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Distribution and diversity of aquatic macroinvertebrates along a current velocity gradient

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Abstract:

Macroinvertebrates play essential ecological roles in energy flow and nutrient cycling. Their distribution and diversity in rivers are influenced by current velocity. The abundance of these organisms in fast-flowing or still water areas varies according to physiological and morphological adaptations. Furthermore, many groups depend on the current for respiration or feeding. This study aims to investigate the influence of environmental factors, such as current velocity and stream depth, on the composition and distribution of aquatic macroinvertebrates. Sampling was conducted at two sites in the upper part of Itatiaia National Park in June 2016. At each site, simple random samples were collected from five 30x30 cm quadrants. For each site, abiotic microhabitat variables such as depth and current velocity were determined, measured with a ruler using the "Head Rod" method. The collected material was stored in vials containing 70% ethyl alcohol and subsequently sorted and identified. The Shannon-Wiener diversity index was used. A total of 398 specimens were collected, distributed among the orders Trichoptera, Ephemeroptera, Plecoptera, Diptera, and Odonata. Diptera was the most abundant order, with 340 individuals. The geometric regression method indicated that current velocity correlated positively with diversity (98.61%), while depth had a negative influence (79.82%). Many studies indicate a tendency for benthic organisms in lotic environments to occupy depths closer to the water's surface. Therefore, we can observe that these animals prefer shallow waters, suggesting that stronger currents and shallower depths may determine their diversity and distribution.

Keywords:

Aquatic insects, Diptera, Shannon-Wiener diversity. lotic environment

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Distribuição e diversidade de macroinvertebrados aquáticos ao longo de um gradiente de velocidade da corrente

Resumo:

Os macroinvertebrados desempenham papéis ecológicos essenciais no fluxo de energia e na ciclagem de nutrientes. Sua distribuição e diversidade em rios são influenciadas pela velocidade da corrente. A abundância desses organismos em áreas de águas rápidas ou paradas varia de acordo com adaptações fisiológicas e morfológicas. Além disso, muitos grupos dependem da corrente para respiração ou alimentação. Este estudo teve como objetivo investigar a influência de fatores ambientais, como a velocidade da corrente e a profundidade do curso d'água, na composição e distribuição de macroinvertebrados aquáticos. A amostragem foi realizada em dois locais na parte superior do Parque Nacional de Itatiaia, em junho de 2016. Em cada local, amostras aleatórias simples foram coletadas em cinco quadrantes de 30x30 cm. Para cada local, variáveis abióticas do microhabitat, como profundidade e velocidade da corrente, foram determinadas e medidas com uma régua utilizando o método da "Head Rod". O material coletado foi armazenado em frascos contendo 70% de álcool etílico e posteriormente triado e identificado. O índice de diversidade de Shannon-Wiener foi utilizado. Um total de 398 espécimes foram coletados, distribuídos entre as ordens Trichoptera, Ephemeroptera, Plecoptera, Diptera e Odonata. Diptera foi a ordem mais abundante, com 340 indivíduos. O método de regressão geométrica indicou que a velocidade da corrente correlacionou-se positivamente com a diversidade (98,61%), enquanto a profundidade teve uma influência negativa (79,82%). Muitos estudos indicam uma tendência de organismos bentônicos em ambientes lóticos ocuparem profundidades mais próximas da superfície da água. Portanto, podemos observar que esses animais preferem águas rasas, sugerindo que correntes mais fortes e profundidades menores podem determinar sua diversidade e distribuição.

Palavras-chave:

Insetos aquáticos, Diptera, diversidade de Shannon-Wiener, ambiente lótico

Distribución y diversidad de macroinvertebrados acuáticos a lo largo de un gradiente de velocidad de corriente.

Resumen:

Los macroinvertebrados desempeñan funciones ecológicas esenciales en el flujo de energía y el ciclo de nutrientes. Su distribución y diversidad en los ríos están influenciadas por la velocidad de la corriente. La abundancia de estos organismos en áreas de aguas rápidas o estancadas varía según adaptaciones fisiológicas y morfológicas. Además, muchos grupos dependen de la corriente para respirar o alimentarse. Este estudio tiene como objetivo investigar la influencia de factores ambientales, como la velocidad de la corriente y la profundidad del arroyo, en la composición y distribución de los macroinvertebrados acuáticos. El muestreo se realizó en dos sitios en la parte alta del Parque Nacional de Itatiaia en junio de 2016. En cada sitio, se recolectaron muestras aleatorias simples de cinco cuadrantes de 30x30 cm. Para cada sitio, se determinaron variables de microhábitat abiótico como la profundidad y la velocidad de la corriente, medidas con una regla utilizando el método de la "head rod". El material recolectado se almacenó en viales que contenían alcohol etílico al 70% y posteriormente se clasificó e identificó. Se utilizó el índice de diversidad de Shannon-Wiener. Se recolectaron un total de 398 especímenes, distribuidos entre los órdenes Trichoptera, Ephemeroptera, Plecoptera, Diptera y Odonata. Diptera fue el orden más abundante, con 340 individuos. El método de regresión geométrica indicó que la velocidad de la corriente se correlacionó positivamente con la diversidad (98,61%), mientras que la profundidad tuvo una influencia negativa (79,82%). Numerosos estudios indican una tendencia de los organismos bentónicos en ambientes lóticos a ocupar profundidades más cercanas a la superficie del agua. Por lo tanto, podemos observar que estos animales prefieren aguas poco profundas, lo que sugiere que las corrientes más fuertes y las profundidades menores pueden determinar su diversidad y distribución.

Palabras clave:

Insectos acuáticos, Diptera, diversidad de Shannon-Wiener, ambiente lótico

1 INTRODUCTION

Aquatic macroinvertebrates are small sessile or mobile invertebrates that live associated with the bottom or adjacent substrates (organic or inorganic) of aquatic ecosystems for at least part of their life cycle (Resh; Rosenberg, 1993; Egler, 2002; Figueiró *et al.* 2008). This group is represented by insects, mollusks, crustaceans, and oligochaetes, with insect immatures generally tending to be the most numerous group because they are totally or partially dependent on aquatic environments for their development (Egler, 2002).

Macroinvertebrates play a significant role in ecological functions, occupying an intermediate position in the food chain, with relevant participation in ecosystem energy flows, nutrient cycling, and the biogeochemical cycle (Malmqvist; Sackmann, 1996; Motta; Uieda, 2007).

Rivers are classified as lotic environments, that is, environments in which the water is flowing, therefore they present different characteristics along their course (Figueiró; Gil-Azevedo, 2010). These patterns form differentiated micro-habitats, whose characteristics influence the structure of the macroinvertebrate community present (Hawkins; Sedell, 1981; Dajoz, 2008).

The biota present in these lotic environments exhibits the most varied taxonomic classes, which diverge from each other according to the special morphological adaptations for each meso-habitat. For example, aquatic invertebrates from rapids areas have some adaptive conformations for locomotion, either to move freely or to maintain their position in the face of currents, such as claw attachment, flattened body shape, reduction of projection structures, presence of setae, sticky secretions and presence of suckers (Kikuchi; Uieda, 1998; Egler, 2002; Figueiró; Gil-Azevedo, 2010).

The distribution pattern of macroinvertebrates is the result of interactions between biotic and abiotic variables, that is, between the habits and physical conditions that characterize the Habitat structure, chemical conditions, and food availability (Mazzoni *et al*. 2014; Albuquerque Ferreira *et al*. 2024). The distribution and diversity of these organisms along the course of rivers are influenced by several determining factors such as current speed, conductivity, substrate, temperature and pH, luminosity, habitat structure, habits, available food, and interaction with other organisms; (Hawkins; Sedell, 1981; Merritt; Cummins, 1984; Callisto; Goulart, 2003; Santana *et al*. 2021).

Some studies have reinforced that the distribution of benthic macroinvertebrates in lotic ecosystems is strongly associated with local environmental filters, especially flow velocity, depth, substrate composition, organic matter availability and riparian vegetation structure (Szałkiewicz *et al*. 2022; Gleason *et al*. 2023).

The speed of the current plays a fundamental role in displacement and transport downstream, that is, from the source to the mouth, enabling the emergence of physiological, morphological, and behavioral adaptations in macroinvertebrates according to the current. Many organisms also need the current to feed and breathe, and the current can also influence the nature of the substrate, and thus, the composition and distribution of these organisms; (Kikuchi; Uieda, 1998; Egler, 2002). According to Allan (1995), the substrate is a complex factor of the physical environment, as it provides a contact surface, shelter from predators and currents, and a food source when it is organic. Some groups have certain preferences regarding the size and composition of the substrate, which consequently reflects in their life cycles (Mazzoni *et al.* 2014)

These microhabitat-scale variables influence not only taxonomic composition, but also functional feeding groups and the suitability of habitats for aquatic insects. In tropical streams, Ephemeroptera, Plecoptera and Trichoptera (EPT) remain important indicators of habitat integrity because they respond sensitively to physical and chemical environmental gradients (Veras *et al.* 2026). Recent projections for the Atlantic Forest indicate

that EPT insects are vulnerable to climate change, especially Plecoptera, whose occurrence is associated with cold, fast-flowing and well-oxygenated waters (Souza *et al.* 2024).

In addition to all the environmental determinants, when analyzing the distribution and diversity of macroinvertebrates, it is also important to assess the interactions between organisms present in the habitat (Kikuchi; Uieda, 1998). Macroinvertebrate species are differently sensitive, and can respond to the most diverse biological impacts with distinct responses (Resh; Rosenberg, 1993; Egler, 2002). The greater the heterogeneity of the habitat, the greater its diversity; therefore, the composition and distribution of aquatic biota plays a fundamental role in assessing the state of ecological diversity, serving as an important tool for environmental biomonitoring (Queiroz; Silva; Trivinho-Strixino, 2008; Docile; Figueiró, 2013).

This study aims to investigate the influence of environmental factors, such as current speed and stream depth, on the composition and distribution of aquatic macroinvertebrates.

2 MATERIALS AND METHODS

2.1 Study area

The collection was carried out in the Itatiaia National Park, which is located in the Mantiqueira mountain range, in the southeast of the state of Rio de Janeiro, in the municipalities of Itatiaia and Resende and in the south of the state of Minas Gerais, situated between the coordinates 44º34 – 44º42 W and 22º16 – 22º28 S (Santos; Zikan, 2000). The Itatiaia National Park has a total area of 30,000 hectares, with altitudes ranging from 600 m to the highest point ("Pico das Agulhas Negras") at 2.791 m (Santos; Zikan, 2000; ICMBio, 2018).

The Itatiaia National Park stands out for its hydrography, encompassing the headwaters of 12 influential regional river basins that flow into two main basins: in the North, the Grande River basin, a tributary of the Paraná River, and in the South, the Paraíba do Sul River basin, the most important river in the State of Rio de Janeiro and containing the largest number of rivers (Santos; Zikan, 2000).

2.2 Data Collection and Analysis

Data collection was carried out at two points in the upper part of Itatiaia National Park on June 31, 2016. The first collection site was Brejo da Lapa and the second was Alsene, which receives this name due to its proximity to the deactivated hotel of the same name. Brejo da Lapa is located at coordinates S22º 21' 30.5'', W 44º 44' 126´´, at an altitude of 2145 meters above sea level. Alsene is located at an altitude of 2400 meters, at coordinates S 22º22` 06.7``, W 44º 42` 32.7``.

At each site, simple random samples of 5 quadrats of 30 x 30 cm were taken according to Figueiró *et al.* (2006). For each site, abiotic micro-habitat variables such as depth and current speed were determined, measured with the aid of a ruler using the "Head Rod" method (Wilm; Storey, 1944).

The collected material was stored in graduated conical tubes with Falcon-type screw caps, containing 70% hydrated ethyl alcohol, and transported for subsequent identification and quantification at the Zoology Laboratory of UniFOA. Each tube was properly labeled and identified according to its respective collection points. The material was then sorted, grouped to the order level, and quantified using a stereoscopic microscope and the dichotomous keys of Mugnai *et al.* (2010).

For the analysis, it was decided to work only with insect orders and, based on a data matrix of the number of individuals per sample and the area of each sampling device, residual analysis was performed

to eliminate outliers. Subsequently, a curve fitting analysis was performed to determine the best regression model to explain the data obtained. The Shannon-Wiener diversity index was used to calculate the diversity index of benthic macroinvertebrates.

3 RESULTS AND DISCUSSION

A total of 398 specimens of benthic macroinvertebrates were collected, distributed among the orders Trichoptera, Ephemeroptera, Plecoptera, Diptera, and Odonata.

The order with the highest representation was Diptera, with 340 individuals sampled and identified; followed by the order Ephemeroptera with 5 individuals; the order Trichoptera with 4 individuals; the order Odonata with 3 individuals; and the order Plecoptera with only 1 individual.

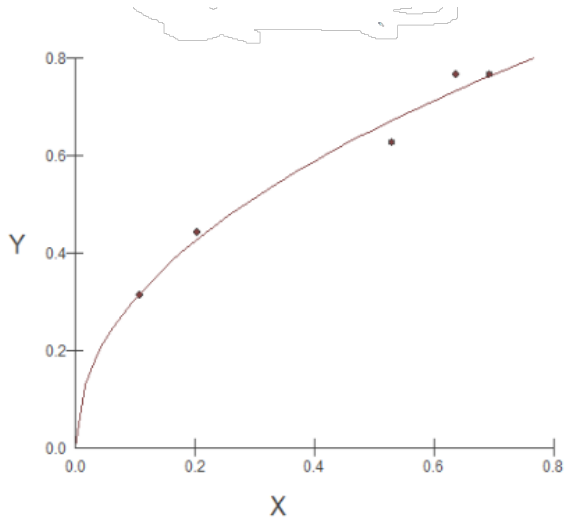
The current velocity and its relationship with diversity was best explained by the geometric regression model, showing an adjustment coefficient of 98.61% (Table 1; Fig. 1) and a positive correlation.

Table 1 - Curve fitting analysis indicating that the geometric regression model best explains the positive correlation between current and diversity.

	Linear Regression	Exponential Regression	Logarithmic Regression	Geometric Regression
Coef. determination (R2) =	97.76%	95.79%	96.66%	98.61%*
(p) =	0.0014	0.0037	0.0026	0.0007*

Fonte: Autor

Figure 1 - Geometric regression demonstrating the positive correlation between current velocity and diversity.



Fonte: Autor

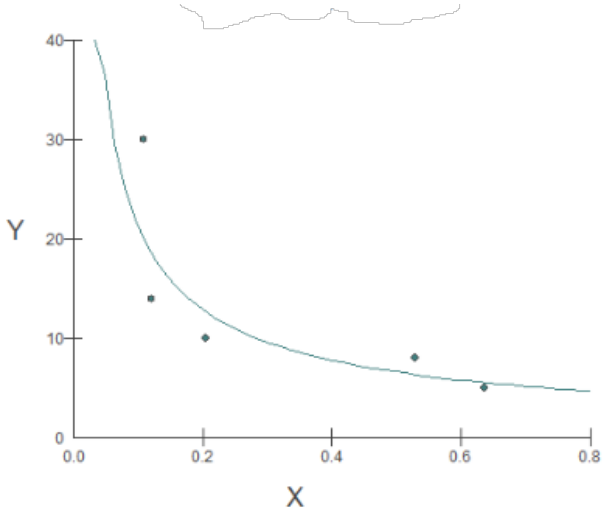
The geometric regression method also showed that depth was a determining factor, presenting a rate of 79.82%, negatively influencing distribution and diversity; that is, macroinvertebrates tend to be more widely distributed and diverse at shallower depths (Table 2; Fig. 2).

Table 2 - Curve fitting indicating that the geometric regression model best explains the negative correlation between depth and diversity.

	Linear Regression	Exponential Regression	Logarithmic Regression	Geometric Regression
Coef. determination (R2) =	52.71%	73.57%	62.17%	79.82%*
(p) =	0.1648	0.063	0.113	0.041*

Fonte: Autor

Figure 2 - Geometric regression demonstrating the negative correlation between depth and macroinvertebrate diversity.



Fonte: Autor

The current gradient is an environmental variable of great structural importance in aquatic ecosystems, as it is associated with the amount of organic matter, oxygen availability, food distribution, nutrient removal, and micro-habitat availability (Merritt; Cummins, 1984; Egler, 2002; Allan, 1995).

The current speed is correlated with the presence and aspects of riparian vegetation, which is responsible for maintaining the dynamic balance in the current flow and the arrangement of habitats, representing a source of allochthonous material that serves as substrate and food for macroinvertebrates (Kikuchi; Uieda, 1998). It maintains the morphology of the river, preventing erosive processes resulting from sediment deposition, reduces variations caused by intense rainfall, and reduces anthropogenic impacts (Mazzoni *et al*. 2014; Egler, 2002).

The frequency of macroinvertebrates in areas of current or backwater varies according to physiological and morphological requirements and adaptations; many groups depend on the effect of current speed, either because they need it for respiration or feeding.

Regarding depth, according to Kikuchi and Uieda (1998) studies show that in places where there are shallower depths, the water flows rapidly and consequently there is a higher density of macroinvertebrates when compared to places with more still water. Many studies point to a tendency for benthic organisms in lotic environments to occupy depths closer to the surface of the water column.

The abundance of the order Diptera corroborates the data in the literature, since it is an extremely diverse order and is among the most abundant components in lotic ecosystems (Alves, 1998; Resh; Rosenberg, 1993). According to Callisto *et al.* (2001) Diptera, in addition to possessing great competitive ability, are capable of withstanding hypoxic situations, being highly tolerant, as they can survive under various environmental conditions, from clean water environments to polluted environments.

Another aspect that influenced the distribution of Diptera under the current speed gradient was due to the fact that most immature stages of this order have a filter-feeding habit, which means that their efficiency in capturing food and the functioning of feeding structures, such as bristles that retain food particles through water movement, are dependent on the current speed, promoting this factor as a limiting resource for these invertebrates, due to the greater amount of food particles that are transported in these stretches (Callisto *et al.* 2001; Carvalho; Uieda, 2004; Egler, 2002). The predominance of Diptera observed in this study agrees with bioassessment studies indicating that this order is frequently abundant in stream macroinvertebrate assemblages and may be associated with broader tolerance to environmental variation (Tszydel *et al.*, 2024).

The presence of the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) also goes against the data in the literature, since they are strongly influenced by the speed of the current and all the variables dependent on it. These orders use the current for feeding, maintaining their metabolism, and finding shelter (Malmqvist *et al.*, 2004; Egler, 2002). Most individuals of these orders are characterized as organisms that are extremely sensitive to pollution (Resh; Rosenberg, 1993).

In contrast, the occurrence of EPT taxa, even in lower abundance, is ecologically relevant because these orders are commonly associated with better habitat integrity and greater sensitivity to changes in water quality, dissolved oxygen, flow regime and substrate structure (Veras *et al.*, 2026; Souza *et al.*, 2024). Recent projections for the Atlantic Forest also suggest that EPT insects, especially Plecoptera, may be vulnerable to climate change due to their association with cold, oxygenated and fast-flowing waters, reinforcing the importance of conserving high-altitude lotic habitats such as those found in Itatiaia National Park (Souza *et al*., 2024).

Some Ephemeroptera, according to Merritt and Cummins (1996), have legs projected laterally from the body, which is flattened and smooth with adaptations to the current. In addition, they have respiratory structures such as gills, which requires these organisms to have higher concentrations of oxygen for their survival, which justifies their representativeness at these points and confirms the authors' ideas.

Organisms of the order Plecoptera breathe through gills and depend on higher proportions of dissolved oxygen in the water. Although only one element of this order was found at all collection points, it can be estimated that, due to these characteristics and requirements, the tendency of its presence goes against the data in the literature, as it is a segment of a lotic environment and presents greater current, which allows for greater oxygenation of the water; (Allan, 1995; Odum, 1985). On the other hand, according to the studies of Allan (1995) and Esteves (1988), although the current increases the oxygenation of the water through turbulence, there may have been some accumulation of organic matter at these points, which ends up consuming high amounts of dissolved oxygen for its decomposition, resulting in the possibility of lower concentrations of oxygen available in that environment.

The abundance of Trichoptera can be explained by the transport of these individuals due to higher currents. According to Kikuchi and Uieda (1998) the current can exert a direct effect on organisms, when during periods of high volume and flow, the stones and substrate at the bottom of the river are displaced, causing the removal of organisms that are on the substrate. Most Trichoptera have low mobility and a poorly hydrodynamic body, resulting in high displacement rates (Bispo; Oliveira, 1998; Bispo, 2001).

The presence of organisms of the order Odonata confirms the proposal of the author Carvalho and Nessimian (1998), these invertebrates prefer lotic environments with high current speed and significant amounts of organic matter.

The occurrence of EPT taxa is ecologically relevant because biological indices based on Ephemeroptera, Plecoptera and Trichoptera, together with BMWP and FBI, have been used to assess preservation, water quality and pollution levels in lotic environments (Albuquerque Ferreira *et al.*, 2024). These studies support the interpretation that abiotic variables and habitat structure are central factors in determining the composition and distribution of benthic macroinvertebrates.

The predominance of Diptera observed in the present study can also be discussed in light of recent evidence on Simuliidae, since black fly larvae are filter-feeding Diptera strongly dependent on water flow and suitable substrates, reinforcing the importance of current velocity in structuring aquatic insect assemblages (Rodrigues da Costa *et al*., 2024).

4 CONCLUSION

In summary, it can be observed that the trend is for the influence of current speed and shallower depths to be determining factors in the diversity and distribution of benthic macroinvertebrates.

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