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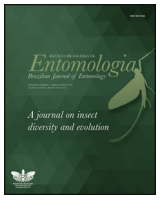

The SISBIOTA-Diptera Brazilian Network: A long-term survey of Diptera from unexplored Brazilian Western Arc of Amazon, Cerrado, and Pantanal

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ABSTRACT

The SISBIOTA-BRASIL was a three-year multimillion-dollar research program of the Brazilian government to document plants and animals in endangered/understudied areas and biomes in Brazil. Distributional patterns and the historical events that generated them are extensively unknown regarding Brazilian fauna and flora. This deficiency hinders the development of conservation policies and the understanding of evolutionary processes. Conservation decisions depend on precise knowledge of the taxonomy and geographic distribution of species. Given such a premise, we proposed to research the diversity of Diptera of the Brazilian western arc of Amazon, Cerrado, and Pantanal in the states of Mato Grosso, Mato Grosso do Sul, and Rondônia. Three important biomes of the South American continent characterize these Brazilian states: Amazon forest, Cerrado (Brazilian Savannah), and Pantanal. Besides their ecological relevance, these biomes historically lack intensive entomological surveys. Therefore, they are much underrepresented in the Brazilian natural history collections and in the scientific literature, which is further aggravated by the fact that these areas are being exponentially and rapidly converted to commercial lands. Our project involved over 90 collaborators from 24 different Brazilian institutions and one from Colombia among researchers, postdocs, graduate and undergraduate students, and technicians. We processed and analyzed nearly 300,000 specimens from ~60 families of Diptera collected with a large variety of methods in the sampled areas. Here, we provide a detailed overview of the genera and species diversity of 41 families treated. Our results point to a total of 2,130 species and 514 genera compiled and identified for the three states altogether, with an increase of 41% and 29% in the numbers of species and genera known for the three states combined, respectively. Overall, the 10 most species-rich families were Tachinidae, Cecidomyiidae, Tabanidae, Psychodidae, Sarcophagidae, Stratiomyidae, Bombyliidae, Syrphidae, Tephritidae, and Asilidae. The 10 most diverse in the number of genera were Tachinidae, Stratiomyidae, Asilidae, Mycetophilidae, Syrphidae, Tabanidae, Muscidae, Dolichopodidae, Sarcophagidae, and Chloropidae. So far, 111 scientific papers were published regarding taxonomic, phylogenetic, and biogeographical aspects of the studied families, with the description of 101 new species and three new genera. We expect that additional publications will result from this investigation because several specimens are now curated and being researched by specialists.

Introduction

The true flies (Diptera) comprise one of the four megadiverse insect orders in the world. There are *ca.* 160,000 known species worldwide in 153 recognized families (Whitmore et al., 2021; Evenhuis and Pape, 2022). Despite their ubiquitous presence and importance in every terrestrial and freshwater ecosystem on the planet and their tremendous impact on human civilization, dipterans are still poorly known, meaning that our knowledge about species richness, distribution, and biology are in construction especially in the Neotropical Region. The fauna of Diptera in the Neotropics is known to be of approximately 34,000 species (Borkent et al., 2018), which is probably only a tiny fraction of the actual diversity of the order, estimated as being at least five times higher than the current number of described species (Amorim, 2009). There is an enormous lack of intensive collecting events in most South American biomes. Even in relatively known areas, such as the southeast coastal portion of the Atlantic Forest in Brazil, the number of undescribed species is still very high (Amorim, 2009).

The SISBIOTA-BRASIL was a research program of the Brazilian government intended to document plants and animals in understudied or threatened areas and biomes in Brazil. In contrast to the most historically studied areas in southern Brazil regions (*e.g.*, states of Paraná, Rio de Janeiro, Santa Catarina, and São Paulo), other areas of the country remain under-sampled. Overall, most studies have focused on some selected families, and there is insufficient knowledge of the general fauna of Diptera and other groups of insects.

The central-west and northern states of Mato Grosso (MT), Mato Grosso do Sul (MS), and Rondônia (RO) are characterized by three important South American biomes (Amazon forest, Cerrado, and Pantanal) that fit well with this description. Unfortunately, these areas historically received less attention in terms of entomological surveys. The last extensive expeditions carried out in Mato Grosso and Rondônia, for example, were undertaken in the 1950s, conducted by entomologists of the "Museu Nacional" (Carvalho et al., 2002), and in the 1980s, in the context of the "Polonoroeste" faunistic expedition (Marinoni et al., 2005). Nowadays, few Diptera taxonomists are based in those states (Marques and Lamas, 2006).

The primary aim of our proposal entitled "Diptera of the states of Mato Grosso, Mato Grosso do Sul and Rondônia: diversity, systematics, and distributional limits" was to conduct an updated and thorough investigation of the systematics of the entire Diptera distributed in the aforementioned Brazilian states. We mainly directed our focus to the taxonomy, phylogeny, and biogeography of Diptera. The goals of this study were twofold: (1) to investigate, catalog, and document the dipteran diversity in MS, MT, and RO, and (2) to capacitate human resources to continuously study this fauna in subsequent years. Participants were also involved in the effort to publish descriptions of new species of each family, taxonomic revisions, checklists, identification keys, and new records of species/genera/families already reported from other regions, in Brazil or neighboring countries not necessarily from our target areas. Our research program gathered experts in different families of Diptera, who were able to examine and identify the collected specimens. The project involved a combination of systematists from various institutions, mainly Brazilian graduate and undergraduate students, who performed most of the studies, and lab technicians who coordinated the sorting and preparation of specimens.

In this paper, we provide an overview of our survey. We briefly describe the studied areas, the implemented collecting methods, and present general results on the richness of the families of Diptera in MS, MT, and RO. Moreover, we list the number of published papers so far, the finished thesis, and other end-products from this project.

Material and Methods

Study area and fieldwork

Twelve expeditions were conducted between August 2011 to February 2013, which target 10 different localities in the states of Mato Grosso, Mato Grosso do Sul, and Rondônia (Table 1, Fig. 1), with four collecting events in each state. We set up Malaise traps in each locality, within the limits of each municipality, and at more than one point.

Table 1
Summary of the 12 expeditions, four in each state, and sampling sites represented by municipalities.

1. 02 to 10 August 2011 – Mato Grosso do Sul, localities: Corumbá, Bodoquena.
2. 01 to 10 September 2011 – Mato Grosso, localities: Chapada dos Guimarães, Cuiabá.
3. 13 to 23 October 2011 – Rondônia, localities: Cacaulândia, Campo Novo de Rondônia, Monte Negro.
4. 04 to 14 December 2011 – Mato Grosso do Sul, localities: Corumbá, Porto Murtinho, Bodoquena.
5. 03 to 15 December 2011 – Rondônia, localities: Campo Novo de Rondônia, Monte Negro.
6. 14 to 24 January 2012 – Mato Grosso, localities: Chapada dos Guimarães, Cuiabá.
7. 30 March to 07 April 2012 – Mato Grosso do Sul, localities: Aquidauana, Corumbá, Bodoquena.
8. 19 to 27 May 2012 – Rondônia, localities: Cacaulândia, Campo Novo de Rondônia, Monte Negro.
9. 07 to 20 July 2012 – Mato Grosso, localities: Chapada dos Guimarães, Cuiabá, Poconé.
10. 04 to 12 December 2012 – Mato Grosso do Sul, localities: Aquidauana, Porto Murtinho, Bodoquena.
11. 12 to 22 January 2013 – Mato Grosso, localities: Chapada dos Guimarães, Cuiabá, Poconé.
12. 15 to 17 February 2013 – Rondônia, localities: Cacaulândia, Campo Novo de Rondônia, Monte Negro.

The complete information, including the number given for each Malaise trap, specific localities, and geographic coordinates, is available in Suppl. File 1. In addition, to cover distinct types of physiognomies, habitats, and altitudinal ranges (a sample of sites are shown in Fig. 1); in these events, we also applied other sampling techniques in as many sites as possible to make the sampling as thorough as possible. There were 58 collecting points (Fig. 1, Suppl. File 1), in which Malaise traps were set up and kept for the duration of the project. Each expedition assembled a team of specialists in one or various groups of Diptera mainly, and technicians. During the survey, over 90 people, including researchers, postdocs, graduate and undergraduate students, and technicians, contributed directly to the fieldwork (see Suppl. File 2 for details about the people involved).

Collecting techniques

Different collecting strategies were extensively used, and they were either group-specific or broad-spectrum, with a special focus on the use of passive flight interception (Malaise traps) and attractive traps (*e.g.*, Shannon, light, and pan traps) (see Figs. 2–4 for some of the traps used). Overall, 10 different types of traps were used (CDC light trap, drift net, light trap, Malaise trap classic type, Malaise 6-meter-long, McPhail trap, pan trap, Pennsylvania insect-light trap, Shannon trap, and different types of Van Sommeren-Rydon) and, additionally, we extensively used sweeping nets (Fig. 2n) and mist net for capturing and examining bats for bat flies (Fig. 4). We took advantage of the complementarity of each technique to assess the maximum species diversity during specimen collection. Besides the periodical expeditions, we had three Malaise traps installed, separated from each other by around 200 meters, during 12 consecutive months in the following localities: Mato Grosso (MT): Chapada dos Guimarães (Parque Nacional), Poconé (Fazenda Rio Claro); Mato Grosso do Sul (MS): Aquidauana (Reserva Ecológica-UEMS), Corguinho (Distrito de Taboco), Corumbá (Base de Estudos do Pantanal (BEP-UFMS), Porto Murtinho (Fazenda Retiro Conceição), Serra da Bodoquena (Fazenda Califórnia); and Rondônia (RO): Cacaulândia (Fazenda do Seu Zé Careca; Cachoeira and Chacareiros).

Sample and data processing

We preserved the bulk of the samples in 70% ethanol. Each expedition team sorted the material by family while in the field during laboratory work. Only some hand-swept specimens of robust families (*e.g.*, Asilidae, Bombyliidae, Stratiomyidae, Tabanidae, Tachinidae) were pinned directly after being collected. In the "Museu de Zoologia da Universidade de São Paulo" (MZUSP), the process of sorting was intensified by the permanent staff of technicians, where samples were first separated into fractions: non-Diptera and each of the different families of Diptera. Then most medium- and large-sized family flies had to be further dried and pinned. Minute and delicate flies, such as Cecidomyiidae, Mycetophilidae, and Sciaridae, were preserved in 80% ethanol. For some of these small-sized families, we selected specimens for slide-mounting following the specifications determined by each specialist. Other small-sized families (*e.g.*, Chloropidae, Drosophilidae, Phoridae) had most of the specimens glued to card points mounted on insect pins. Although the project involves at some point an inventory of all Diptera species collected and a comparison to what had been reported to MS, MT, and RO before our survey, we did not effectively prepare all the specimens collected from Malaise traps or any other kind of trap. This decision was taken to save time, effort, and also to reduce the infrastructure and facilities necessary to store the curated specimens. For rarer taxa, every specimen was prepared. However, for abundant taxa, our sorting process selected morphotypes for further preparation and sent them to the experts, indicating that additional specimens would probably be available in ethanol.

For genus and species level identification over 80 primary collaborators studied the Diptera fauna and groups of other insect orders such as Psocodea, Neuroptera, Hymenoptera, and Coleoptera. In the case of Diptera, the experts agreed to examine and identify the specimens they received, sent a list with the identifications (which was a datasheet in Excel format) to the coordinators, and proceeded with the description of the new taxa. In a few cases, there was an additional level of sorting done by a taxonomic expert who partly split processed samples into workable fractions (*e.g.*, subfamilies, tribes, or genera) and disseminated these to (other) taxonomic experts.

The spreadsheet-filling process generated a list of species (or morphospecies) for all families for which an expert was available to work on the material. The spreadsheet included the total number of specimens per species/morphospecies per locality (each of the localities mentioned in Table 1). Each specialist had to point out if they were a new record or taxon for each state and/or for Brazil.

Specimens are currently either deposited at the MZUSP collection or retained by the experts for further study (temporarily or permanently, in the case of duplicates). The specialists' institutions (or other suggested institutions) are depositories of part of the studied material, including holotypes and paratypes.

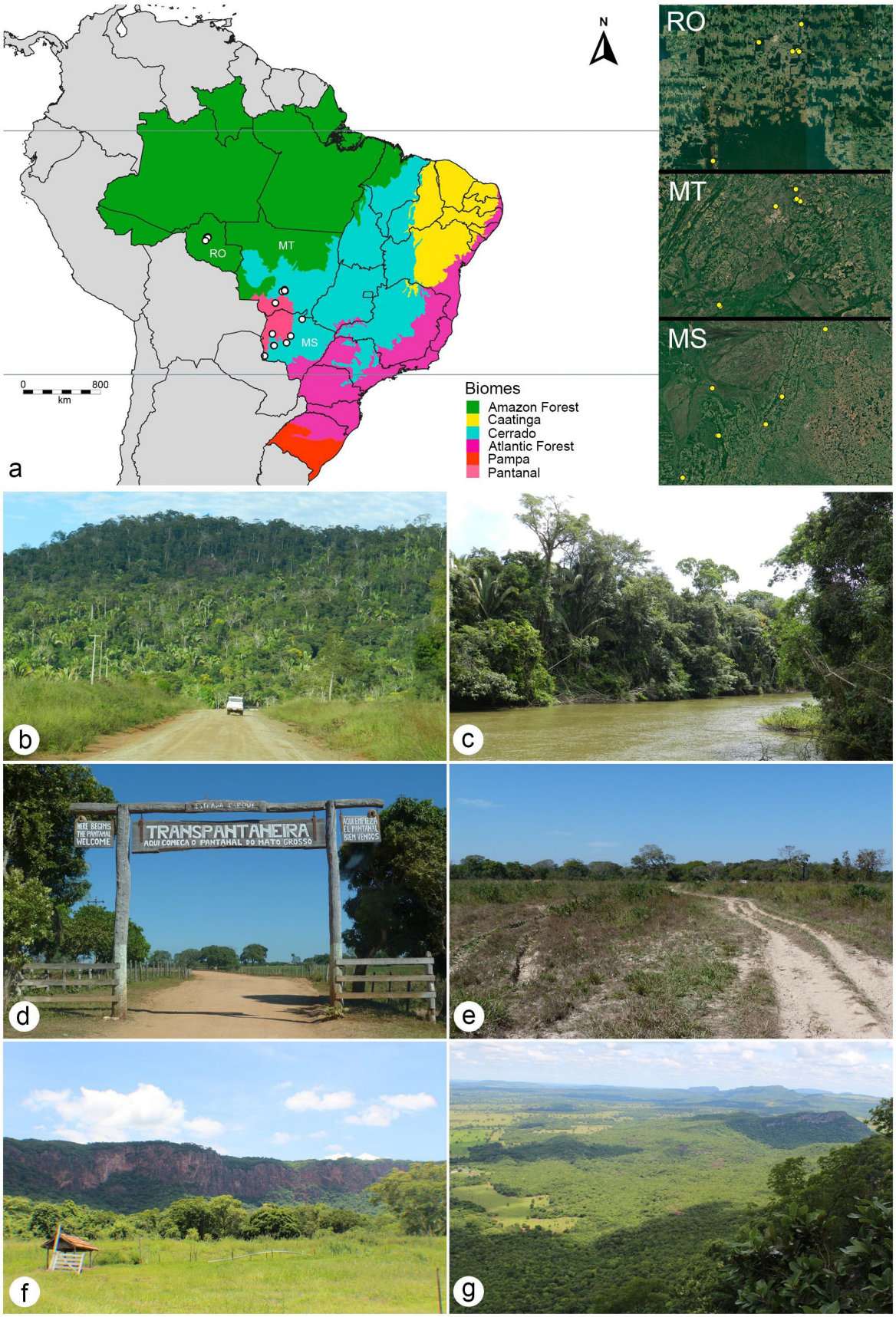


Figure 1 Map of the main biomes of Brazil showing collecting points and sampling sites in the states of Rondônia (RO), Mato Grosso (MT), Mato Grosso do Sul (MS). (a) geographical limits of the Brazilian states and main biomes (left map) and satellite images of each area, depicting all collecting points (white circles on the left and yellow circles on the right); (b) general landscape of forest in Cacaulândia, Rondônia; (c) forest along a river in Cacaulândia, Rondônia; (d) gate of Transpantaneira road in Poconé, Mato Grosso; (e) open vegetation area with patches of forests in Poconé, Mato Grosso; (f) open vegetation area with a mosaic of forest over the rocky formation in Aquidauana, Mato Grosso do Sul; (g) general landscape in Bodoquena, Mato Grosso do Sul.

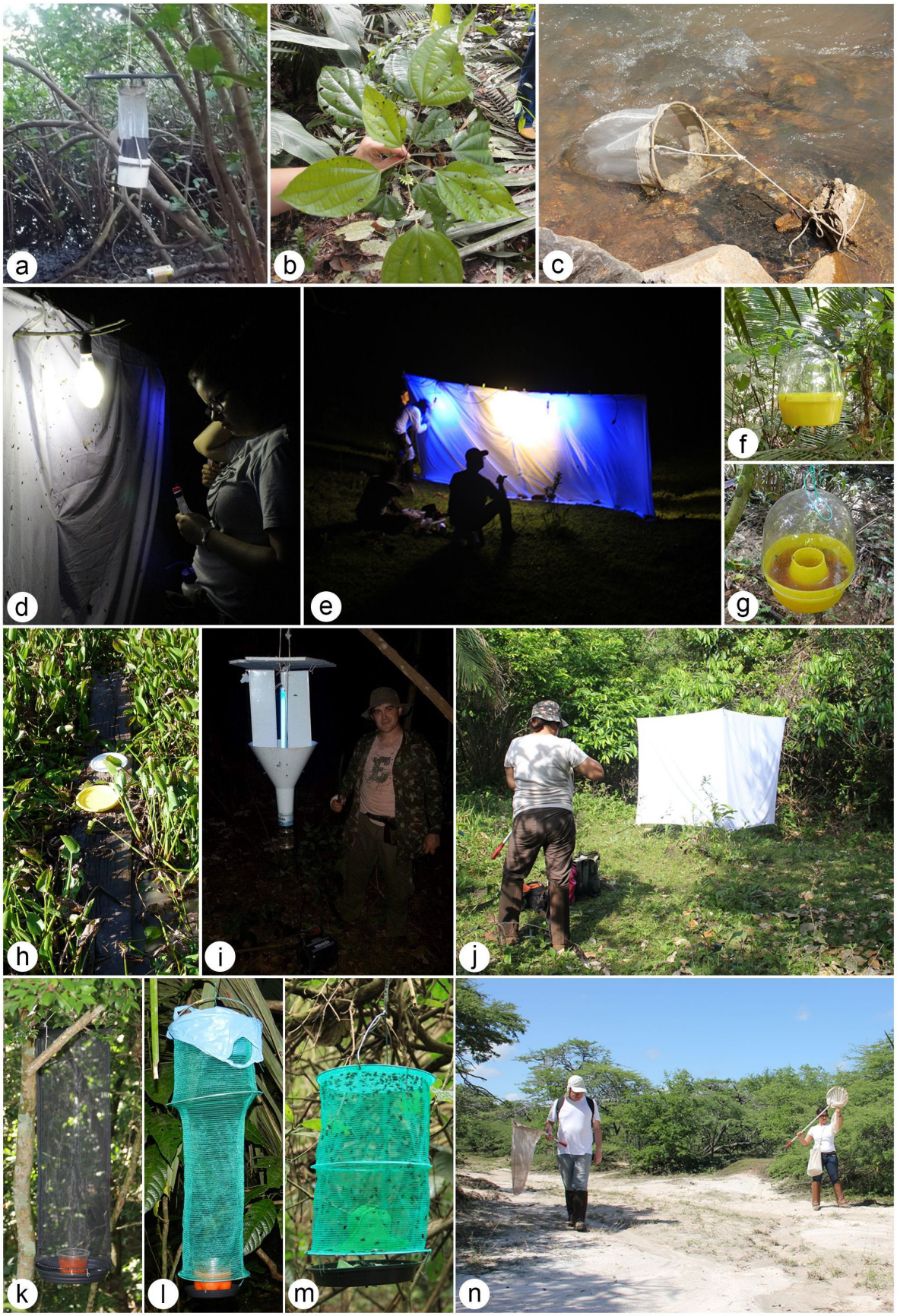


Figure 2 Collecting techniques used in the SISBIOTA-Diptera long-term survey. (a) CDC light trap; (b) manual collecting of cecidomyiid galls; (c) drift net; (d–e) classic light trap, with a white vertical sheet and different types of lights; (f–g) McPhail trap, filled with fermented fruit; (h) yellow and white pan traps near temporary ponds; (i) Pennsylvania light trap; (j) Shannon trap, baited with pieces of rotten fish or chicken; (k–m) three different types of Van Sommeren-Rydon (also known as Nymphalidae butterfly trap), modified to collect flies, baited with fermented fruit or decomposing fish; (n) net sweeping of vegetation.

Figure 3 Different types of Malaise traps installed in various sampling sites. (a) in a dry, open area of vegetation in Poconé, Mato Grosso; (b) in a shaded area in open vegetation in Porto Murtinho, Mato Grosso; (c) in a shaded area of forest along a stream in Cacaulândia, Rondônia; (d) in a shaded area of forest in Cacaulândia, Rondônia; (e) classic Malaise trap supported by a metallic structure set up in rocky formation with shrubby vegetation in Chapada dos Guimarães, Mato Grosso; (f) six-meter-long Malaise trap in open vegetation in Poconé, Mato Grosso; (g) six-meter-long Malaise trap in open vegetation in Porto Murtinho, Mato Grosso do Sul.

Figure 4 Mist net for trapping and examining bats for collecting bat flies (Streblidae). (a) setting up a mist net in a flooded area in the Pantanal, in Poconé, Mato Grosso; (b) mist net set on the flooded area, indicated with red arrows, in Poconé, Mato Grosso; (c) mist net set on drier area, in the Pantanal, in Corumbá, Mato Grosso do Sul; (d) *Noctilio albiventris* Desmarest, 1818 (Chiroptera: Noctilionidae) trapped with mist net and examined for bat flies, in Corumbá, Mato Grosso do Sul.

The classification of Diptera in Tables 2–3, Figures 5–6, and supplementary file 5 follows Pape et al. (2011) and in the supplementary files 3–4, the families are presented in alphabetical order.

Results and Discussion

Approximately 300,000 specimens in ~60 families have been curated and identified for MS, MT, and RO. Of these, only 41 families (Figs. 5–6 represent one member of each family), for which the fauna known before the beginning of the project is in Table 2 (columns 1–4), were treated in detail, rendering 2,130 species and 641 genera known for the three states, combining published records (see Rafael et al., 2023) and our new data (Table 3). Compared to the known fauna for the three states altogether excluding publications and data from the SISBIOTA-Diptera project, which total is 1,179 species and 392 genera (Table 2), the examination of the material collected in the SISBIOTA-Diptera adds 951 records of species and 122 genera to the fauna of the three states combined. These species and genera correspond to new records and new taxa to the states. In total, we recovered 770 new records of species and 281 genera to MS, 566 new records of species and 211 genera to MT, and 430 new records of species and 204 genera to RO. Some of these data have been published (see below) and more will be published in the next years. The numbers of new records and taxa, however, are likely higher. Some species-rich families, such as Ceratopogonidae, Culicidae, Drosophilidae, and Phoridae, although present in the samples, are still not identified and other families were only partially identified, so we expect even higher numbers of genera and species among the collected material.

Regarding the fauna of three states, our current results showed that the richest family in the number of genera was Tachinidae, with 152 genera, followed by Stratiomyidae, with 51 genera, Asilidae, with 37, Syrphidae, with 28, Mycetophilidae, Tabanidae, and Muscidae, all with 27, Dolichopodidae and Sarcophagidae, with 26, and Chloropidae, with 24 (Fig. 7). Together, these ten most genera-rich families accounted for ~61% of all genera diversity. The richest family in the number of species considering the three states was Tachinidae, with 350 species, followed by Cecidomyiidae, with 244 species, Tabanidae, with 196, Psychodidae, with 171, Sarcophagidae, with 168, Stratiomyidae, with 124, Bombyliidae, with 103, Syrphidae, with 94, Tephritidae, with 82, and Asilidae, with 80 (Fig. 8). Together, these ten most species-rich families accounted for ~76% of all species diversity. As observed, the rankings of the 10 most genera- and species-rich families differ from each other, that of each state individually, and that of the current Brazilian list (Figs. 9–10; data used to rank the families and diversity graphs for each state individually, either the total number of taxa or new record only, can be found in Suppl. File 5). Although we have not examined in detail all captured families (for example, species-rich families such as Ceratopogonidae, Culicidae, and Phoridae were collected but not identified into species until now), this suggests that the current understanding of species richness per family is still poorly known from the sampled biomes and Brazilian states and that the type of vegetation (either humid forest or Cerrado, for example) may have an influence on the species diversity of the families, meaning that a group of families can be more diverse in a type of biome, but not necessarily is as diverse as in another biome. An example of that is Bombyliidae, which is in the top 10 of the most diverse families in the states of Mato Grosso and Mato Grosso do Sul, two states covered by extensive areas of drier and sparse vegetation, but the family is not in the top 10 in the state of Rondônia, which is covered by dense and humid forests.

Table 2
List of families studied in detail in the SISBIOTA-Diptera long-term survey, with their current number of species reported to Brazil (Rafael et al., 2023) and genera and species known for the three Brazilian states (MS = Mato Grosso do Sul, MT = Mato Grosso, and RO = Rondônia), the focus of the present expedition, previous to the publication of the first taxonomical results in 2012.

Family	Total named species in Brazil	Known genera/species MS, MT, RO	Known genera/species MS	Known genera/species MT	Known genera/species RO
Tipulidae	160	4 gen./8 spp.	0/0	1 gen./3 spp.	3 gen./5 spp.
Psychodidae	576	26 gen./206 spp.	13 gen./56 spp.	19 gen./121 spp.	23 gen./162 spp.
Chironomidae	659	30 gen./78 spp.	8 gen./10 spp.	27 gen./64 spp.	2 gen./7 spp.
Anisopodidae	24	2 gen./2 spp.	1 gen./1 sp.	1 gen./1 sp.	0/0
Bibionidae	50	3 gen./5 spp.	1 gen./1 sp.	2 gen./4 spp.	0/0
Ditomyiidae	11	0/0	0/0	0/0	0/0
Diadocidiidae	1	0/0	0/0	0/0	0/0
Mycetophilidae	422	8 gen./14 spp.	8 gen./14 spp.	0/0	0/0
Keroplatidae	91	7 gen./8 spp.	5 gen./6 spp.	2 gen./2 spp.	0/0
Lygistorrhinidae	5	0/0	0/0	0/0	0/0
Cecidomyiidae	326	8 gen./10 spp.	2 gen./2 spp.	6 gen./8 spp.	1 gen./2 spp.
Mythicomyiidae	15	0/0	0/0	0/0	0/0
Bombyliidae	112	10 gen./23 spp.	7 gen./12 spp.	9 gen./17 spp.	2 gen./2 spp.
Asilidae	468	34 gen./70 spp.	20 gen./35 spp.	23 gen./47 spp.	5 gen./10 spp.
Mydidae	31	5 gen./10 spp.	1 gen./1 sp.	5 gen./7 spp.	3 gen./3 spp.
Therevidae	37	6 gen./7 spp.	2 gen./2 spp.	2 gen./2 spp.	4 gen./5 spp.
Rhagionidae	20	0/0	0/0	0/0	0/0
Pantophthalmidae	12	1 gen./3 spp.	1 gen./1 sp.	1 gen./1 sp.	1 gen./1 sp.
Stratiomyidae	344	24 gen./41 spp.	11 gen./14 spp.	18 gen./25 spp.	7 gen./11 spp.
Xylomyidae	7	1 gen./1 sp.	0/0	1 gen./1 sp.	0/0
Tabanidae	492	25 gen./167 spp.	18 gen./63 spp.	24 gen./111 spp.	21 gen./99 spp.
Xylophagidae	7	0/0	0/0	0/0	0/0
Dolichopodidae	219	7 gen./12 spp.	4 gen./5 spp.	3 gen./5 spp.	2 gen./2 spp.
Empididae	164	3 gen./4 spp.	0/0	2 gen./3 spp.	1 gen./1 sp.
Pipunculidae	175	3 gen./7 spp.	1 gen./1 sp.	2 gen./4 spp.	2 gen./3 spp.
Syrphidae	594	28 gen./90 spp.	27 gen./79 spp.	13 gen./36 spp.	14 gen./27 spp.
Chloropidae	137	4 gen./9 spp.	0/0	3 gen./8 spp.	1 gen./1 sp.
Lauxaniidae	109	10 gen./15 spp.	6 gen./6 spp.	3 gen./4 spp.	3 gen./3 spp.
Neriidae	17	5 gen./7 spp.	4 gen./5 spp.	4 gen./5 spp.	4 gen./5 spp.
Agromyzidae	127	0/0	30 gen./12 spp.	0/0	0/0
Ropalomeridae	30	7 gen./23 spp.	3 gen./6 spp.	6 gen./11 spp.	3 gen./6 spp.
Ulidiidae	58	5 gen./6 spp.	2 gen./3 spp.	2 gen./2 spp.	0/0
Platystomatidae	7	0/0	0/0	0/0	0/0
Tephritidae	288	5 gen./48 spp.	3 gen./34 spp.	4 gen./27 spp.	2 gen./12 spp.
Streblidae	99	16 gen./45 spp.	14 gen./38 spp.	7 gen./7 spp.	8 gen./14 spp.
Fanniidae	82	1 gen./8 spp.	1 gen./5 spp.	1 gen./6 spp.	1 gen./3 spp.
Muscidae	959	27 gen./49 spp.	15 gen./18 spp.	18 gen./24 spp.	16 gen./16 spp.
Calliphoridae	37	7 gen./14 spp.	6 gen./12 spp.	2 gen./4 spp.	2 gen./3 spp.
Mesembrinellidae	24	1 gen./8 spp.	1 gen./2 spp.	1 gen./3 spp.	1 gen./8 spp.
Sarcophagidae	406	20 gen./85 spp.	13 gen./56 spp.	19 gen./58 spp.	2 gen./3 spp.
Tachinidae	806	49 gen./96 spp.	24 gen./39 spp.	50 gen./70 spp.	2 gen./4 spp.
Total	8,208	392 gen./1,179 spp	252 gen./539 spp.	281 gen./691 spp.	136 gen./418 spp.

Table 3
List of families studied in detail in the SISBIOTA-Diptera long-term survey, with the number of genera and species previously known in the three states altogether (MS = Mato Grosso do Sul, MT = Mato Grosso, and RO = Rondônia) (first column) plus newly records of genera and species, and individually (second to fourth columns), with only the number of new records of genera and species for each state (fifth to seventh columns), and collaborators responsible for data identification and compilation.

Family	genera/species MS, MT, RO	genera/species MS	new records MS	genera/species MT	new records MT	genera/species RO	new records RO	Specialist(s)
Tipulidae	4 gen./12 spp.	1 gen./2 spp.	1 gen./2 spp.	1 gen./3 spp.	0/0	3 gen./7 spp.	0 gen./2 spp.	AVGF; LHGA
Psychodidae	18 gen./171 spp.	13 gen./56 spp.	16 gen./113 spp.	16 gen./136 spp.	2 gen./3 spp.	0/0	0/0	FB; PHFS; MXA
Chironomidae	7 gen./14 spp.	5 gen./7 spp.	4 gen./8 spp.	0/0	1 gen./1 sp.	1 gen./1 sp.	1 gen./2 spp.	LMF; CB; SW
Anisopodidae	3 gen./6 spp.	2 gen./4 spp.	1 gen./3 spp.	2 gen./3 spp.	1 gen./2 spp.	1 gen./1 sp.	1 gen./1 sp.	RLF
Bibionidae	5 gen./11 spp.	5 gen./10 spp.	4 gen./9 spp.	2 gen./6 spp.	1 gen./3 spp.	2 gen./8 sp.	2 gen./8 sp.	DCSP; RLF
Ditomyiidae	1 gen./1 sp.	0/0	0/0	1 gen./1 sp.	1 gen./1 sp.	1 gen./1 sp.	1 gen./1 sp.	RLF
Diadocidiidae	1 gen./1 sp.	1 gen./1 sp.	1 gen./1 sp.	0/0	0/0	0/0	0/0	RLF
Mycetophilidae[1]	27 gen./42 spp.	22 gen./10 spp.	14 gen./8 spp.	15 gen./4 spp.	15 gen./4 spp.	23 gen./14 spp.	23 gen./14 spp.	SSO; DSA
Keroplatidae	14 gen./16 spp.	13 gen./14 spp.	8 gen./8 spp.	5 gen./6 spp.	2 gen./3 spp.	8 gen./8 spp.	8 gen./8 spp.	RLF
Lygistorrhinidae	1 gen./1 sp.	0/0	0/0	0/0	0/0	1 gen./1 sp.	1 gen./1 sp.	SSO
Cecidomyiidae	22 gen./244 spp.	8 gen./80 spp.	6 gen./78 spp.	9 gen./98 spp.	5 gen./92 spp.	8 gen./68 spp.	7 gen./68 spp.	AMC-N; BP; CAG; MVUG; SA; VCM
Mythicomyiidae	1 gen./1 sp.	1 gen./1 sp.	1 gen./1 sp.	0/0	0/0	0/0	0/0	CJEL
Bombyliidae	22 gen./103 spp.	22 gen./80 spp.	14 gen./68 spp.	18 gen./60 spp.	9 gen./42 spp.	7 gen./ 9 spp.	5 gen./7 spp.	CJEL; CY
Asilidae	37 gen./80 spp.	22 gen./40 spp.	2 gen./5 spp.	25 gen./52 spp.	2 gen./5 spp.	6 gen./12 spp.	1 gen./2 spp.	AC
Mydidae	6 gen./11 spp.	3 gen./4 spp.	2 gen./3 spp.	5 gen./7 spp.	0/0	3 gen./3 spp.	0/0	JC
Therevidae	7 gen./21 spp.	5 gen./13 spp.	2 gen./2 spp.	5 gen./14 spp.	1 gen./10 spp.	3 gen./3 spp.	2 gen./2 spp.	FLO; LLM
Rhagionidae	1 gen./1 sp.	1 gen./1 sp.	1 gen./1 sp.	0/0	0/0	0/0	0/0	BMC; CMDS
Pantophthalmidae	1 gen./1 sp.	0/0	0/0	0/0	0/0	1 gen./1 sp.	0 gen./1 sp.	DAF
Stratiomyidae	51 gen./124 spp.	41 gen./82 spp.	31 gen./66 spp.	20 gen./38 spp.	9 gen./26 spp.	29 gen./107 spp.	25 gen./83 spp.	DAF
Xylomyidae	2 gen./6 spp.	1 gen./2 spp.	1 gen./2 spp.	1 gen./1 sp.	1 gen./1 sp.	2 gen./5 spp.	2 gen./5 spp.	DAF
Tabanidae	27 gen./196 spp.	22 gen./77 spp.	4 gen./14 spp.	25 gen./116 spp.	1 gen./5 spp.	22 gen./109 spp.	1 gen./10 spp.	ALH; TKK
Xylophagidae	1 gen./1 spp.	1 gen./1 spp.	1 gen./1 spp.0	0/0	0/0	0/0	0/0	DAF
Dolichopodidae	26 gen./58 spp.	21 gen./44 spp.	17 gen./39 spp.	16 gen./25 spp.	13 gen./21 spp.	17 gen./4 spp.	15 gen./2 spp.	RSC
Empididae	4 gen./6 spp.	1 gen./2 spp.	1 gen./2 spp.	4 gen./5 spp.	2 gen./2 spp.	2 gen./2 spp.	1 gen./1 sp.	JAR
Pipunculidae	3 gen./9 spp.	1 gen./1 sp.	1 gen./1 sp.	2 gen./4 spp.	0/0	2 gen./3 spp.	0 gen/1 sp.	JAR
Syrphidae	28 gen./94 spp.	35 gen./98 spp.	8 gen./19 spp.	23 gen./51 spp.	10 gen./15 spp.	18 gen./45 spp.	4 gen./18 spp.	MNM
Chloropidae	24 gen./46 spp.	9 gen./13 spp.	9 gen./13 spp.	17 gen./28 spp.	14 gen./20 spp.	8 gen./9 spp.	7 gen./8 spp.	PRR
Lauxaniidae	24 gen./43 spp.	17 gen./24 spp.	12 gen./19 spp.	8 gen./14 spp.	2 gen./6 spp.	9 gen./11 spp.	6 gen./8 spp.	VCS
Neriidae	2 gen./2 spp.	1 gen./1 sp.	0/0	1 gen./1 sp.	0/0	0/0	0/0	RLM
Agromyzidae	4 gen./18 spp.	3 gen./9 spp.	3 gen./9 spp.	3 gen./6 spp.	3 gen./6 spp.	3 gen./12 spp.	3 gen./12 spp.	VRS
Ropalomeridae	7 gen./29 spp.	5 gen./9 spp.	2 gen./3 spp.	6 gen./13 spp.	0 gen./1 sp.	4 gen./7 spp.	1 gen./1 sp.	RAR
Ulidiidae	6 gen./13 spp.	3 gen./4 spp.	5 gen./9 spp.	0/0	0/0	0/0	0/0	RLM
Platystomatidae	1 gen./2 spp.	1 gen./2 spp.	1 gen./2 spp.	1 gen./2 spp.	1 gen./2 spp.	1 gen./2 spp.	1 gen./2 spp.	JPVR; RLM
Tephritidae	24 gen./82 spp.	14 gen./52 spp.	11 gen./18 spp.	18 gen./50 spp.	14 gen./23 spp.	9 gen./19 spp.	6 gen./7 spp.	MS
Streblidae	17 gen./55 spp.	14 gen./43 spp.	0 gen./4 spp.	7 gen./12 spp.	1 gen./12 spp.	9 gen./15 spp.	1 gen./1 sp.	DMCA; GG
Fanniidae	1 gen./9 spp.	1 gen./6 spp.	0 gen./1 sp.	1 gen./7 spp.	0 gen./4 spp.	1 gen./3 spp.	0 gen/2 spp.	CJBC; MSC
Muscidae	27 gen./65 spp.	15 gen./26 spp.	4 gen./8 spp.	18 gen./33 spp.	5 gen./13 spp.	16 gen./19 spp.	5 gen./8 spp.	CJBC; MSC
Calliphoridae	5 gen./14 spp.	4 gen./5 spp.	1 gen./1 sp.	5 gen./11 spp.	5 gen./10 spp.	6 gen./8 spp.	4 gen./8 spp.	JRPL
Mesembrinellidae	1 gen./3 spp.	1 gen./1 sp.	0/0	1 gen./2 spp.	0/0	1 gen./4 spp.	0/0	JRPL
Sarcophagidae	26 gen./168 spp.	22 gen./100 spp.	9 gen./44 sp.	24 gen./103 spp.	5 gen./45 spp.	7 gen./24 spp.	5 gen./21 spp.	CAMP; MMG; JRS
Tachinidae	152 gen./350 spp.	100 gen./187 spp.	83 gen./185 spp.	107 gen./195 spp.	85 gen./188 spp.	67 gen./116 spp.	65 gen./115 spp.	FMG; LB; MDS; RVPD; SSN
Total	641 gen./2,130 spp.	457 gen./1,112 spp.	281 gen./770 spp.	412 gen./1,107 spp.	211 gen./566 spp.	301 gen./662 spp.	204 gen./430 spp.	

[1]*Mycetophilidae only partially identified into species.*

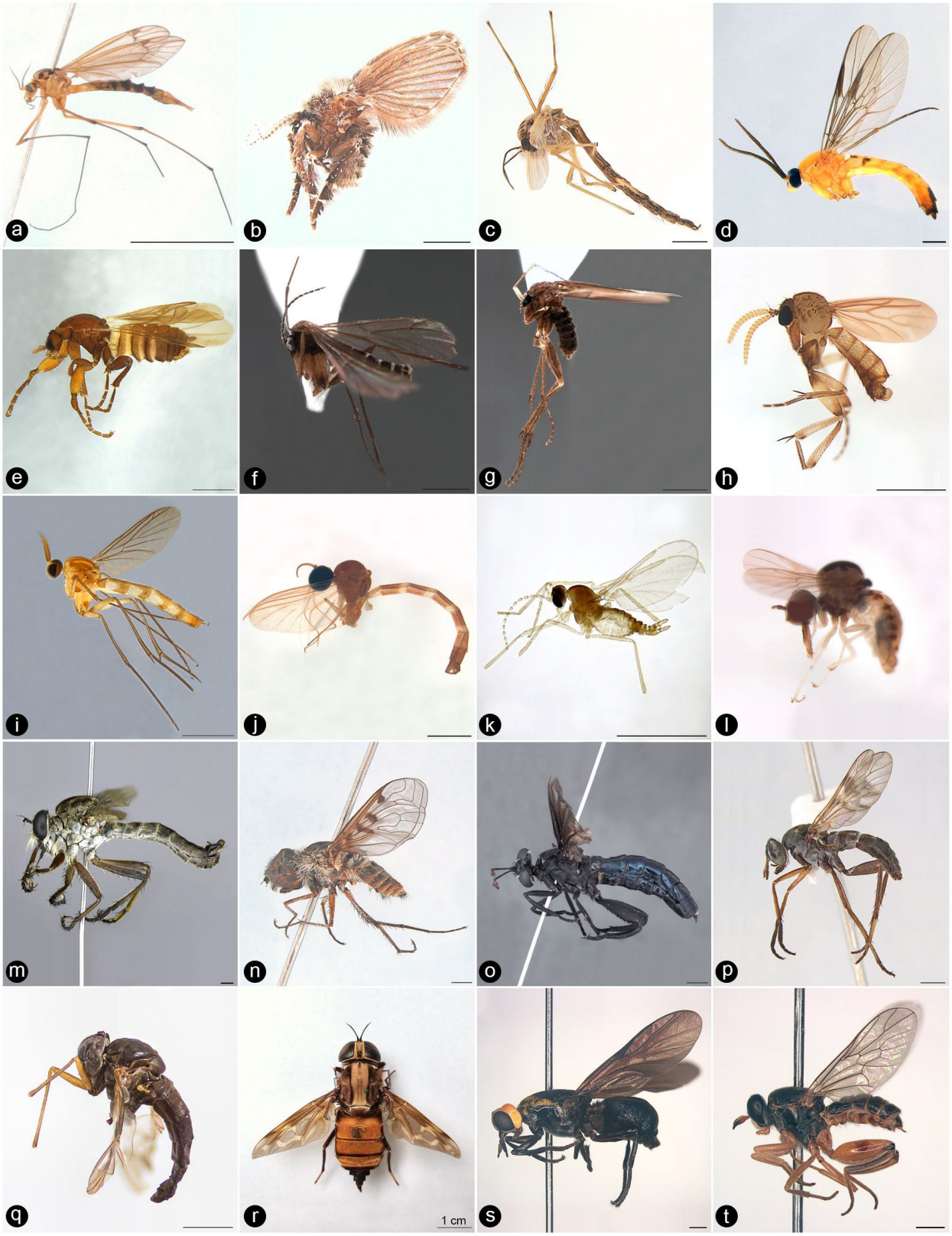


Figure 5 Diptera collected in the SISBIOTA-Diptera, *habitus*. (a) *Nephrotoma* sp. (Tipulidae), female, Bodoquena, MS; (b) *Clogmia* sp. (Psychodidae), male, Poconé, MT; (c) *Stenochironomus* sp. (Chironomidae), male, Aquidauana, MS; (d) *Olbiogaster* sp. (Anisopodidae), female, Bodoquena, MS; (e) *Enicoscolus* cf. *hardy* Fitzgerald, 1997 (Bibionidae), female, Bodoquena, MS; (f) *Rhipidita* sp. (Ditomyiidae), male, Monte Negro, RO; (g) *Diadocidia* sp. (Diadocidiidae), female, Porto Velho, RO; (h) *Aphrastomyia shannoni* Lane, 1956 (Mycetophilidae), male, Porto Velho, RO; (i) *Placoceratias gorgasi* Matile, 1990 (Keroplatidae), male, Chapada dos Guimarães, MT; (j) *Lygistorrhina barrettoi* Lane, 1956 (Lygistorrhinidae), male, Bodoquena, MS; (k) *Insulestremia sinclairi* Jaschhof, 2004 (Cecidomyiidae), male, Bodoquena, MS; (l) *Amydrostylus triadicophallus* Lamas et al. 2015 (Mythicomyiidae), male, Porto Murtinho, MS; (m) *Cerozodus platylobus* Camargo, Vieira & Rafael, 2022 (Asilidae), male, Cuiabá, MT; (n) *Anthrax trimaculatus* Macquart, 1848 (Bombyliidae), female, Porto Murtinho, MS; (o) *Messiasia zikani* d'Andretta, 1951 (Mydidae), female, Bodoquena, MS; (p) *Cerocatus* sp. (Therevidae), female, Corguinho, MS; (q) *Chrysopilus kafkai* Cegolin & Santos, 2021 (Rhagionidae), male, Bodoquena, MS (modified from Cegolin et al. 2020; (r) *Pantophthalmus tabaninus* Thunberg, 1919 (Pantophthalmidae), female, Porto Velho, RO; (s) *Pseudocyphomyia mimetica* Kertész, 1916 (Stratiomyidae), male, Monte Negro, RO; (t) *Solva* sp. (Xylomyidae), female, Rio Verde, MS. Scale bar = 1 mm.

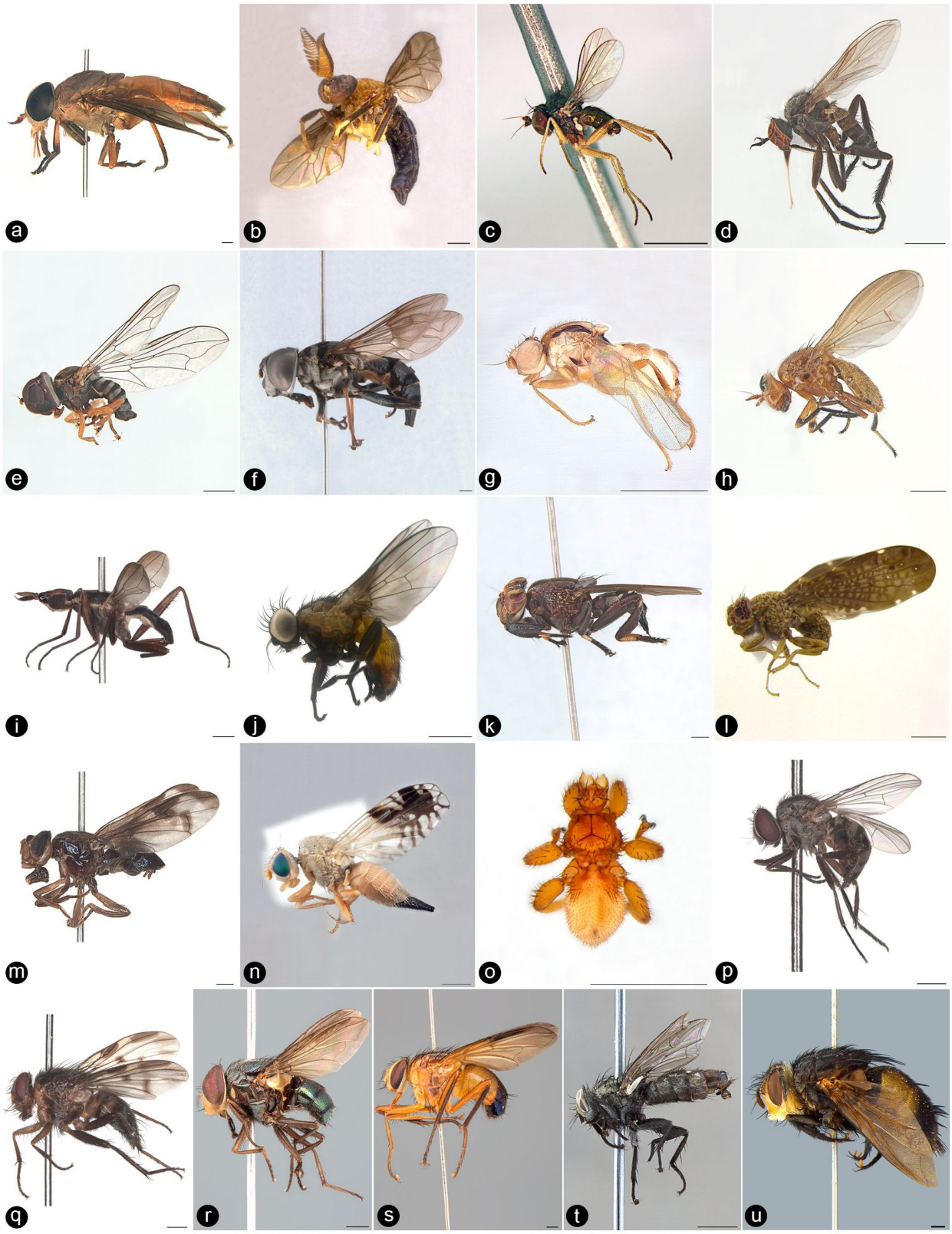


Figure 6 Diptera collected in the SISBIOTA-Diptera, *habitus*. (a) *Tabanus importunus* Wiedemann, 1828 (Tabanidae), female, Bodoquena, MS; (b) *Rachicerus carrerai* Pujol-Luz, 2019 (Xylophagidae), male, Bodoquena, MS; (c) *Chrysotus* sp. (Dolichopodidae), male, Corumbá, MS; (d) Empidini (Empididae), male, Corumbá, MS; (e) *Eudorylas* sp. (Pipunculidae), male, Corguinho, MS; (f) *Palpada scutellaris* (Fabricius, 1805) (Syrphidae), female, Porto Velho, RO; (g) *Gaurax* sp. (Chloropidae), male, Chapada dos Guimarães, MT; (h) *Physegenua* sp. (Lauxaniidae), male, Aquidauana, MS; (i) *Glyphidops etele* Aczél, 1961 (Neriidae), female, Cacaulândia, RO; (j) *Phytobia cacaulandia* Sousa & Couri, 2018 (Agromyzidae), male, Cacaulândia, RO; (k) *Ropalomera* sp. (Ropalomeridae), female, Chapada dos Guimarães, MT; (l) *Pterocalla* sp. (Ulidiidae), male, Porto Murtinho, MS; (m) *Senopterina macularis* (Fabricius, 1805) (Platystomatidae), male, Bodoquena, MS; (n) *Trupanea bonariensis* (Brèthes, 1908) (Tephritidae), female, Aquidauana, MS; (o) *Noctiliostrebla morena* Alcantara, Graciolli & Nihei, 2019 (Streblidae), male, Corumbá, MS; (p) *Fannia heydenii* (Wiedemann, 1830) (Fanniidae), female, Bodoquena, MS; (q) *Polietina prima* (Couri & Machado, 1990) (Muscidae), female, Cacaulândia, RO; (r) *Chloroprocta idioidea* (Robineau-Desvoidy, 1830) (Calliphoridae), male, Cacaulândia, RO; (s) *Mesembrinella randa* (Walker, 1849) (Mesembrinellidae), male, Monte Negro, RO; (t) *Helicobia chapadensis* Tibana & Lopes, 1984 (Sarcophagidae), male, Chapada dos Guimarães, MT; (u) *Euepalpus flavicauda* Townsend, 1908 (Tachinidae), male, Aquidauna, MS. Scale bar = 1 mm.

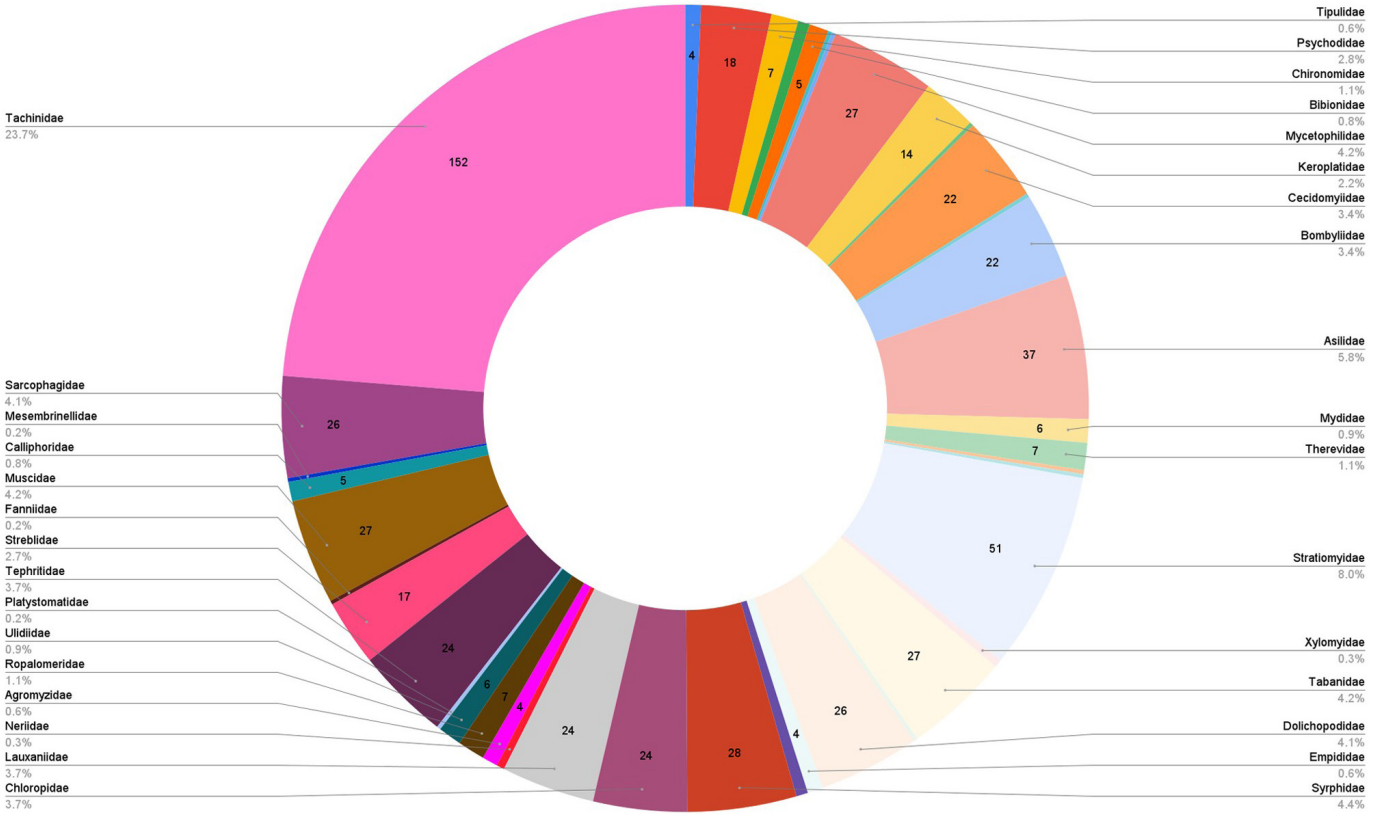


Figure 7 Diversity of genera in each Diptera family in the material collected and identified of the three states combined (Mato Grosso, Mato Grosso do Sul, and Rondônia) in the SISBIOTA-Diptera.

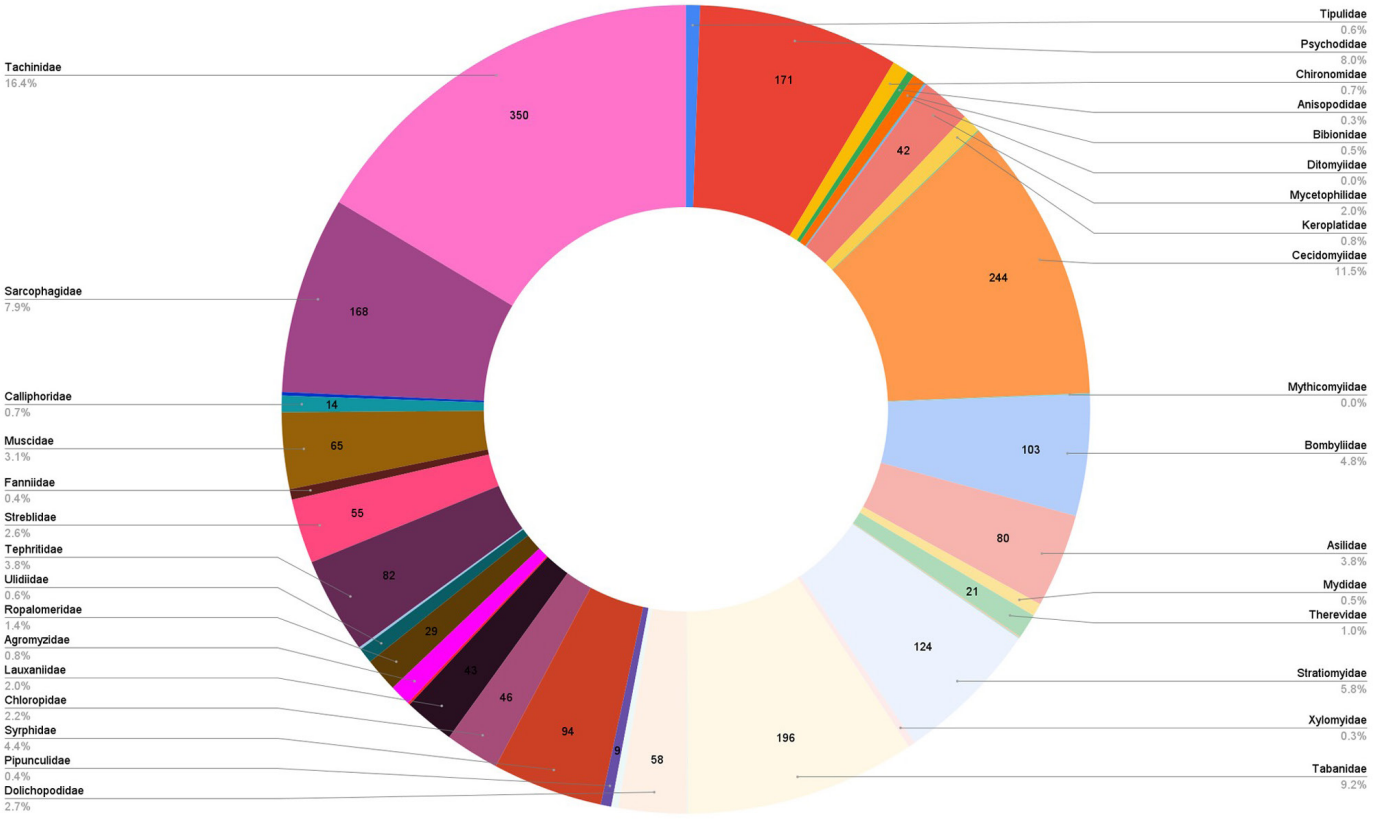


Figure 8 Diversity of species in each Diptera family in the material collected and identified of the three states combined (Mato Grosso, Mato Grosso do Sul, and Rondônia) in the SISBIOTA-Diptera.

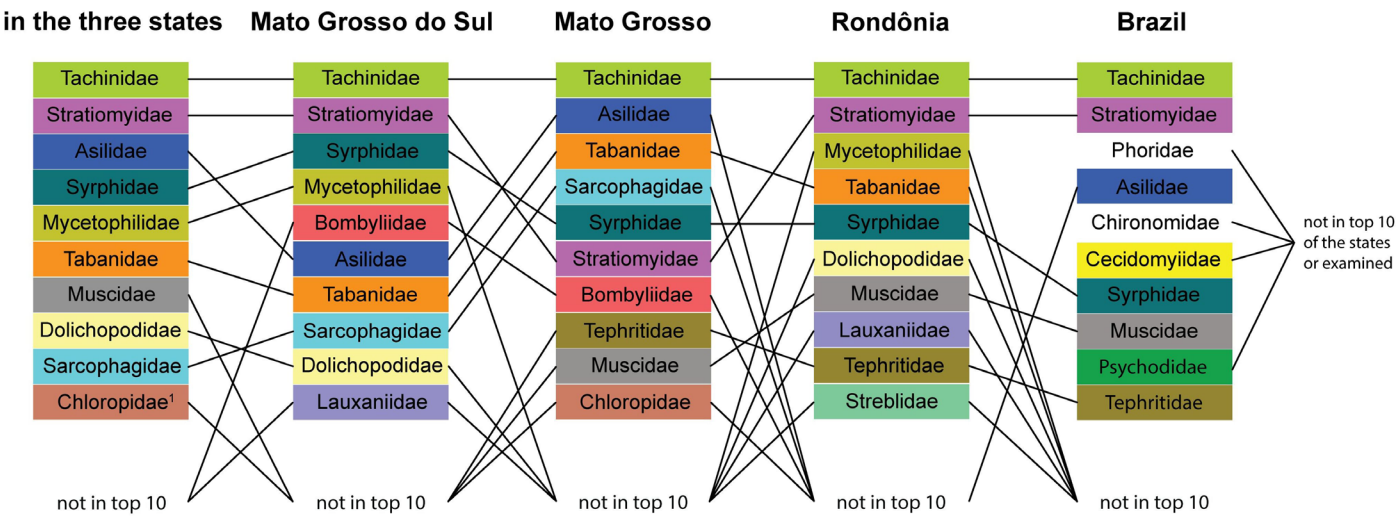


Figure 9 Comparison of generic richness rankings of the top 10 families collected and identified of Mato Grosso, Mato Grosso do Sul, Rondônia, the three states combined, and Brazil ([1]also includes Lauxaniidae and Tephritidae in the same position, with 24 genera known.). Horizontal lines and bars represent equal ranking; each family is represented by a different color.

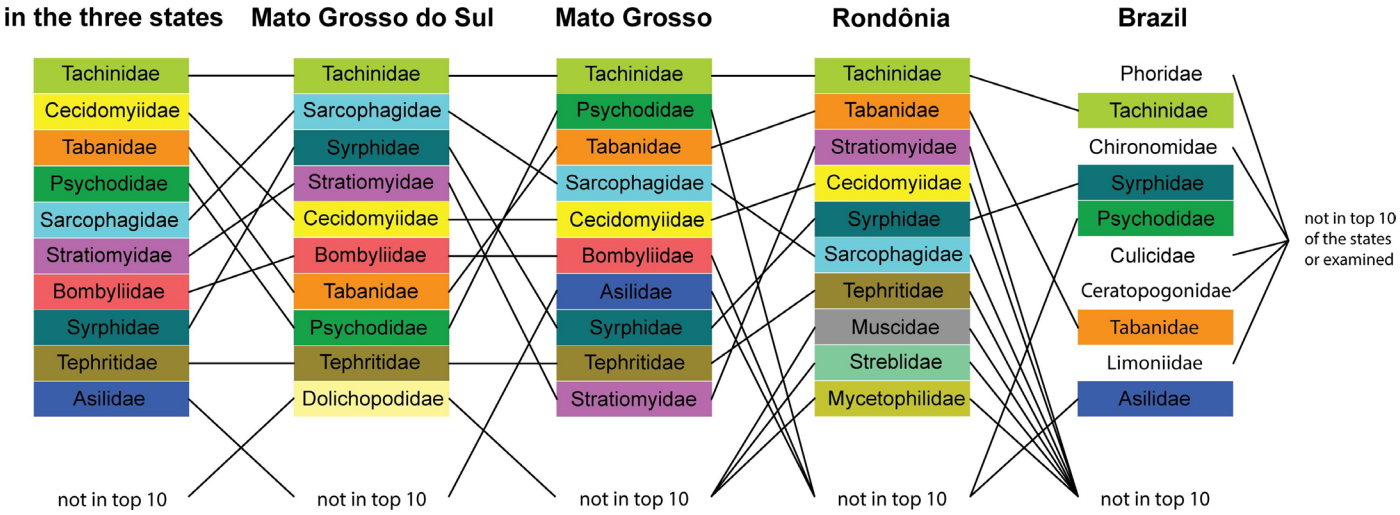


Figure 10 Comparison of species richness rankings of the top 10 families collected and identified of Mato Grosso, Mato Grosso do Sul, Rondônia, the three states combined, and Brazil. Horizontal lines and bars represent equal ranking; each family is represented by a different color.

The comparative study among the samples obtained in the three permanent Malaise traps, placed in the same localities for 12 months, indicated that many species are present in only one of the three traps, even though they have been separated by ca. 150–200 meters from each other. Some species are present in two of the three traps and others in all three collecting points. For example, in Serra da Bodoquena (Mato Grosso do Sul) we had three permanent traps (Malaise traps 4, 5, and 6, Fig. 11). We captured Bombyliidae only in traps 5 and 6, but the Lomatiinae genus *Ylasoia* Speiser, 1920, represented by its single extant species *Y. pegasus* (Wiedemann, 1828), was captured only in trap 5. Other similar cases with different families and localities, for example, were *Amydrostylus triadicophallus* (Mythicomyiidae) (see Lamas et al., 2015) and *Paracalamoncosis brasiliensis* (Chloropidae) (see Riccardi et al., 2018). Both species were found only in two of the three permanent Malaise traps installed in Fazenda Retiro Conceição, a private farm in the municipality of Porto Murtinho, Mato Grosso do Sul, respectively in the traps 31/32 and 31/33. These results highlight the importance of our meticulous sampling approach, which enabled us to obtain impactful outcomes for documenting the biodiversity associated to each surveyed area.

During three years (2011-2013), we drove most of our efforts toward curatorial procedures (collecting, processing, logistics, and identifying material). As a result, only five articles including material from the SISBIOTA-Diptera were published during this period. The scientific production increased exponentially after the end of the project in early 2014. In the last nine years, from 2014 to 2022, 101 articles have been published (Fig. 12). In total, from 2012 (the year of the first publication) until June 2023 (the date of submission of the present study), 111 papers resulting from the SISBIOTA-Diptera have been published associated with 46 families of Diptera, one family of Psocodea: Psocoptera (Silva-Neto et al., 2014), and one family of Hymenoptera (Onody and Penteado-Dias, 2019; Santos et al., 2019, 2021) (see Suppl. File 3 for details of all publications). Among the families of Diptera, the five best-represented in the resulting publications were Cecidomyiidae, Chironomidae, Sarcophagidae, Tachinidae, and Asilidae/Stratiomyidae, with 15, 11, 9, 8, and 5 articles, respectively (Fig. 13).

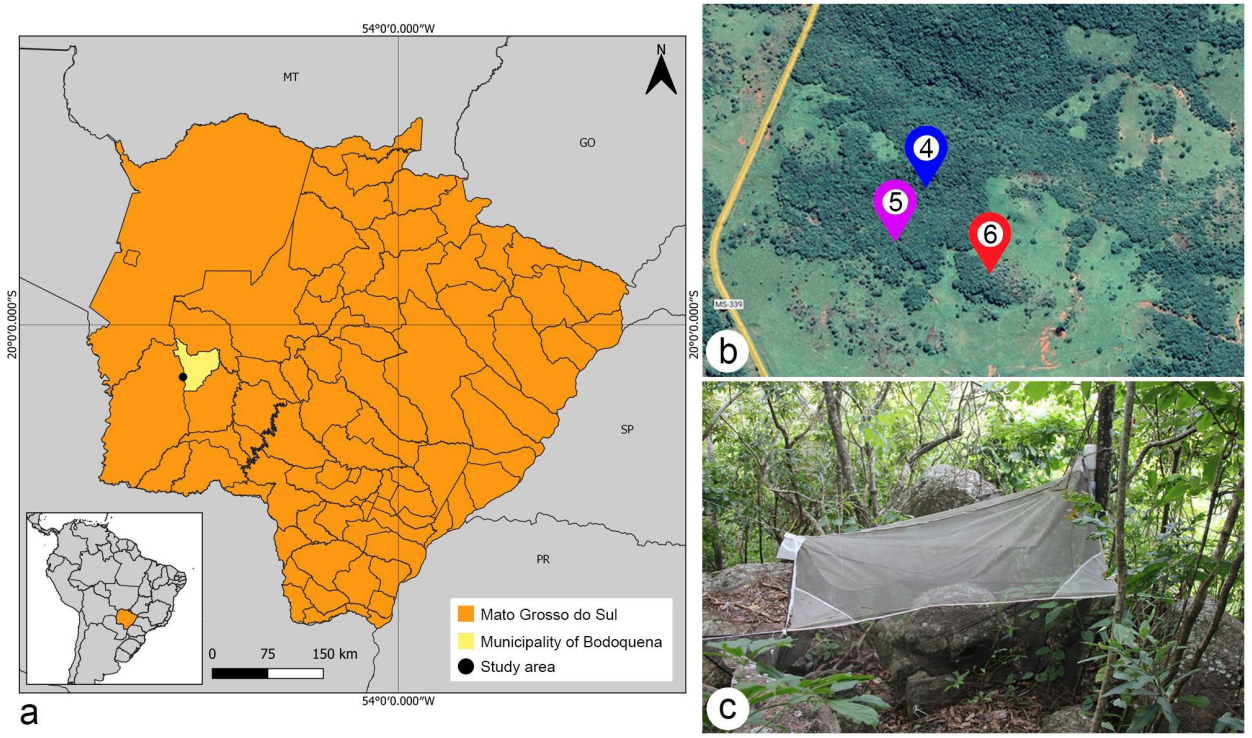


Figure 11 Map of the area of study in a private site in Bodoquena, Mato Grosso do Sul. (a) limits of all municipalities of the state, highlighting the limits of Bodoquena and the sampling site; (b) satellite image of Fazenda Califórnia, Serra da Bodoquena, showing the sampling points where Malaise traps 4, 5, and 6 were installed; (c) Malaise trap number 6 installed in a seasonal decidual forest fragment.

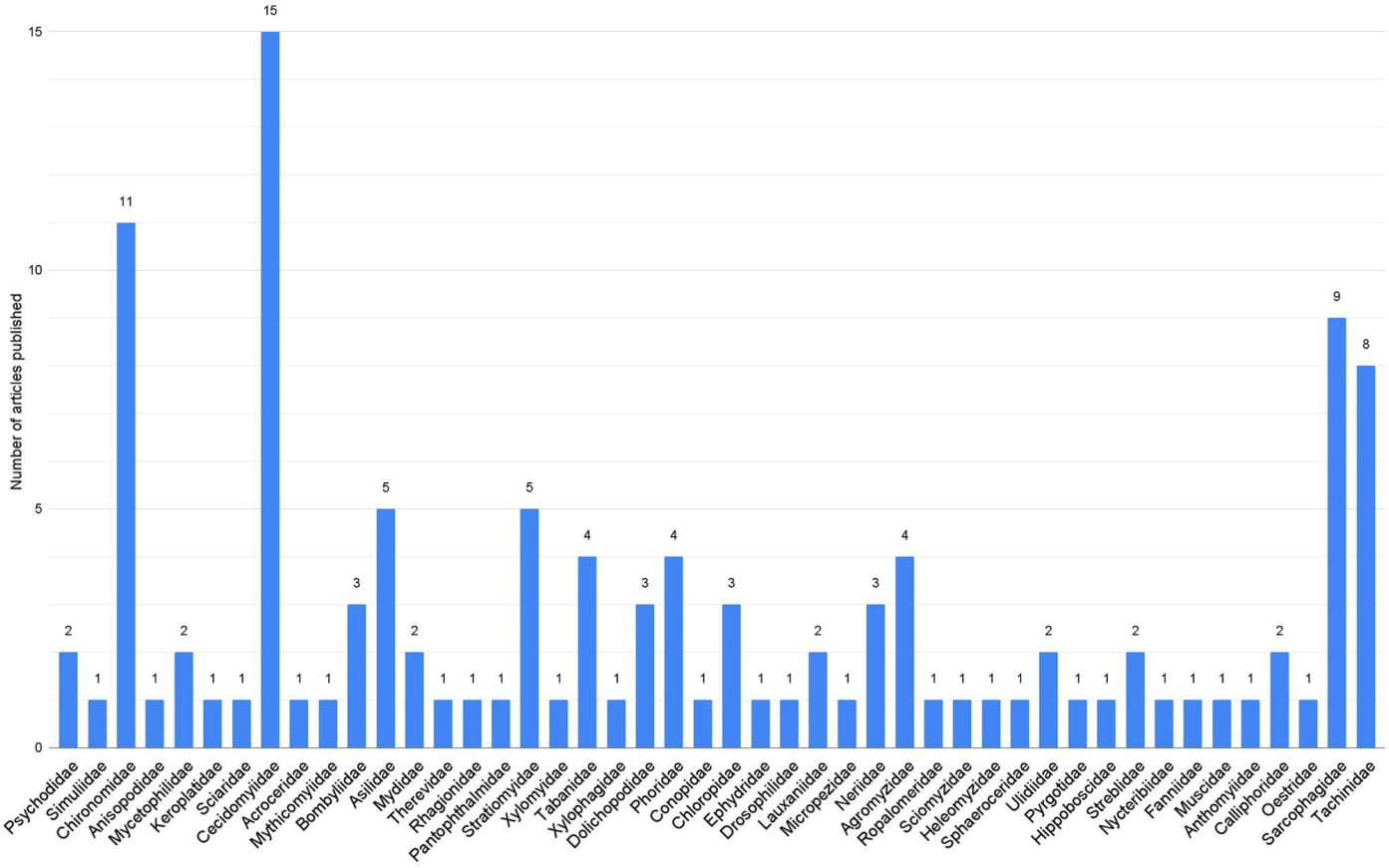


Figure 12 Number of articles per Diptera families resulting from the SISBIOTA-Diptera published between the first publication in 2012 and 2022.

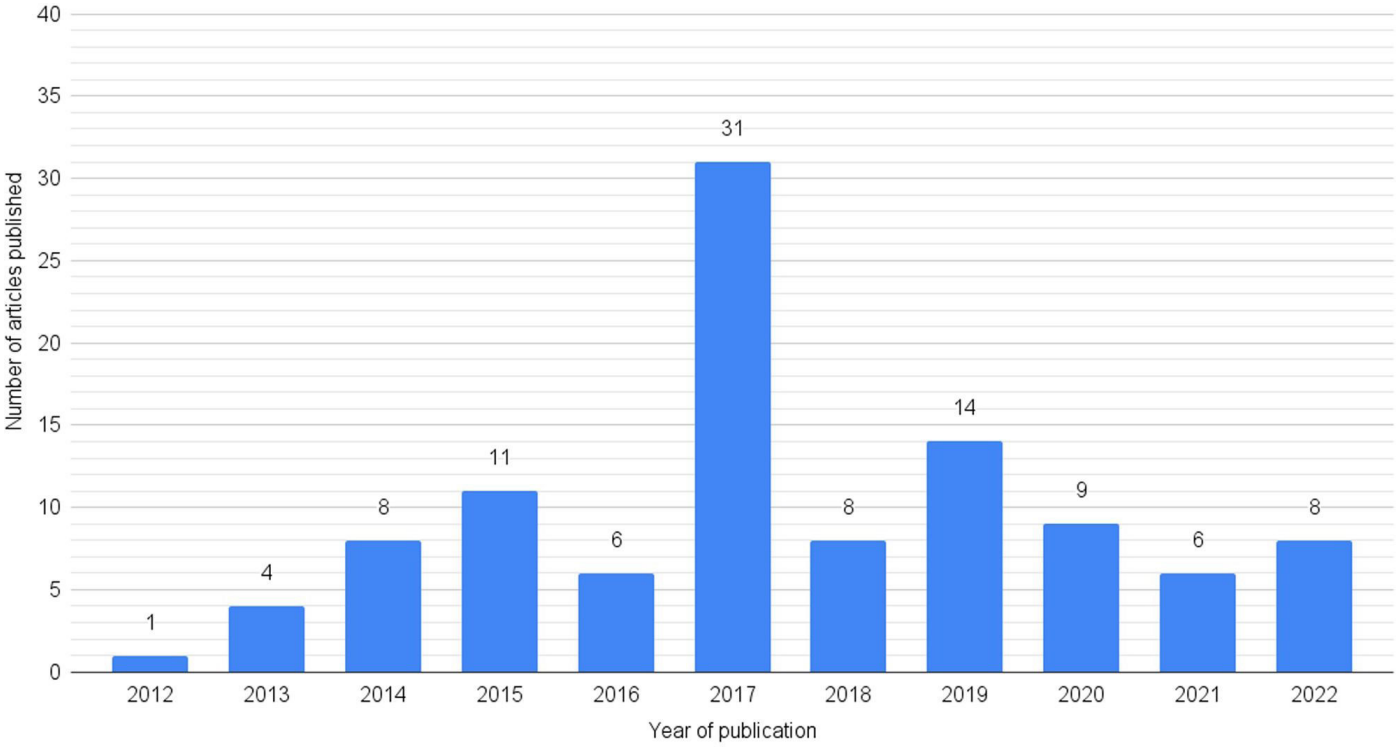


Figure 13 Number of articles resulting from the SISBIOTA-Diptera published between 2012 and 2022 (2023 is still in course, so it was not included in the graph).

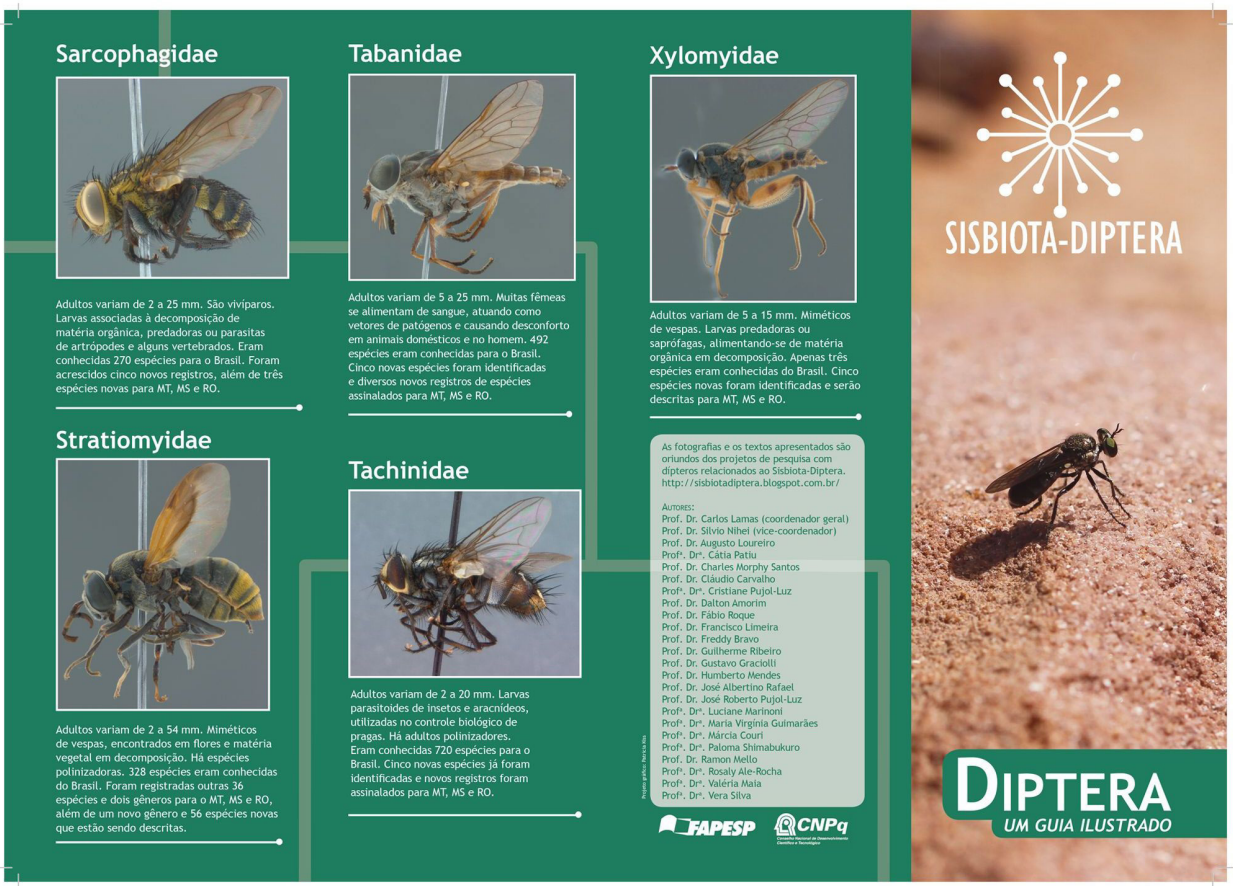
As expected, the vast majority of the studies referred to the description of new taxa, which was, indeed, one of the main goals of our long-term survey. In total, 95 new species and three new genera of Diptera were described, as well as one new species of Psocodea and three of Hymenoptera in the publications derived from the SISBIOTA-Diptera (see Suppl. File 4). In terms of new taxa described, the five best-represented families of Diptera were Agromyzidae, with 19 new species, followed by Cecidomyiidae, with 18, Chironomidae, with 10, Tachinidae, with 9, and Sarcophagidae, with 5 new species described. We expect a continuously growing number of papers published in the following years since a significant part of the samples is now curated and with the experts.

An exciting aspect of projects such as the SISBIOTA-Diptera is their potential to impact taxonomic studies for decades. The processed and identified material will lead to further studies, publications, and results in the coming years as long as more specialists begin working on specific groups. It is also important to point out that the analysis of the number of papers published by year (Fig. 12) indicates that the most productive period by this research team occurred between the 6th and the 8th year after the project started, which demonstrates the peculiarity of these studies on biodiversity (mainly on systematics and taxonomy) when compared to other areas of science. When comparisons are made with similar projects dealing with terrestrial invertebrates, also funded by The Fundação de Amparo à Pesquisa do Estado de São Paulo—FAPESP—(the São Paulo Research Foundation), Noll et al. (2022) showed that there is a pattern in which the peak production in terms of publications takes place from the third to the seventh year from the beginning of each project (whose average duration is about five years), with about 50% of all articles being published within the duration of each project. The complexity of studying a megadiverse insect order, which required building a research network with different skills on Diptera taxonomy, together with the long period of collecting, sorting, and mounting the collected specimens, may explain the long period with higher performance on publishing results. In this sense, besides the published studies, one of the most important legacies of this project is the resulting specimen collection. This material constitutes a solid base for systematics, biogeographic, taxonomic, ecological, morphological, and molecular studies for many generations of entomologists.

In addition to the impressive numbers of specimens collected for each family and publications with dozens of new taxa, over 20 projects (including PhD, Master's and undergraduation theses) benefited from the material of the SISBIOTA-Diptera. In addition, there are many other ongoing studies.

The SISBIOTA-Diptera is also greatly concerned with outreach and scientific literacy to a broader audience. These outreach initiatives included publicizing descriptions of expeditions with photographs of the fieldwork, and highlights of the scientific publications, PhD and Master's theses defenses on social networks and websites (e.g., Facebook: https://www.facebook.com/sibiotadipt; Twitter: https://twitter.com/sisbiotadiptera; and Blogspot: http://sisbiotadiptera.blogspot.com/). Moreover, there is a showcase made of drawers of insects collected in the context of the project as part of the exhibit of MZUSP, aiming to make available to the general public some of the main results of this study and its importance to increase our knowledge of biodiversity. In order to contribute to the increase of knowledge on the diversity of flies, a pamphlet presenting the habitus and biology of some Diptera families (Fig. 14) was also prepared and distributed to undergraduate students and the general public that visited the MZUSP's exhibit. These outreach activities have also been an opportunity to increase the awareness about the extent of insect diversity and need to protect threatened biomes such as the Amazon forest, Cerrado, and Pantanal.

Undoubtedly, the SISBIOTA-Diptera project has had an impact in bridging gaps in the knowledge of Neotropical biodiversity by producing noteworthy results and perspectives for insect biodiversity studies, investing in human resources to address the current biodiversity crisis, and creating public awareness about the importance of flies.



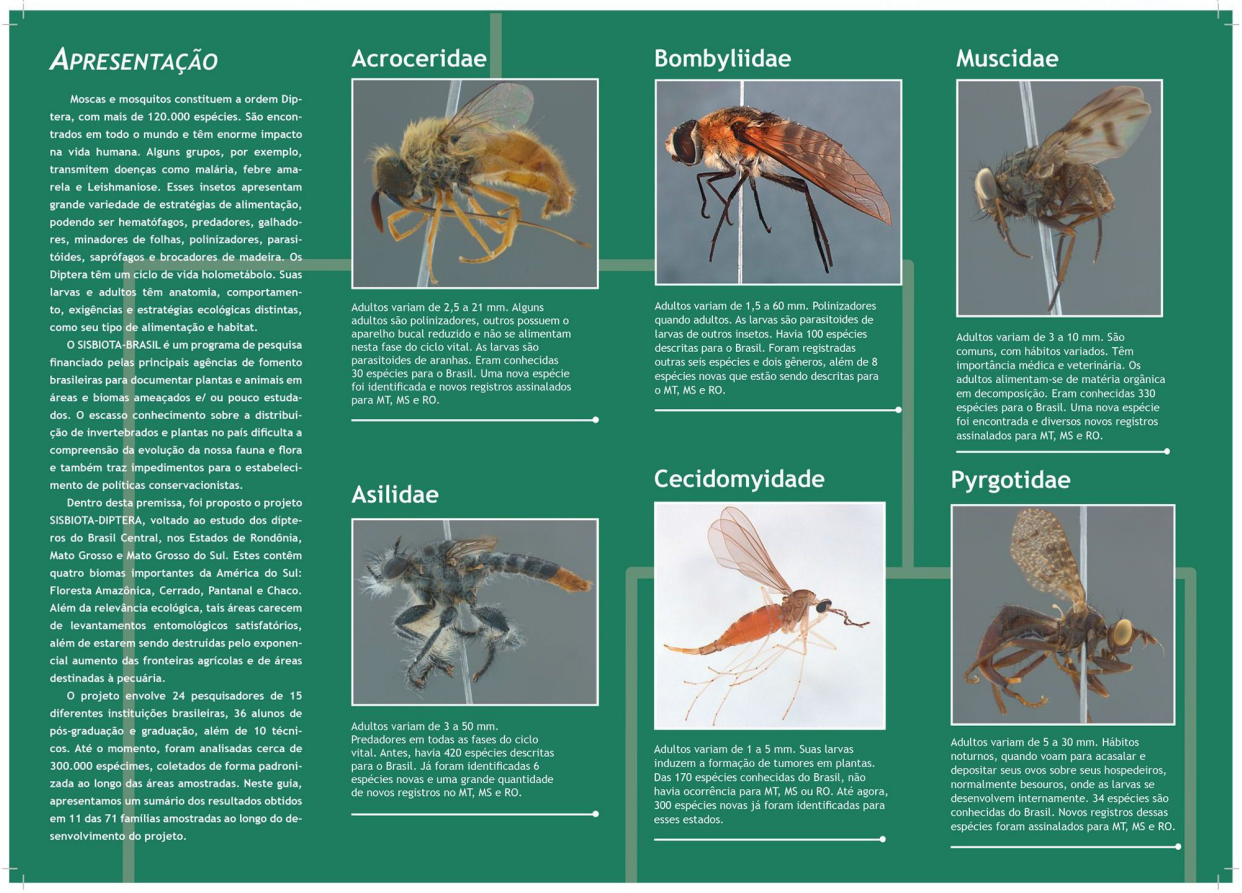


Figure 14 Outreach pamphlet of the SISBIOTA-Diptera, produced in 2015, highlighting the main results of 11 out of over 60 families reported from the material collected during the project.

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Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Author contribution statement

CJEL and SSN contributed to the study conception and design. The original draft of the text and the figures were prepared by CJEL, DAF, RLF, and SSN. Material preparation, data collection, analysis were performed by CJEL, DAF, RLF, DMCA, RAR, DSA, MXA, SA, LB, CFB, FB, JC, RSC, AMCN, BMC, MSC, CJBC, RVPD, AVGF, LMF, CAG, LHGA, MMG, GG, FMG, ALH, TKK, LLM, FLO, VCM, LM, RLM, CAMP, MNM, SSO, CP, BP, CVAPL, JRPL, JAR, PRR, JPVR, FOR, MAMS, MDS, CMDS, JRS, MS, PHFS, VCS, DCSP, AMSN, AC, VRS, MVUG, SW, CY, SSN. All authors contributed with the reviewing and editing of previous versions of the manuscript and have read and approved the final version.

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Supplementary material

The following online material is available for this article:

Supplementary File 1 - Complete locatity data of the sampling site_SISBIOTA-Diptera.

Supplementary File 2 - Researchers involved with the SISBIOTA-Diptera.

Supplementary File 3 - List of publications resulting from the SISBIOTA-Diptera.

Supplementary File 4 - List of new taxa resulting from the SISBIOTA-Diptera long-term survey.

Supplementary File 5 - Genera and species diversity and new records per family and per state.