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ORIGINAL ARTICLE

Black fly species and their association with Brazilian biomes

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Abstract

The family Simuliidae occurs widely around the globe, except in the Antarctic region, deserts, and islands that lack water streams. Because fresh stream water environments are breeding grounds for their immature forms. This study sought to relate and compare Brazilian biomes based on their simuliid faunas. After gathering information on the distribution patterns of Simuliid species included in the most recent global taxonomic review, a table on their presence in the Brazilian territory was prepared, indicating the regions in which the different species were present in each biome. Subsequently, correspondence and cluster analyses were performed to determine the biomes with which the species were most associated and the similarities of the simuliid faunas among those biomes, respectively. The correspondence analysis showed that most species were predominantly associated with three biomes: The Amazon, Cerrado, and Atlantic Forest, while the cluster analysis showed that the simuliid faunas of the Cerrado and Atlantic Forest are similar and that when taken together, these two biomes are similar to the Amazon biome.

Keywords: Black fly; Brazilian biomes; distribution; similarity

1. Introduction

Black flies (Simuliidae) are distributed throughout the world, with their highest diversity found in neotropical, nearctic, afrotropical, and palaearctic regions [1]. Some of these flies are onchocerciasis and mansonellosis vectors [2], while others are associated with the blistering condition known as Fogo selvagem [3]. Although black flies are widely spread across the globe, they are limited to areas where their immature forms find adequate lotic habitats [4]. These flies are particularly abundant in areas with fast-flowing rivers and streams [5,6] and lay their eggs on rocks or vegetation near the water's edge [7]. Black fly larvae are aquatic and filter feed on algae and organic matter present in the water [8], whereas adult black flies feed on the blood of various vertebrates, such as birds and mammals, including humans [8].

Simuliid flies are often referred to as bioindicators [9,10]. Scholars suggest that these insects can become strongly influenced by land use and water pollution [11] and that they can serve as an important trophic link because of their ability to transform organic matter [12] while being prey to various invertebrate predators [13].

Research on black flies in the holarctic region and Brazil has focused on a variety of topics, including their distribution and abundance, their behavior and ecology, and methods of controlling their populations. Black flies are the key organisms in the Boreal Forest biome [12]. Even though the black flies in the Neotropical zone have often been studied [11,13,14,15], it is yet to be confirmed whether they have the same role in the Neotropics.

Brazil is a megadiverse country, which has five biomes: Amazonia, Cerrado, Mata Atlântica, Caatinga, Pantanal, and Pampa (also called Campos Sulinos). These biomes harbor highly diverse black fly species some of which have country-wide distributions [1].

Although the black fly fauna of Brazil is extensively described, indicating their presence in all Brazilian biomes, most of the related ecological studies have been concentrated only on the Amazonia and Atlantic Forest biomes [2,16], which may lead to some bias in the understanding of the distribution patterns of the black flies and their underlying processes. Furthermore, neotropical black fly inventories are often mentioned in the literature [1]; however, in studies on the microhabitat features of species distributions [11,15], large-scale ecological studies on black fly ecology are scarce [17,18], making black fly distribution patterns a poorly understood subject.

Given this backdrop, this study aimed to associate black fly species and different biomes toward identifying the biomes where these black fly species are abundantly present and their optimal landscape associations and comparing the similarities among the Brazilian biomes with respect to their black fly faunas.

Consequently, this study tests the following hypotheses: (1) Species preferences on Neotropical black flies are at biome level; and (2) landscape differences among Brazilian biomes lead to different features at habitat level, which result in dissimilarities among their black fly faunas.

2. Materials and methods

A first matrix was constructed based on the list of Brazilian Simuliidae species and their respective occurrence localities, according to an existing taxonomic review for this fly family [1], showing the number of localities within each biome, expressed as frequency, where a given species is present. A dataset correspondence analysis was performed to test hypothesis 1 and to determine the biome with which each species was most associated. A second matrix was built with the percentage of localities where each species occurred, and a cluster analysis, based on the Bray–Curtis index, tested hypothesis 2, comparing the biomes based on their Simuliidae faunal compositions.

The spatial distribution of the Simuliidae species, as shown by the correspondence analysis, reveals their optimal biomes with the following assumptions: the species have a Gaussian distribution, and thus the respective locations of the plots on the ordination graph represent species frequency peaks. Only species present in at least five localities were considered in the analysis. The Voronoi lines in the graph, obtained through correspondence analyses, identify species-biome associations dividing the graph according to biome "areas of influence". The biomes were compared using the percent occurrence of the total number of sites sampled.

3. Results and discussion

According to the correspondence analysis, *Simulium oyapockense, Simulium argenstiscutum, Simulium maroniense, Simulium rorotaense, Simulium ochraceum, Simulium guianense, Lutzsimulium simplicicolor,* and *Simulium goeldii* were the species most associated with the Amazon biome because they occurred in the highest number of locations within this biome when compared to the sites in other biomes considered. The other species in the Amazon biome were only present in a few locations.

The species best associated with the Cerrado biome were *Simulium hirtipupa, Simulium spinibranchium, Simulium pertinax, Simulium nigrimanum*, and *Simulium scutistriatum*, whereas the species associated with the Atlantic Forest biome were *Lutzsimulium hirticosta, Simulium striginotum, Simulium distinctum, Simulium travassoss*i, and *Simulium orbitale*. The correspondence analysis revealed that the Cerrado and Atlantic Forest biomes were the regions with which most species were primarily associated (Figure 1).

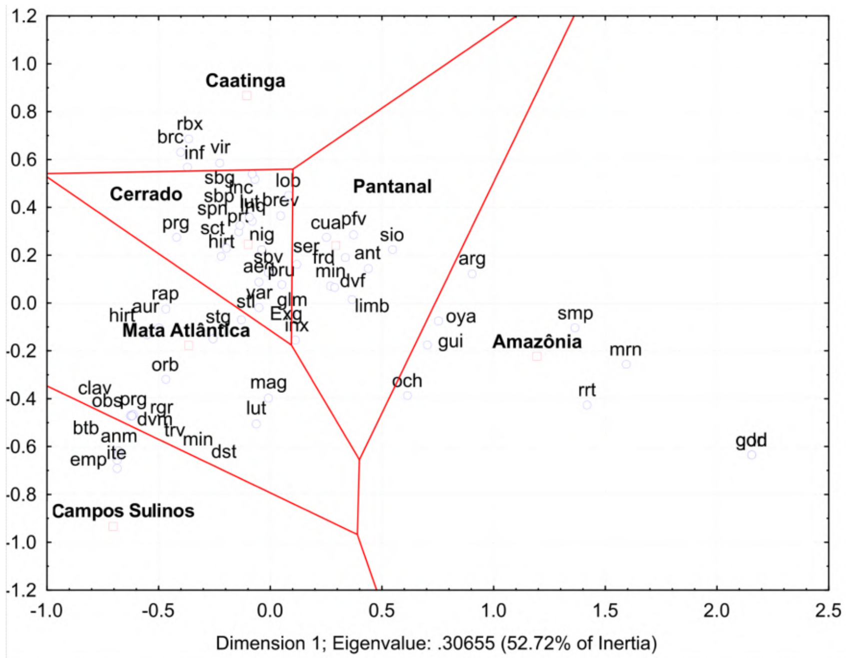

Figure 1. Correspondence analysis with Voronoi lines indicating the black fly species associations to the Brazilian biomes according to the data from the geographic inventory of Adler (2022). Only species present at least in five localities were used in the analysis. Abbreviations refer to species epithets (AEQ= aequifurcatum, AMZN=amazonicum, AMZE=amazonense, ANM=anamariae, ANT=antunesi, ARG=argentiscutum, AUR=auristriatum, BIF=bifenestratum, BRC=brachycladum, BREV=brevibranchium, BRVM=brevifurcatum, BTB= botulibranchium, CAT=catarinense, CCH=cauchense, CLAV=clavibranchium, COV=covagarciai, CRD=cerradense, CRIS=cristalinum, CRN=criniferum, CSC=coscaroni, CUA=cuasiexiguum, DEL=delponteianum, DLH=datanhani, DST=distinctum, DVF=diversifurcatum, DVM=diversibranchium, DUOD= duodenicornium, EMP=empascae, EXG=exiguum, FLVP=flavopubescens, FLV=fulvinotum, FRD=friedlanderi, GAP=guaporense, QDRI=quadrifidum, GLM=glaucophthalmum, GOD=goeldii, GUI=guianense, HIRT=hirticosta, HIRTI=hirtipupa, IBR= iberaensis, INC=incertum, INC=incrustatum, INF=infuscatum, INQ=ineaquale, INX=inexorable, IRC= iracouboense, ITE=itaunense, JEF=jefersoni, JET=jeteri, KAB=kabanayense, LIT=litobranchium, LIMB=limbatum, LND=lundi, LOB=lobatoi, LUT=lutzi, LUT=lutzianum, MAG=magnum, MAR=marins, MEN=mauense, MGRT= margaritatum, MIN=miniatum, MIN=minusculum, MNM=minuanum, MRG= maranguapense, MRN=maroniense, NDEM= nunesdemelloi, NIG=nigrimanum, OBS=obesum, OCH= ochraceum, ORB=orbitale, OYA=oyapockense, PET=petropoliense, PFV=perflavum, PRG=paraguayense, PRG=pernigrum, PRP=perplexum, PRT=pertinax, PRU=pruinosum, PUJ=pujoli, QNQ=quinquefurcatum, QUD= quadristrigatum, RAP=rappae, RBX=rubrithorax, RGR=riograndense, ROR=roraimense, RRT=rorotaense, SBV=subviridae, SBP=subpallidum, SBG=subnigrum, SCT=scutistriatum, SER=serranus, SHW=shewellianum, SIO=siolii, SMP=simplicicolor, SPN=spinibranchium, STG=striginotum, STL=stellatum, SUC=sucamense, SUB=subclavibranchium, SUZ=suarezi, SXT=sextobecium, TERG=tergospinosum, TRMB=trombetense, TRV=travassosi, VAR=varians, VEZ=venezuelense, VTR=vitribasi, VIR=virescens, ULYS=ulyssesi).

Four species, namely *Simulium brachycladum*, *Simulium rubrithorax*, *Simulium infuscatum*, and *Simulium virescens* (Figure 1), were present in a small number of locations in the Caatinga biome (Table 1). In the Pantanal biome, species were more sparsely distributed than in any of the other biomes, and the most abundant species occurred in only two localities; *S. diversifurcatum, S. siolii, S. limbatum*, and *S. aequifurcatum* were some of these species. Lastly, only a handful of species were predominantly associated with the Pampa biome (Figure 1).

Table 1. Black fly species and their respective frequencies per Brazilian biome.

Similiidae Species	Brazilian Biome					
	Amazonia	Cerrado	Mata Atlantica	Pantanal	Caatinga	Campos Sulinos
Lutzsimulium flavopubescens	0	0	1	0	0	0
Simulium bifenestratum	0	1	1	0	0	0
L. hirticosta	0	3	7	0	1	1
L. pernigrum	0	2	4	0	0	1
S. distinctum	0	2	6	0	0	1
S. empascae	0	1	4	0	0	1
S. obesum	0	2	5	0	0	1
S. inexorabile	3	2	6	2	1	1
S. striginotum	1	2	6	1	1	1
Glaucophthalmum Knab	1	2	2	0	0	0
S. anamariae	0	1	6	0	0	1
S. auristriatum	0	2	4	0	0	0
S. stellatum	1	3	4	0	0	0
S. clavibranchium	0	2	6	0	0	1
S. aequifurcatum	2	3	6	2	2	1
S. limbatum	4	3	5	1	1	0
S. miniatum	0	2	5	0	0	1
S. varians	2	4	6	2	1	1
S. hirtipupa	1	6	7	2	2	1
S. pertinax	1	5	4	0	1	0
S. spinibranchium	1	7	5	1	1	0
S. vitribasi	0	2	2	0	0	0
Araucnephia iberaensis	0	0	1	0	0	0
L. simplicicolor	3	1	0	1	0	0
S. covagarciai	1	0	0	0	0	0
S. friedlanderi	1	2	1	1	0	0
S. infuscatum	0	2	2	0	1	0
S. riograndense	0	2	5	0	0	1
S. serranus	1	3	2	1	0	0
S. subpallidum	1	3	3	0	2	0
S. subviride	2	3	5	2	2	1
S. cuasiexiguum	1	3	1	1	0	0
S. exiguum	1	2	2	0	0	0
S. incertum	0	2	2	0	0	0
S. paraguayense	0	4	5	0	1	0

Table 1. Black fly species and their respective frequencies per Brazilian biome.

Similiidae Species	Brazilian Biome					
	Amazonia	Cerrado	Mata Atlantica	Pantanal	Caatinga	Campos Sulinos
S. amazonicum	1	0	0	0	0	0
S. amazonense	3	0	0	0	0	0
S. argentiscutum	3	1	1	0	1	0
S. delponteianum	0	0	1	0	0	1
S. oyapockense	4	3	3	2	0	0
S. quadristrigatum	0	0	1	0	0	0
S. roraimense	1	0	0	0	0	0
S. siolii	3	5	1	2	0	0
S. tergospinosum	2	0	0	0	0	0
S. venezuelense	1	0	0	0	0	0
S. botulibranchium	0	1	5	0	0	1
S. marins	0	1	1	0	0	0
S. petropoliense	0	0	2	0	0	0
S. inaequale	1	4	3	0	1	0
S. lundi	1	0	0	0	0	0
S. maranguapense	0	0	0	0	1	0
S. margaritatum	0	1	1	0	1	0
S. pujoli	0	1	0	0	0	0
S. rappae	0	2	3	0	0	0
S. subnigrum	1	2	3	0	2	0
S. travassosi	0	2	6	0	0	1
S. guaporense	2	1	0	1	0	0
S. incrustatum	1	3	3	0	2	0
S. lutzi	1	6	4	1	1	0
S. minuanum	0	0	1	0	0	1
S. minusculum	6	8	6	1	2	1
S. cauchense	4	0	0	0	0	0
S. sextobecium	1	0	0	0	0	0
S. cerradense	0	1	1	0	1	0
S. daltanhani	1	0	0	0	0	0
S. goeldii	5	0	0	0	0	0
S. quadrifidum	7	0	0	0	0	0
S. ulyssesi	2	0	0	0	0	0
S. catarinense	0	0	1	0	0	0
S. ochraceum	3	1	3	0	0	0
S. shewellianum	0	1	1	0	0	0
S. maroniense	5	1	0	1	0	0
maroniense 'A' Hamada & Adler, 1999 (cytoform)	1	0	0	0	0	0
maroniense 'B' Hamada & Adler, 1999 (cytoform)	1	0	0	0	0	0

Table 1. Black fly species and their respective frequencies per Brazilian biome.

Similiidae Species	Brazilian Biome Amazonia	Cerrado	Mata Atlantica	Pantanal	Caatinga	Campos Sulinos
maroniense 'C' Hamada & Adler, 1999 (cytoform)	2	0	0	0	0	0
maroniense 'D' Hamada & Adler, 1999 (cytoform)	1	0	0	0	0	0
S. perflavum	3	2	3	0	2	0
S. antunesi	2	1	2	0	1	0
S. mauense	1	0	0	0	0	0
S. rorotaense	5	1	1	0	0	0
S. fulvinotum	1	0	0	0	0	0
S. suarezi	2	0	0	0	0	0
S. trombetense	4	0	0	0	0	0
S. kabanayense	0	0	0	0	1	0
S. iracouboense	4	0	0	0	0	0
S. lutzianum	2	2	5	0	0	1
S.virescens	0	2	2	1	1	0
S. coscaroni	0	1	1	0	0	0
S. criniferum	1	0	0	0	0	0
S. duodenicornium	0	2	2	0	0	0
S. guianense	3	3	2	0	0	0
S. itaunense	0	1	3	0	0	1
S. jeteri	0	0	1	0	0	1
S. litobranchium	0	2	1	0	0	0
S. nigrimanum	1	6	4	2	0	0
S. pruinosum	1	3	2	0	0	0
S. nunesdemelloi	1	0	0	0	0	0
S. orbitale	0	2	4	1	0	1
S. perplexum	1	0	0	0	0	0
S. scutistriatum	1	7	7	1	1	0
S. brachycladum	0	3	5	0	3	0
S. brevibranchium	1	2	2	0	1	0
S. cristalinum	1	0	0	0	0	0
S. lobatoi	1	3	2	1	1	0
S. rubrithorax	0	3	3	0	2	0
S. magnum	2	2	5	1	0	1
S. quinquefurcatum	0	1	1	0	1	0
S. jefersoni	0	1	1	0	1	0
S. sucamense	1	0	0	0	0	0
S. subclavibranchium	1	0	0	0	0	0
S. diversibranchium	0	2	5	0	0	1
S. diversifurcatum	3	5	4	2	0	0
S. brevifurcatum	0	1	2	0	0	1

While most of the species-biome associations are consistent with the findings of the few ecological studies on black flies in the Neotropical region, in light of the existing literature, we detected some shifts in known species-biome associations. Interestingly, in some of these cases, the ecology of the newly best-associated biome has been studied only superficially, at its best. For instance, *S. pertinax*, a species frequently studied in the Atlantic Forest biome [11,13], appeared, thanks to the correspondence analysis, as a species more associated with the Amazon biome than with the Atlantic Forest biome.

Cluster analysis (Figure 2) showed that the Cerrado and Atlantic Forest biomes have similar species compositions and that taken together, these two biomes have similarities with the Amazon biome. Likewise, the Pantanal and Caatinga biomes have similar species compositions. In contrast, the Pampa biome (Campos Sulinos) has the most distinct simuliid fauna, as indicated by the correspondence analysis results.

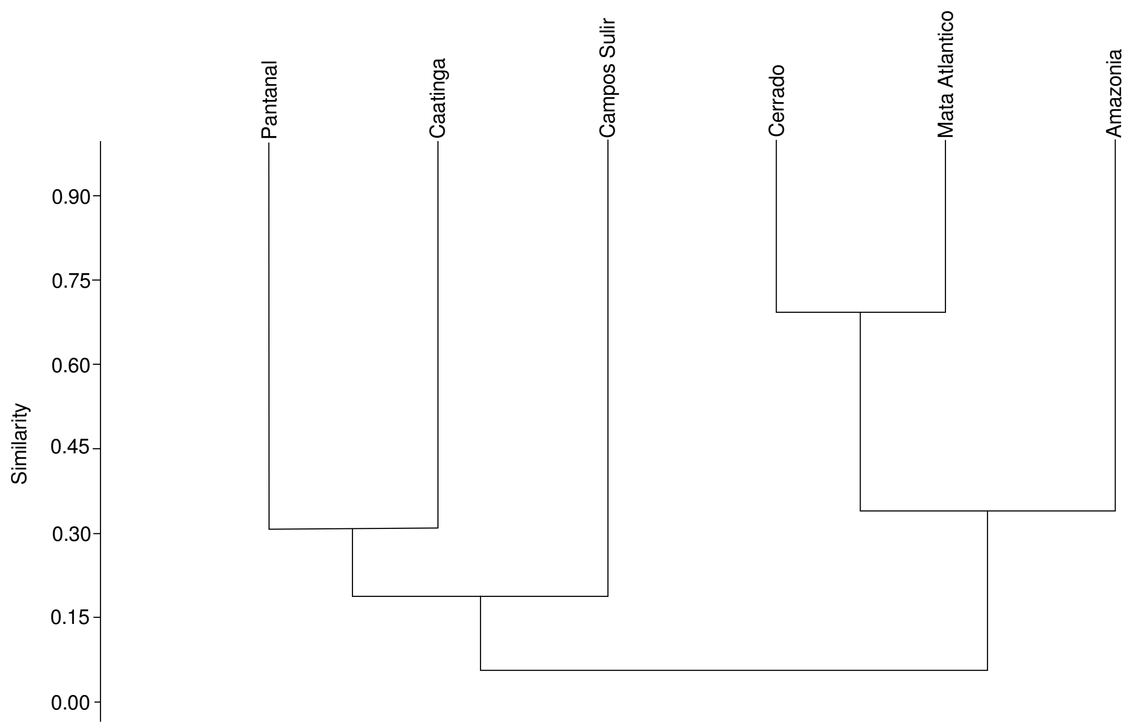

Figure 2. Cluster analysis built from the Bray-curtis dissimilarity index indicating biome clusters based on their respective Simuliidae faunas.

Similarities between biomes likely depend on their closeness, namely the existence of an ecotone between them. Although the three largest biomes in Brazil, Caatinga, Pantanal, and Pampa, have been extensively studied, they only had a few localities where black flies were present, which could have led to similarities between these three biomes and the rest of the biomes even though the species percent of occurrence in the total number of localities helped to standardize the data and minimize the effects of different sampling efforts.

Holland et al. [19] defined ecotones as transition zones between adjacent ecological systems, with their characteristics defined by space and time scales and by the level of interaction between the two ecological systems. The transition zone between the Atlantic Forest and Cerrado can extend to hundreds of kilometers and comprise savanna, grassland, and forest vegetation along with the representative species of the two biomes [20,21].

The Amazon–Cerrado ecotone, one of the largest and most important ecotonal mosaics in the world and the largest savanna-forest transition on earth, covers approximately 4.85% of Brazil [22] [23], with a contact zone, exceeding 6000 km in length [24]. The region is characterized by a strong species exchange, where different phytophysiognomies coexist under the same environmental conditions [25].

The Atlantic Forest–Cerrado and Amazon–Cerrado ecotones can be used to explain the similarities among the three biomes Atlantic Forest, Cerrado, and Amazon, where similar black fly faunas are present according to cluster analysis results; in Brazil, most transitional forests are in disjoint areas and separate the typical vegetation formations of the Amazon and Atlantic Forest from the unique phytophysiognomies of the Caatinga and Cerrado [26,27,28,29], giving rise to gradients [30,31], which could explain the association patterns observed on the present study.

4. Conclusions

The results of the correspondence analysis confirmed this study's first hypothesis, and suggest that some species can be strongly associated with certain biomes; however, for certain simuliid species, the biomes with which they were predominantly associated, are not the biomes in which they have usually studied. Such is the case of *S. pertinax*, which is consistently studied in association with the Atlantic Forest, although the correspondence analysis results indicate that this fly species is more associated with the Amazon.

Cluster analysis results confirmed the second hypothesis, although the similarity patterns of the biomes revealed by the analysis differed markedly from the expectations. For instance, a semi-arid biome (Cerrado) and a tropical forest (Atlantic Forest) were more similar than two tropical rainforests. This similarity pattern is a likely consequence of the distribution range of these biomes since the Cerrado stands between two rainforests, giving rise to two ecotones well described in the literature on Atlantic Forest–Cerrado and Amazon–Cerrado ecotones [22,23].

Overall, results suggest that most species are predominantly associated with the three largest Brazilian biomes: the Amazon, Cerrado, and Atlantic Forest, but some species are endemic to the Caatinga and Pampa biomes. The similarity patterns among the simuliid faunas of the Brazilian biomes appear to reflect the similarities among their respective landscapes to some extent and, thus, are consistent with the environmental gradients described in the literature. However, studies modeling black fly species distributions in the Neotropics are scarce, resulting in a significant gap in the knowledge of Simuliidae geographic distribution range patterns.

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6. Conflict of interest

The authors declare that there are no conflicts of interest.

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Especies de mosca negra y su asociación con los biomas brasileños

Resumen: La familia Simuliidae se encuentra ampliamente distribuida alrededor del mundo, excepto en la región antártica, o en desiertos e islas que carecen de corrientes de agua. Esto se debe a que los arroyos de agua dulce son los lugares de reproducción de sus formas inmaduras. Este estudio buscó relacionar y comparar los biomas brasileños en base a sus faunas de moscas negras (Simuliidae). Después de recopilar información sobre los patrones de distribución de las especies de Simuliidae incluidas en la revisión taxonómica global más reciente, se preparó una tabla sobre su presencia en el territorio brasileño, indicando las regiones en las que las diferentes especies estaban presentes en cada bioma. Posteriormente, se realizaron análisis de correspondencia y de conglomerados para determinar los biomas con los que las especies estaban más asociadas y las similitudes de las faunas de moscas negras entre esos biomas, respectivamente. El análisis de correspondencia mostró que la mayoría de las especies estaban asociadas predominantemente con tres biomas: la Amazonía, el Cerrado y la Mata Atlántica, mientras que el análisis de conglomerados mostró que las faunas de moscas negras del Cerrado y la Mata Atlántica eran similares y que, tomados en conjunto, estos dos biomas eran similares al bioma Amazónico.

Palabras Clave: Mosca negra; Biomas brasileños; Distribución; Similitud

Espécies de borrachudos e sua associação com os biomas brasileiros

Resumo: A família Simuliidae ocorre amplamente ao redor do mundo, exceto na região antártica, e em desertos e ilhas desprovidas de cursos d'água. Isso ocorre porque os cursos de água doce são locais de reprodução de suas formas imaturas. Este estudo buscou relacionar e comparar os biomas brasileiros com base em suas faunas de simulídeos. Após reunir informações sobre os padrões de distribuição das espécies de simulídeos incluídas na revisão taxonômica global mais recente, foi elaborada uma tabela sobre sua presença no território brasileiro, indicando as regiões em que as diferentes espécies estavam presentes em cada bioma. Posteriormente, foram realizadas análises de correspondência e de agrupamento para determinar os biomas com os quais as espécies estavam mais associadas e as similaridades das faunas de simulídeos entre esses biomas, respectivamente. A análise de correspondência mostrou que a maioria das espécies estava predominantemente associada a três biomas: Amazônia, Cerrado e Mata Atlântica, enquanto a análise de agrupamento mostrou que as faunas de simulídeos do Cerrado e da Mata Atlântica eram semelhantes e que, quando considerados juntos, esses dois biomas eram semelhantes ao bioma Amazônia.

Palavras-chave: Borrachudos; Biomas brasileiros; Distribuição; Similaridade

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