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Analysis of Brazilian Ceratopogonidae (Diptera: Culicomorpha) species diversity and knowledge assessment

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ABSTRACT. An updated list of the biting midges recorded from the 26 Brazilian states and the Federal District is provided based on the data available in the "Taxonomic Catalog of the Brazilian Fauna" (Portuguese CTFB). The Brazilian Ceratopogonidae fauna is represented by 529 known species, corresponding to 40% of the Neotropical fauna. A table showing the number of species of Ceratopogonidae genera in the Neotropical region, Brazil, and Brazilian Amazon is included. In accordance with the family knowledge worldwide, the subfamily Ceratopogoninae is the best represented in the number of species due to the study of *Culicoides*, which has sanitary importance. The analysis of the diversity in each region and in the Brazilian states indicates the need for further studies in the five Brazilian geopolitical regions, especially in the Midwest and Northeast, which are home to the natural biomes of Cerrado, Pantanal, and Caatinga.

KEY WORDS. Biting midges, Brazil, distribution, taxonomy.

INTRODUCTION

Ceratopogonidae Newman, 1834 includes small dipteran species that compose a diverse, abundant, and widely distributed group. Borkent and Dominiak (2020) recognize 6,206 valid species divided into three subfamilies and 112 genera. They are distributed throughout the world, except in Antarctica, occurring from coastal areas to the highest mountain peaks, with the uppermost record at 4,651 m from Lake Huacracocha in Peru (Tapia et al. 2018). The immature stages are abundant and present in almost all aquatic and subaquatic habitats, including phytotelmata and rock pools, seeps, streams, rivers, ponds, swamps and lakes, moist substrates such as mud, decaying plant material and dung. Some species are terrestrial, occurring under the bark of trunks, in damp mosses and fungi. Adult females have the broadest dietary repertoire of any group of biting insects, with many requiring extra proteins to develop their eggs (Borkent and Dominiak 2020). Vertebrate hosts include mammals, reptiles, birds, amphibians, and even fish (Wirth and Hubert 1989, Spinelli et al 2002). Most of the genera include predators of other small insects, usually other dipterans, which are captured and injected with a proteolytic enzyme; after liquefaction, the prey contents are sucked out. Another lineage of females feeds on hemolymph from other arthropods much larger than themselves, such as centipedes, spiders, phasmids, dragonflies, coleopterans, and other large insects (Downes 1978, Borkent and Spinelli 2007, Borkent et al. 2009, Borkent 2017). Some Ceratopogonidae are exclusively floral visitors, constituting important pollinators of tropical plants such as cocoa (*Theobroma cacao* L.), rubber tree (*Hevea brasiliensis* Müll. Arg.) and avocado (*Persea americana* Mill.), having great importance for agriculture (Wirth and Cavalieri 1977). In this case, males and females look for nectar as a source of energy.

Many species of *Culicoides* Latreille, 1809, a hyperdiverse genus with 1,347 species, act as vectors for a wide range of viruses, protozoa, and nematodes that affect humans and domestic and wild animals (Borkent 2004). Some species of *Culicoides*, *Leptoconops* Skuse, 1889, *Austroconops* Wirth & Lee, 1958 and *Forcipomyia* (*Lasiohelea*) Kieffer, 1921 occur in such large numbers that their hematophagic habit

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affects tourism (Hendry 2011). On the other hand, their presence protects several vulnerable habitats by restricting the distribution of humans in some locations, such as in Scotland, some beaches in the Caribbean, areas of Australia, and some mangroves that would otherwise be vulnerable to disturbance caused by humans (Borkent and Dominiak 2020). Furthermore, veterinary diseases such as Bluetongue, and human diseases such as Mansonellosis and Oropouche Fever, are transmitted by different species of *Culicoides* (Mellor et al. 2000).

Despite Brazil's large size, diversity of biomes, and the agricultural and sanitary importance of some species, the Brazilian fauna of biting midges is still little studied; in some parts of the country, the diversity of these dipterans is completely unknown. Data from records of Ceratopogonidae species have been provided in different publications, making research into the knowledge of the specific distribution of the Brazilian fauna very laborious. In this context, catalogs and lists of species are important tools that contribute to the study of biodiversity in localities, states, countries, and zoogeographic regions. Along the years, several catalogs, as well as lists of Ceratopogonidae tribes and genera, have been created to update the species lists for family study facilitation. Ceratopogonidae catalogs and lists from different parts of the world are accessible at http://campus.belmont.edu/cienews/cie.html.

From the Neotropical region, the most recent Ceratopogonidae species catalogs have been elaborated by Borkent and Spinelli (2000, 2007). The Nicaraguan, Mexican, and Argentinian species were published sequentially by Maes and Wirth (1990), Ibáñez-Bernal et al. (1996), and Spinelli et al. (2023). The Ceratopogonidae fauna was also mentioned by Wirth (1952), Davies and Giglioli (1979), and Borkent (1991) for Juan Fernandez, Grand Cayman, and Galápagos islands, respectively. *Culicoides* species lists from Argentina, Colombia and Costa Rica are available in the publications by Spinelli et al. (2005, 2009a) and Spinelli and Borkent (2004). The *Culicoides* species from Panama, West Indies, Mexico, and Ecuador were published by Wirth and Blanton (1959), Wirth (1974), Mendez-Andrade and Ibáñez-Bernal (2023), and Mosquera et al. (2022). From Brazil, Wirth and Blanton (1973) and Castellón and Felippe-Bauer (2015) have published *Culicoides* species and their distribution in the Brazilian Amazon area. Since 2015, the Brazilian fauna has been updated on the website "Taxonomic Catalog of the Brazilian Fauna" (Catálago Taxonômico da Fauna Brasileira – CTFB, http://fauna.jbrj.gov.br/) and in the Fiocruz Collection website (Santarém and Felippe-Bauer 2023).

Considering the need for a reference publication of data on the distribution of midges in Brazil, this work aims to list the species of Ceratopogonidae recorded from the 26 Brazilian states and the Federal District based on the data available in the CTFB, as well as to carry out an analysis of the knowledge of the diversity of this important family in Brazil.

MATERIAL AND METHODS

In this work, we follow the species arrangement according to the "Catalog of the Biting Midges of the World" (Borkent and Dominiak 2020). The distribution of species was based on the specific literature, in addition to reliable localities of specimens deposited in the entomological collections of the following institutions: Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil (FSP); Coleção de Ceratopogonidae da Fundação Oswaldo Cruz, Rio de Janeiro, Brazil (CCER); National Museum of Natural History, Washington, D.C., USA (USNM); The Natural History Museum, London, United Kingdom (BMNH). In the case of doubtful species records, we chose to maintain them in the distribution and in the result analysis until further studies, such as revisions of genera, subgenera or species groups, are carried out to confirm or not their validity.

In the species list, the records are given in alphabetical order of Brazilian states after the indication of the type locality, considering the geopolitical regions. The states that comprise each region are listed: North – Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Rondônia (RO), Roraima (RR), Tocantins (TO); Northeast – Alagoas (AL), Bahia (BA), Ceará (CE), Maranhão (MA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Rio Grande do Norte (RN); Midwest – Distrito Federal (DF), Goiás (GO), Mato Grosso (MT), Mato Grosso do Sul (MS); Southeast – Espírito Santo (ES), Minas Gerais (MG), Rio de Janeiro (RJ), São Paulo (SP); and South – Paraná (PR), Rio Grande do Sul (RS), Santa Catarina (SC) (Fig. 1). In 1977, the state of Mato Grosso was split into the states of Mato Grosso and Mato Grosso do Sul; in 1989, the state of Goiás was divided into the states of Goiás and Tocantins. Localities mentioned in manuscripts before these dates had to be updated due to the newly created states. When the collection site of the species is not provided in the original description, we considered the cited geographic region of the species.

We have also counted the species recorded from the Neotropical region and Brazilian Amazon region, aiming to compare and update this data. To consider a species as recorded from the Neotropical region, we employed the biogeographical regionalization of this region proposed by

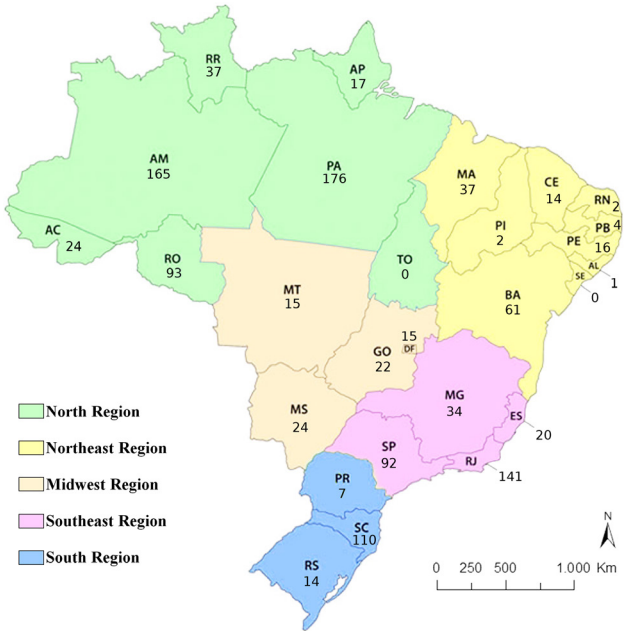

Figure 1. Political map of Brazil showing the number of Ceratopogonidae records from the 26 Brazilian States and the Federal District.

Morrone (2014). For inclusion of a species in the Brazilian Amazon region, we considered the political map of the "Amazônia Legal Brasileira." Brazilian municipalities and states included here can be accessed at http://www.cidades.ibge.gov.br/xtras/home.php.

The distribution data of Brazilian species of biting midges were uploaded to the CTFB website and to the Fiocruz Collections website (Santarém and Felippe-Bauer 2023). They were also listed herein in the Supplementary file S1.

RESULTS AND DISCUSSION

Herein, we recognized 1,329 extant valid Ceratopogonidae species from the Neotropical region, 529 from Brazil, and 303 from the Brazilian Amazon region (Table 1, Supplementary file S1).

It is possible to observe that almost 40% of the Neotropical Ceratopogonidae fauna has already been recorded from Brazil, highlighting the country's importance in the distribution of these insects. It is also noteworthy that approximately 57% of the Brazilian fauna was recorded from the Amazon region, indicating that this biome has favorable environments for the development of biting midges and reinforcing its importance in the study of the country's fauna. The characteristics of the local climate and the number of studies carried out in the Amazon, mainly due to the transmission of the Oropouche virus, are crucial factors in understanding the representativeness of the region in the knowledge of the Brazilian Ceratopogonidae fauna.

Ceratopogoninae Newman, 1834 is the best represented subfamily with 386 species recorded from Brazil (73%), followed by Forcipomyiinae Lenz, 1934 with 140 species (26.5%). The Leptoconopinae Noè, 1907is represented by only three species: *Leptoconops* (*Leptoconops*) *brasiliensis* (Lutz, 1913), *Leptoconops* (*Holoconops*) *knowltoni* Clastrier & Wirth, 1978, and the recently recorded *Leptoconops* (*Meganocops*) *floridensis* Wirth, 1951 (Santarém et al. 2023). These species have been recorded from the coastal areas of northern and southern Brazil. This data corroborates the knowledge of the family worldwide. According to Borkent and Dominiak (2020), Ceratopogoninae is the best-known subfamily in the world, with the number of species driven by the study of the genus *Culicoides*, which has sanitary importance. The authors recognize that there are genera that are clearly much more diverse than others and that the greatest species diversity is restricted to only four genera: *Culicoides* (n = 1,347), *Forcipomyia* Meigen, 1818 (n = 1,142), *Dasyhelea* Kieffer, 1911 (n = 617), and *Atrichopogon* Kieffer, 1906 (n = 513). Together, these genera represent 58% of the known extant diversity of the family in the world. This pattern is quite similar to the diversity found in Brazil, except for the genus *Dasyhelea*, which has only 18 species recorded from the country, behind several predator Ceratopogoninae midges from the tribes Ceratopogonini Newman, 1834, Palpomyiini Enderlein, 1936 and Stenoxenini Coquillett, 1899. This is certainly due to the lack of extensive studies involving this important pollinator genus. On the other hand, there are several studies on the diversity of predatory midges that are widely distributed in the Neotropical region and Brazil, boosting the number of known species for such genera as *Bezzia* Kieffer, 1899 (Dippolito et al. 1995), *Downeshelea* Wirth & Grogan, 1988 (Santarém et al. 2020), *Palpomyia* Meigen, 1818 (Spinelli et al. 2009b, Almeida et al. 2017), *Paryphoconus* Enderlein, 1912 (Spinelli and Wirth 1984) and *Stilobezzia* Kieffer, 1911 (Cazorla and Spinelli 2014, Cazorla 2016, Cazorla et al. 2017, Da Silva et al. 2023). These data corroborate the number of species known in Brazil from the six predatory tribes included in Ceratopogoninae. The tribes Culicoidini and Ceratopogonini, which include *Culicoides* and the main predatory genera, respectively, are those with the largest number of known and described species (151 and 107 species, respectively).

Table 1. Number of species of Ceratopogonidae genera recorded from the Neotropical region, Brazil, and the Brazilian Amazon region.

Subfamily	Tribe	Genus	Subgenus	Neotropical region	Brazil	Brazilian Amazon region
Ceratopogoninae	Ceratopogonini	*Allohelea*		1	–	–
		Alluaudomyia		18	7	5
		Austrohelea		3	–	–
		Baeodasymyia		5	–	–
		Baeohelea		1	–	–
		Bahiahelea		1	1	–
		Borkenthelea		4	–	–
		Brachypogon	*Brachypogon*	23	8	6
		Brachypogon	*Isohelea*	7	1	–
		Bhachypogon	Out of subgenus	2	–	–
		Cacaohelea		1	–	–
		Ceratoculicoides		1	–	–
		Diaphanobezzia		4	–	–
		Downeshelea		46	19	9
		Echinohelea	*Echinohelea*	10	5	4
		Echinohelea	*Echinoideshelea*	1	1	1
		Fittkauhelea		1	1	1
		Isthmohelea		1	–	–
		Leptohelea		1	–	–
		Macrurohelea		17	–	–
		Monohelea		27	18	11
		Nannohelea		1	–	–
		Notiohelea		2	–	–
		Parabezzia		30	8	2
		Rhynchohelea		1	–	–
		Schizonyxhelea		9	4	2
		Spinellihelea		1	–	–
		Stilobezzia	*Acanthohelea*	41	4	4
		Stilobezzia	*Eukraiohelea*	5	5	3
		Stilobezzia	*Stilobezzia*	47	25	13
		Yungahelea		1	–	–
	Culicoidini	*Culicoides*	*Amossovia*	1	–	–
		Culicoides	*Anilomyia*	20	2	1
		Culicoides	*Avaritia*	8	3	2
		Culicoides	*Beltranmyia*	3	–	–
		Culicoides	*Cotocripus*	6	2	–
		Culicoides	*Culicoides*	6	-	–
		Culicoides	*Diphaomyia*	14	3	2
		Culicoides	*Drymodesmyia*	13	3	1
		Culicoides	*Glaphiromyia*	2	–	–
		Culicoides	*Haematomyidium*	38	25	19
		Culicoides	*Hoffmania*	46	37	35
		Culicoides	*Macfiella*	2	1	1
		Culicoides	*Mataemyia*	19	13	10
		Culicoides	*Oecacta*	5	2	2
		Culicoides	*Psychophaena*	2	1	–
		Culicoides	Out of subgenus	116	59	50
		Paradasyhelea		3	–	–
	Heteromyiini	*Clinohelea*	*Ceratobezzia*	1	1	1
		Clinohelea	*Clinohelea*	11	9	6
		Heteromyia		11	6	4
		Pellucidomyia		4	1	–
		Physohelea		2	–	–
	Johannsenomyiini	*Groganhelea*		1	1	1
		Johannsenomyia		2	1	–
		Lanehelea		2	–	–
		Mallochohelea		6	4	2
		Neobezzia		8	6	5
		Nilobezzia		3	3	2
	Palpomyiini	*Amerohelea*		13	4	3
		Bezzia		50	19	11

Continues

Subfamily	Tribe	Genus	Subgenus	Neotropical region	Brazil	Brazilian Amazon region
		Clastrieromyia		4	1	1
		Pachyhelea		2	1	1
		Palpomyia		55	32	6
		Phaenobezzia		2	2	1
	Sphaeromyiini	*Austrosphaeromias*		4	–	–
		Sphaerohelea		1	–	–
	Stenoxenini	*Paryphoconus*		42	30	18
		Stenoxenus		16	7	4
Forcipomyiinae	Dasyheleini	*Dasyhelea*		104	18	7
	Forcipomyiini	*Atrichopogon*	*Atrichopogon*	98	28	5
		Atrichopogon	*Lophomyidium*	5	2	2
		Atrichopogon	*Psilokempia*	17	6	3
		Forcipomyia	*Blantonia*	1	–	–
		Forcipomyia	*Caloforcipomyia*	11	9	4
		Forcipomyia	*Euprojoannisia*	16	5	3
		Forcipomyia	*Forcipomyia*	37	11	4
		Forcipomyia	*Lasiohelea*	11	5	1
		Forcipomyia	*Lepidohelea*	23	10	1
		Forcipomyia	*Metaforcipomyia*	23	1	–
		Forcipomyia	*Microhelea*	50	22	11
		Forcipomyia	*Pedilohelea*	5	3	2
		Forcipomyia	*Phytohelea*	11	5	1
		Forcipomyia	*Pterobosca*	3	2	–
		Forcipomyia	*Rhynchoforcipomyia*	7	2	1
		Forcipomyia	*Saliohelea*	2	1	1
		Forcipomyia	*Schizoforcipomyia*	2	1	1
		Forcipomyia	*Synthyridomyia*	4	1	–
		Forcipomyia	*Thyridomyia*	8	2	–
		Forcipomyia	*Trichohelea*	13	2	1
		Forcipomyia	*Warkea*	7	4	4
Leptoconopinae		*Leptoconops*	*Brachyconops*	1	–	–
		Leptoconops	*Holoconops*	3	1	–
		Leptoconops	*Leptoconops*	7	1	1
		Leptoconops	*Megaconops*	1	1	–
		Leptoconops	*Proleptoconops*	1	–	–
Unplaced	Unplaced	*Ceratopogon*		1	–	–
Total				1,329	529	303

The Brazilian states with the highest number of records of Ceratopogonidae are Pará (176 species), Amazonas (165 species), and Rio de Janeiro (141 species) (Fig. 1). When records are considered by geographic region, those with the highest number are the North (296 species) and Southeast (199 species) regions. The representativeness of these regions can be explained by the existence of research groups in these areas that promoted the study of local faunas and, consequently, increased the number of records. In this sense, we highlight the studies carried out in these areas by Wirth and Blanton (1973), who described 15 new species of *Culicoides* from the Brazilian Amazon region, and the work of Castellón included in the book by Castellón and Veras (2015), in addition to the several species described and recorded by Adolpho Lutz, Osmar Tavares, John Lane, Oswaldo Forattini and Maria Luiza Felippe-Bauer for the North and Southeast regions.

The significant number of records from the state of Bahia (61 species) is the result of Saulo Soria's research on cocoa pollinators from the "Recôncavo Baiano." All specimens that he studied are deposited in the Ceratopogonidae Collection of Fiocruz (Soria et al. 2002). The high number of records from Santa Catarina (110 species) was driven by John William Scott Macfie, who published several important works describing species collected by Fritz Plaumann (Macfie 1939). Furthermore, there are several records of *Forcipomyia* by Jean Clastrier (Clastrier and Wirth 1995).

A closer look at the number of listed species indicates the need for future studies in the five Brazilian geopolitical regions, especially in the Midwest and Northeast, which are home to the natural biomes of Cerrado, Pantanal, and Caatinga. Despite the high number of records from the North region, some states are still poorly represented and certainly have a greater number of species, since the Amazon Forest biome, typical of this region, has characteristics that are favorable to the development of biting midges during all seasons of the year. Despite being politically included in the North region, the state of Tocantins has a Cerrado biome and has

no records of Ceratopogonidae to date. In the Northeast, no species of Ceratopogonidae have been reported for the state of Sergipe, and just *Culicoides insignis* Lutz, 1913 was recorded from Alagoas (Rios et al. 2021). All other states have few records, despite this being a region that covers nine states in an area of 1,558,196 km^2 and includes the Atlantic Forest and Caatinga biomes. The Midwest region also has very few records for Ceratopogonidae and clearly requires broader studies. This region hosts two important Brazilian biomes, the Cerrado and the Pantanal, which have unique characteristics and currently are under great human pressure. The Southeast region is characterized by the presence of the Atlantic Forest and a strong influence of the coastal climate, which makes this region very conducive to the development of "maruins", as is the Amazon. Therefore, the various states that politically make up the Southeast of Brazil are undersampled, even Rio de Janeiro. Finally, the fauna of the South region is basically represented by species from Santa Catarina, with few records from Paraná and Rio Grande do Sul, which indicates the need for broad studies involving these states that present important transition regions and the Atlantic Forest and Pampas biomes.

Therefore, further studies on the Ceratopogonidae fauna from Brazil are urgently needed, especially in states that are characterized by biomes such as the Caatinga, Cerrado, Pantanal, and Pampas. These biomes have very peculiar features, with alternating periods of drought and rain that certainly influence the composition of the fauna and the population dynamics of the "maruins" from these locations, which are mostly unknown to date.

We have been updating the species reported from Brazil and their records from Brazilian states in the CTFB and Fiocruz collections website. We hope that the cited data and references available online will aid the systematic, biodiversity, biogeographical, and epidemiological studies on the Ceratopogonidae fauna.

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Supplementary material 1

Supplementary S1. An updated list of Brazilian species of Biting Midges (Diptera: Ceratopogonidae).

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