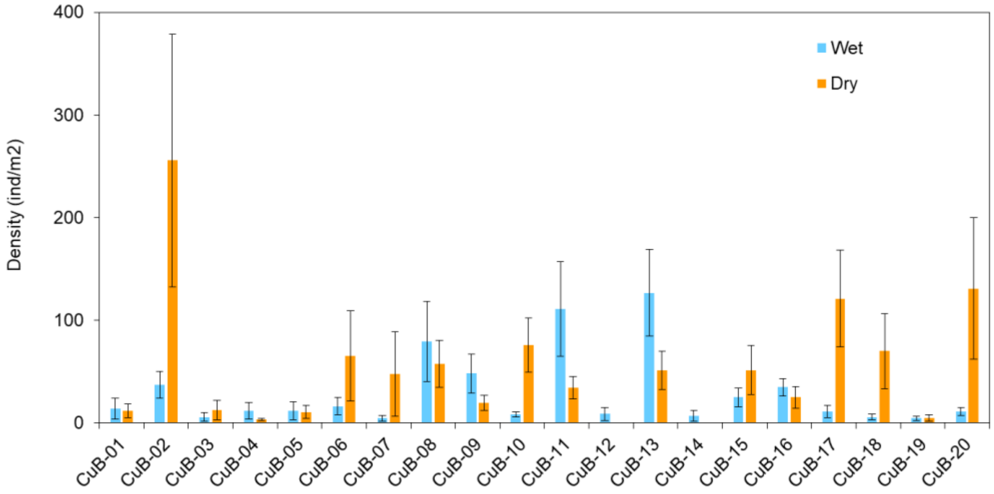

Figure 7. Mayfly average density (ind/m²) from genera found on each sampling site (n=20) distributed along the Cube River Basin (see Figure 2), showing differences (bars ± SE) between the wet (blue) and dry (orange) seasons.

The principal component analysis of environmental variables for the wet and dry seasons individually show that sites (n =20) separate naturally between predominantly intermittent streams and mostly perennials streams (Figure 8). For the wet season separate between W1 – W13 that are geographically located in the headwaters and middle part of the basin, while for the dry season sites separate between D1 – D13 and then D15 – D20 because D14 was completely dry, and no data was possible to measure in this site.

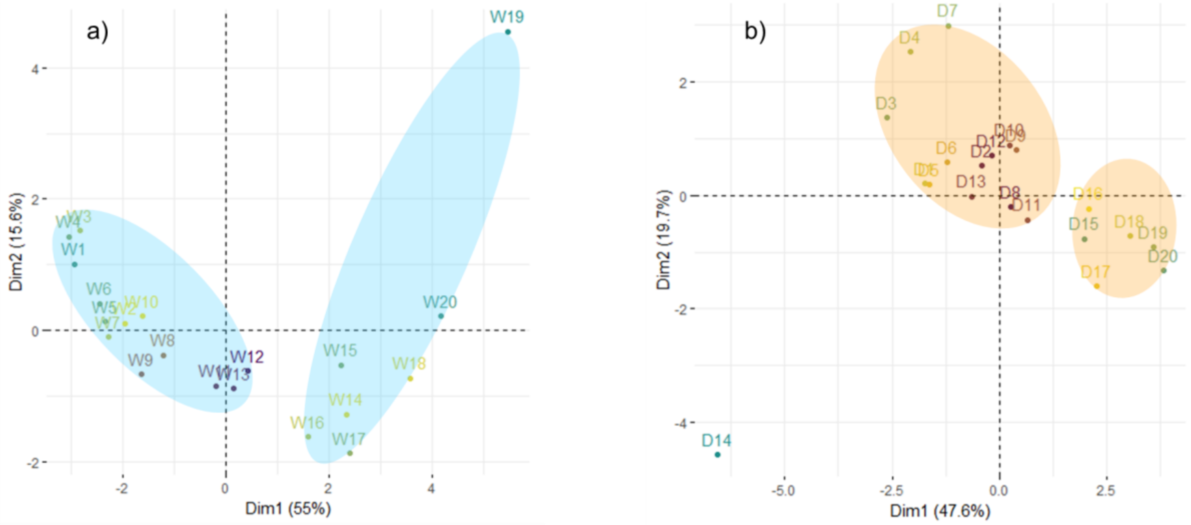

Figure 8. Principal component analysis for the wet (blue) and dry (orange) season using environmental variables of streams (n = 20) in the Cube River Basin, sites separate naturally in intermittent (left shades) and perennial streams (right shades).

The mayfly community in intermittent and perennial streams for the wet and dry seasons show differences that were not observed when comparing the system. Mayfly diversity and density show a distinct pattern with diversity clearly indicating the effect of seasonality on intermittent and perennial streams (Figure 9). In intermittent streams diversity (Simpson Index S) presents a wider range in the dry season compared to the wet season (Figure 9a) and the diversity in perennial streams is higher in the dry season than in the wet season (Figure 9a). Overall, perennial streams present a higher diversity than intermittent streams in both the dry and the wet seasons (Figure 9a). Density in perennial and intermittent streams is higher in the dry season compared to the wet season (Figure 9b) but in the wet season density is lower in perennial streams than in intermittent streams.

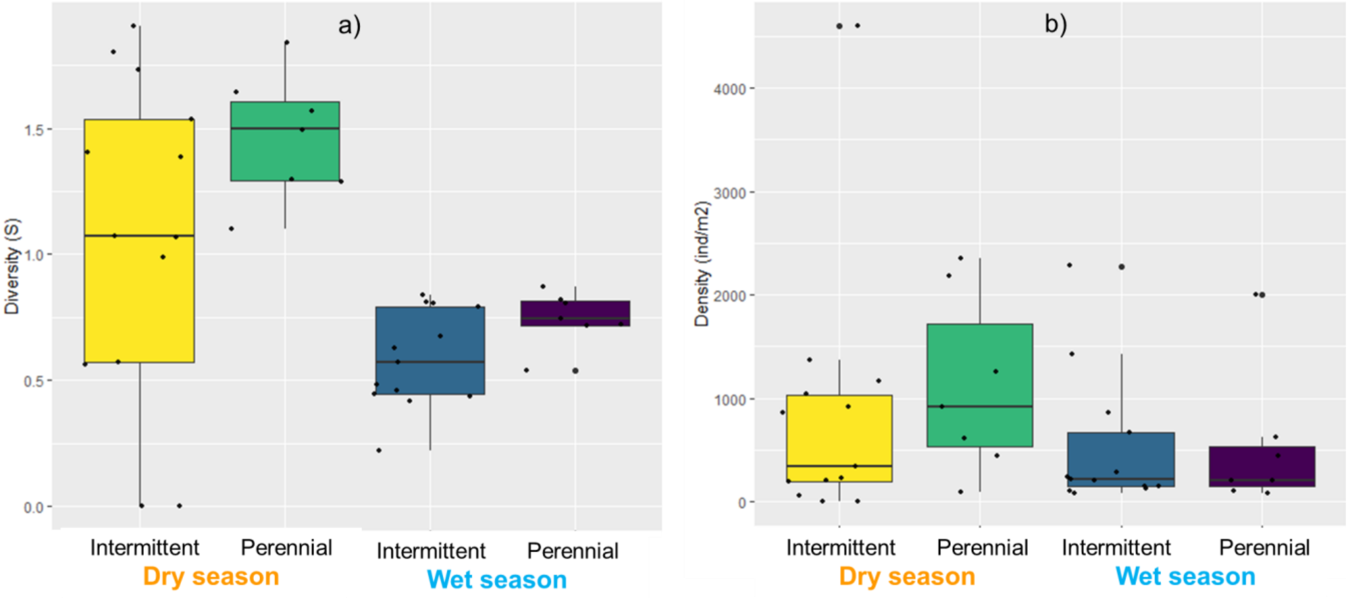

Figure 9. Mayfly genera diversity (a) and density (b) in intermittent and perennial streams of the Cube River basin sampled in the wet and dry seasons of 2021.

DISCUSSION

This study has shown that in an intermittent system the mayfly community structure does not vary between seasons (Figure 3). This analysis considered all sites in an aggregated way overriding any difference among sites and depicting the potential resilience of the mayfly community to changes in seasonality at the basin scale. The mayfly community was dominated by the Baetidae and Leptohyphiidae families allowing only two genera to be replaced between seasons: Atopophlebia and Hexagenia in the wet season, and Traverella and Latineosus in the dry season. The dominance of Leptophlebiidae has been reported previously in intermittent rivers of Brazil (Brasil et al., 2013) and Venezuela (Maldonado et al., 2001a). Particularly, a study from the Cerrado streams in Brazil, presented how the abundance of the family Leptophlebiidae did not change between seasons (Brasil et al., 2013). The persistence of these families in intermittent systems during the dry and wet seasons suggest the importance of functional diversity within the Ephemeroptera order to face seasonal changes as well as potential climate change effects in intermittent systems (Wolda & Flowers, 1985). The effect of seasonality on perennial streams have been extensively researched, showing that environmental variables can exert distinct effects on the community structure of mayflies (Brasil et al., 2013; Jacobsen & Encalada, 1998; Maldonado et al., 2001b; Wolda & Flowers, 1985). Although, the community structure presented no differentiation between seasons, environmental variables showed a clear seasonal effect depicted by the change in flow due to the precipitation pattern reported for the Pacific lowlands (Molinero et al. 2019). Elevation and dissolved ions in water, such as magnesium and sulfates explained 40.1% of the variance of sites between seasons. However, the elevational gradient is not susceptible to changes of seasonality as ions and flow are in streams. Other studies have found that elevation could explains 18% of the mayfly community variance in perennial systems (Farooq et al., 2021). In this sense, stream's morphology could play a major role in controlling environmental factors according to the elevation gradient favoring a more homogeneous community structure resilient enough to face extreme seasonal changes.

Site specific attributes has been a main factor for mayfly assemblages and has been evidenced in various studies with the most important variables being bed roughness (Brooks et al., 2005), stream size, and substrate diversity (Sweeney et al., 2009). By comparing the diversities and densities of intermittent and perennial streams from both seasons, we see that there is a difference between the assembly of mayfly communities across sites. This difference could be due to previously mentioned morphological features that act as predictors (Brooks et al., 2005; Farooq et al., 2021; Jacobsen & Encalada, 1998; Ramulifho et al., 2020;

Sweeney et al., 2009; Wolda & Flowers, 1985) or by other factors not taken into consideration such as vegetation cover and anthropogenic interventions (Brasil et al., 2013; Ramulifho et al., 2020). The main threats from anthropogenic activities include the loss of habitats and the presence of water pollutants which can reduce favorable conditions for narrow-tolerance species although previously adapted for fluctuating flow regimes (Ramulifho et al., 2020).

Mayfly community resilience in intermittent streams could be accounted by variables not explored in this study which relate to the life history of different mayfly species. Certain stages during the life cycle can be associated to the preference for specific substrates in bed streams that are available during dry seasons or under lower turbulence caused by the combination of velocity, depth, and substrate roughens of the stream (Brooks et al., 2005). Site specific variance could be the explanation of diversity differences between intermittent and perennial streams, which matches the hydrographical distribution of streams that group together and are more prone to be populated by the same mayfly genera. Streams aggrupation allows a deeper analysis that remarks the actual differences that can be considered significant when analyzing a community assemblage.

CONCLUSIONS

This study has concluded that there are no differences in the diversity of mayfly communities in the Cube River Basin when comparing the wet and dry seasons. The environmental factors that have a strongest effect on the community structure are altitude and dissolved ions in water. When comparing between sites within seasons the diversity is higher in perennial streams compared to intermittent streams. These results are an indicative of a particular seasonal comparison that takes place in a time-continuum. The higher diversity of mayfly genera in perennial stream could dilucidated the mayfly resilience to seasonal changes. However, perennial streams could be also the source or pool for different genera found in intermittent streams. Suggesting that, although showing a wide range, diversity in intermittent streams during the dry season could be an indicative of a potential tipping point in this system. To understand the response along the gradient of seasonal change, further analysis is needed in time using all sites in this intermittent system. Responses of a highly mobile insect community could be extrapolated to other invertebrates to comprehend mechanisms to cope with natural drying and use this information to extrapolate to climate change scenarios in the Neotropics.

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