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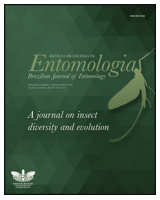

A Scientometric Approach to the Taxonomy of Brazilian Plecoptera: An Overview of Data

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ABSTRACT

The order Plecoptera comprises nearly 4,400 species of freshwater insects known for their specific temperature requirements. In Brazil, there are 207 valid extant species, with 172 (83%) being endemic, and particularly the genus *Anacroneuria* is well-represented. This study aims to present a comprehensive overview of the taxonomy of Brazilian Plecoptera using a scientometric approach. Initially, European authors dominated the taxonomy, describing 67 species by the mid-20th century, but Brazilian researchers, notably Claudio Gilberto Froehlich, have made significant contributions, describing 82 species. Type-specimens of Brazilian species are mostly held in Brazilian institutions, with the MZSP in São Paulo housing the majority (79.8%). São Paulo is the state with the highest number of species (67), followed by Rio de Janeiro (47) and Santa Catarina (47). The states of Alagoas, Paraíba, and Rio Grande do Norte have no recorded Plecoptera species. Among Brazilian terrestrial biomes, the Atlantic Forest exhibits the highest number of species, with 140 known species, followed by the Brazilian Savanna (57). The Hydrographic Region of Southeast Atlantic is that with the largest number of species (82). Limited data exist on the immature stages of Plecoptera across most genera, representing only a quarter of the current diversity in Brazil. Additionally, only 9.7% of the species have available molecular sequence data. Despite these challenges, the Plecoptera in Brazil demonstrate remarkable species diversity, with a significant proportion of endemism. Both European and Brazilian researchers have played crucial roles in advancing the taxonomy and understanding of this fascinating group of insects.

Introduction

Stoneflies, as the insects of the order Plecoptera are known, are a small group of aquatic insects that encompasses nearly 4,400 species distributed worldwide, except for Antarctica (DeWalt and Ower, 2019; DeWalt et al., 2023). Belonging to the larger group of Pterygota, specifically the clade Neoptera, Plecoptera includes insects capable of flexing and folding their wings over their bodies (Gullan and Cranston, 2010). Although the precise relationship between Plecoptera and other neopteran insects is still a subject of discussion (Beutel et al., 2014), recent phylogenetic studies have provided support for Plecoptera as the sister group to a clade consisting of most Polyneoptera, excluding Dermaptera and Zoraptera (Misof et al., 2014; Wipfler et al., 2019). Polyneoptera, in turn, is distinguished by insects with hind wings that feature a broad, fan-like spread (Gullan and Cranston, 2010).

According to Letsch et al. (2021), the observed biogeographical patterns in extant Plecoptera species are the result of long-distance terrestrial dispersal, suggesting that the distribution of the group has been significantly influenced by climate change. The earliest known ancestors of Plecoptera date back to approximately 265 million years, indicating that these insects likely inhabited the ancient supercontinent of Pangea. As Pangea began to break apart around 200 million years ago, the resulting climate changes played a significant role in shaping the evolution of families and extant Plecoptera species (Letsch et al., 2021).

Numerous Plecoptera species inhabit specific and narrow temperature ranges, making them stenothermic organisms that are highly influenced by natural temperature fluctuations within their habitats (Sivec and Yule, 2004). These insects play a crucial role in freshwater ecosystems, serving as important links in trophic transfers and performing various ecosystem services, such as organic matter processing and nutrient cycling (Stewart and Stark, 2002). Due to the sensitivity of their larvae, Plecoptera, along with other sensitive aquatic insect taxa such as Ephemeroptera and Trichoptera, are integral to biomonitoring systems in regions where the taxonomy of the order is well-established (Cheney et al., 2019). Adults are typically found in riparian vegetation or on rocks near streams, and their presence and abundance are greatly influenced by habitat degradation and loss in aquatic environments (Hynes, 1976).

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Since the earliest reports of Plecoptera in South America (e.g., Burmeister, 1839; Pictet, 1841) and the initial publications by South American authors (Froehlich, 1969), over 600 species have been described across six families: Austroperlidae, Diamphipnoidae, Eustheniidae, Gripopterygidae, Notonemouridae, and Perlidae (Pessacq et al., 2019). In Brazil, the recorded species belong to only two families: Gripopterygidae and Perlidae (Fig. 1), encompassing nine documented genera and over 200 species (Lecci and Duarte, 2023). The genera of Gripopterygidae are primarily distributed along the Brazilian Atlantic coast, including *Gripopteryx* Pictet 1841, *Guaranyperla* Froehlich 2001, *Paragripopteryx* Enderlein 1909, and *Tupiperla* Froehlich 1969. On the other hand, the genera of Perlidae are found throughout the country, including *Anacroneuria* Klapálek 1909, *Macrogynoplax* Enderlein 1909, *Kempnyia* Klapálek 1914, and *Enderleina* Jewett 1960 (Lecci and Duarte, 2023). The monotypic genus *Onychoplax* Klapálek 1914 (*O. limbatella* Klapálek) lacks precise collection location information in Brazil, and its distribution is uncertain (Klapálek, 1916; Froehlich, 2008; Stark et al., 2009).

To thoroughly analyze the available data on Plecoptera taxonomy in Brazil, we employed a scientometric approach. The primary objective of this analysis was to deepen our understanding of the historical context while identifying significant publications, influential researchers, relevant research institutions, and collaborations that have played a pivotal role in advancing the taxonomy of this order. Simultaneously, the scientometric approach facilitated the identification of research gaps, emerging trends, and areas that warrant further investigation.

Our study builds upon recent scientometric studies that have focused on Brazil's insect fauna, with specific attention given to the orders Ephemeroptera (Shimano et al., 2013), Odonata (Miguel et al., 2017), Trichoptera (Santos et al., 2020), and Neuroptera (Machado and Martins, 2022). In the context of Plecoptera taxonomy in Brazil, we provide a historical overview starting from the earliest species descriptions in 1839 and acknowledge the invaluable contributions of Professor Claudio Gilberto Froehlich, whose taxonomic studies on Plecoptera have shaped our understanding of this group since the 1960s. This contribution also serves as a tribute to his significant research. With a particular focus on Brazil, our aim is to shed light on the practical factors that have facilitated the expansion of knowledge about Plecoptera within the country.

Figure 1 Plecoptera fauna of Brazil: selected species from the Perlidae family - a) *Anacroneuria* sp., b) *Kempnyia neotropica*, and Gripopterygidae family - c) *Gripopteryx pilosa*, d) *Gripopteryx cancellata*, e) *Gripopteryx* sp., f) *Tupiperla tessellata*, g) *Guaranyperla sp.* Photographs by ©Frederico F. Salles.

Material and methods

All taxonomic data analyzed in this study were compiled from the specialized literature on Brazilian Plecoptera published between 1839 and 2023. These references are available through the Taxonomic Catalog of the Fauna of Brazil (*Catálogo Taxonômico da Fauna do Brasil* - CTFB) website project (http://fauna.jbrj.gov.br), specifically, the section focused on Plecoptera managed by Lecci and Duarte (2023). The initial point for data compilation was Froehlich's 'Catalogue of Neotropical Plecoptera', which provides detailed information on Neotropical species until 2010 (Froehlich, 2010). The compiled information presented here includes the following data: (i) author(s): the author(s) responsible for the species description or first record; (ii) year: the year in which the species was described or first recorded (if subsequently reported); (iii) journal/book title and volume: the title and volume of the journal or book containing the original description and first record (if applicable); (iv) endemism status: indication whether the species is endemic to Brazil or also found in other countries; (v) distribution: information about the species' distribution across different biomes, hydrographic regions (HR), and specific national states within Brazil; (vi) described life stages: descriptions of the life stages for which the species has been described; (vii) institution housing type-specimens: the institution where the type-specimens (representative specimens used for species description) are housed; (viii) author nationality, gender, and ethnicity: the nationality, gender, and ethnicity of the author(s) responsible for the species description; (ix) nucleotide data availability: indication whether nucleotide data (genetic sequence data) for the species is available. The data is organized in an Excel spreadsheet with four tabs, labeled as "Supplementary material 1", which serves as the foundation for the analyses presented in the study. All color palettes used in graphics are adapted for people with dyschromatopsia.

In this study, we have considered currently valid species that have been officially published, species accepted for publication, or those included as part of a thesis. Species with unknown distribution (e.g., *Onychoplax*) were included as country records but without specific assignment to biomes [as defined by the *Instituto Brasileiro de Geografia e Estatistica* (IBGE, 2019)], HR [as defined by *Agência Nacional de Águas e Saneamento Básico* (ANA, 2021)], or national states.

To calculate the percentage of endemic species, we determined the ratio between the number of species recorded and the number of endemic species for the country, each biome, HR, and state. For the calculation of the total number of species assigned to each author, all authors associated with the description of a particular species were considered, not only the first author. The overall rate of species description was calculated based on the number of species described between 1839 and 2023 (a span of 184 years). We also considered the 10-year interval from 1839 to 2023 to identify the highest and lowest rates of species descriptions. For the number of papers published in scientific periodicals, we analyzed the period from 1969 to 2023, which corresponds to the time when Brazilian researchers began studying Plecoptera in Brazil.

Finally, within the section titled 'History of the Studies on Brazilian Plecoptera', the subsections '19th Century' and 'Early to Mid-20th Century' feature unpublished contributions by Professor Dr. Claudio Gilberto Froehlich, generously shared with the authors.

Acronyms of the Brazilian collections: CZMA, Zoological Collection of Maranhão, Universidade Estadual do Maranhão, Maranhão State; DZRJ, Entomological Collection Professor José Alfredo Pinheiro Dutra, Universidade Federal do Rio de Janeiro, Rio de Janeiro State; DZUP, Entomological Collection "Padre Jesus S. Moure", Universidade Federal do Paraná, Paraná State; INPA, Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas State; MNRJ, Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro State; MZSP, Museu de Zoologia, Universidade de São Paulo, São Paulo State; UFMT, Regional Entomology Collection, Universidade Federal de Mato Grosso, Cuiabá, Mato Grosso State; UFVB, Museu de Entomologia, Universidade Federal de Viçosa, Viçosa, Minas Gerais State; CLBA, Aquatic Insects Collection, Aquatic Biology Laboratory, Universidade Estadual Paulista, Assis, São Paulo State.

Results and discussion

An overview on Brazilian Plecoptera

Currently, the taxonomy of Plecoptera in Brazil encompasses two families, nine documented genera, and 207 valid species, from which 172 species (83%) are endemic (Table 1). Among the families, Perlidae is the most diverse with a total of 149 species (72%), followed by Gripopterygidae with 58 recorded species (28%). The genus *Anacroneuria* is the most diverse with 98 recorded species, followed by *Kempnyia* with 36 species, *Tupiperla* with 25 species, and *Gripopteryx* with 17 species (Table 1). The remaining genera collectively contribute with a total of 31 species. Interestingly, despite being the most diverse genus, *Anacroneuria* exhibits the lowest percentage of endemic species in Brazil, standing at 75.5%. Brazil hosts five species of *Enderleina* that are endemic, whereas an additional five species are officially reported for Venezuela (Derka et al., 2019; Hamada and Silva, 2019). Three genera, *Kempnyia*, *Guaranyperla*, and *Onychoplax* are considered endemic to Brazil. However, it is worth noting that the monotypic genus *Onychoplax* (*O. limbatella* Klapálek), supposedly recorded in Brazil, lacks precise collection location information on its label, and its distribution is uncertain (Klapálek, 1916; Froehlich, 2008; Stark et al., 2009). Other four species are labeled with 'Brazil' as the collection location (*Anacroneuria annularis* Pictet, *Kempnyia brasiliensis* Pictet, *K. klugii* Pictet, and *K. sordida* Klapálek) while eight species have record information limited to the state level without a specific locality (*A. diaphana* Klapálek, *A. hyalina* (Pictet), *A. lacunosa* (Navás), *A. laminata* Klapálek, *A. longicauda* (Pictet), *A. melzeri* (Navás), *A. parilobata* Klapálek, *A. ypsilon* Klapálek) (Supplementary material 1).

Table 1
Families, genera, total number of species, and endemic species of Plecoptera recorded from Brazil, respectively. The number in parentheses indicates the number of species on the right and the percentage in relation to the total number of species on the left.

Families	Genera	Number of recorded species	Endemic species	% endemic species
Gripopterygidae (58 spp.; 28%)	*Gripopteryx*	17	13	76.5%
	Guaranyperla	3	3	100%
	Paragripopteryx	13	12	92.3%
	Tupiperla	25	21	84%
Perlidae (149 spp.; 72%)	*Anacroneuria*	98	74	75.5%
	Enderleina	5	5	100%
	Kempnyia	36	36	100%
	Macrogynoplax	9	7	77.8%
	Onychoplax	1	1	100%
Total		**207**	**172**	**83%**

The 'Catalogue of Neotropical Plecoptera' by Froehlich (2010) provides the most comprehensive list of Plecoptera species from the Neotropical Region, including 147 valid species from Brazil. Since Froehlich's publication, 61 new species have been described in Brazil (Table 2), and five new country records have been reported (Novaes and Bispo, 2016; Duarte, 2019; Menezes et al., 2020; Almeida et al., 2023). Furthermore, three species have been designated as junior synonyms (Froehlich, 2011b; Almeida and Bispo, 2020; Duarte et al., 2022), and three species' records have been revised (Derka et al., 2019; Hamada and Silva, 2019). The rate of species reported (either new species or new records) in Brazil has been relatively low, averaging 1.1 species per year since the first Brazilian species was described in 1839. This low rate is likely related to the seven decades during which no species were reported from Brazil (Fig. 2a). However, starting from 1989, the average rate has significantly increased, reaching 2.3 species per year (1989-1998), 3.9 species per year (1999-2008), and peaking at 4.7 species per year in the last decade (2009-2018) (Fig. 2a). The highest number of species reported in Brazil was in 2011, with 12 species (Fig. 2b).

History of the studies on Brazilian Plecoptera

19th century

The German Argentine zoologist Karl Hermann Konrad Burmeister (1807-1892) played a significant role in the taxonomy of Plecoptera in Brazil. He described the first Brazilian species in 1839, which was well after the opening of ports to friendly nations by Prince-Regent D. João when he arrived in Brazil in 1808. Prior to that, the country had been closed to foreign naturalists to visit and make collections due to the Portuguese government's fear that knowledge about Brazil's riches would awaken the greed of other nations. Interestingly, Portugal itself did not show much interest in studying the nature of Brazil, except for the noteworthy expedition by the Brazilian-born Alexandre Rodrigues Ferreira from 1783 to 1792. This expedition, sponsored by Queen D. Maria I, is detailed in the work '*Viagem Filosófica pelas capitanias do Grão Pará, Rio Negro, Mato Grosso e Cuiabá*' (Carvalho, 1983). An exceptional permission for foreigners to collect in Brazil was granted to the German naturalist Johann Centurius Hoffmannsegg in 1801 by the Prince-Regent Dom João, highlighting the benefits of being associated with the monarchy. The collections in Brazil were made by Hoffmannsegg's assistants.

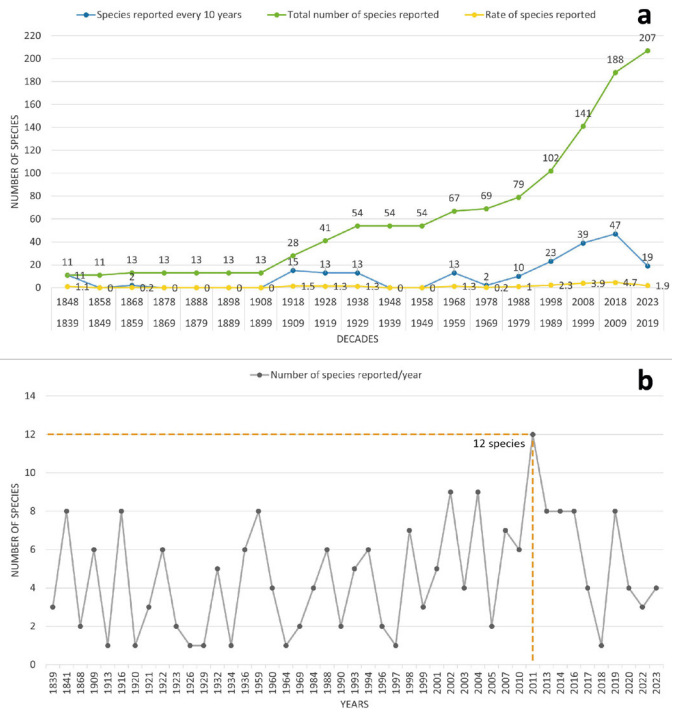


Figure 2 The numbers of Brazilian Plecoptera. a) cumulative count of reported species and the rate of species descriptions over 10-years from 1839 to 2023; b) yearly distribution of reported species.

Table 2
Plecoptera species described and reported for Brazil, including synonyms and revised records for the country after the 'Catalogue of Neotropical Plecoptera' by Froehlich (2010).

Species described for Brazil after Froehlich' 2010 list
• *Gripopteryx caparao* Gonçalves, Novaes & Salles, *G. clemira* Lecci & Froehlich, *G. japi* Lecci & Froehlich,
• *Paragripopteryx dasalmas* Duarte, Calor & Bispo, *P. intervalensis* Bispo & Lecci, *P. kapilei* Bispo & Lecci, *P. ogum* Duarte, Calor & Bispo, *P. paranapiacabae* Bispo & Lecci
• *Tupiperla am&ae* Bispo & Lecci, *T. amorimi* Froehlich, *T. barbosai* Avelino-Capistrano & Nessimian, *T. bispoi* Duarte, Lecci & Calor, *T. froehlichi* Bispo & Lecci, *T. guariru* Duarte, Bispo & Calor, *T. pessacqi* Duarte, Novaes & Bispo, *T. pinhoi* Duarte, Novaes & Bispo, *T. sepeensis* Novaes & Bispo, *T. serrulata* Duarte, Novaes & Bispo, *T. ubuntu* Duarte, Novaes & Bispo, *T. zwicki* Duarte, Novaes & Bispo
• *Anacroneuria amargosa* Righi-Cavallaro & Froehlich, *A. bahiensis* Righi-Cavallaro & Lecci, *A. calori* Duarte & Lecci, *A. corae* Bispo & Novaes, *A. froehlichi* Miguel, Almeida & Bispo, *A. helenae* Deprá & Bispo, *A. iquazu* Novaes & Bispo, *A. itatiaiensis* Baldin, Bispo & Novaes, *A. kariri* Righi-Cavallaro & Lecci, *A. leccii* Carvalho, Almeida & Lima, *A. lencoensis* Righi-Cavallaro & Lecci, *A. mantiqueirae* Froehlich, *A. meloi* Bispo & Novaes, *A. mineira* Novaes & Bispo, *A. otafroehlichi* Righi-Cavallaro & Lecci, *A. paprockii* Novaes & Bispo, *A. patioba* Almeida & Duarte, *A. piti* Gonçalves, Novaes & Salles, *A. quilombola* Righi-Cavallaro & Froehlich, *A. rotunda* Gonçalves, Novaes & Salles, *A. ruschii* Novaes, Bispo & Gonçalves, *A. saofrancisco* Novaes, Vilela, Lopez & Ferreira, *A. simulans* Froehlich, *A. singela* Duarte & Lecci, *A. singularis* Righi-Cavallaro & Lecci, *A. tabatae* Froehlich, *A. terere* Righi-Cavallaro & Lecci, *A. xokleng* Novaes & Bispo, *A. zantedeschia* Rippel, Novaes & Krolow
• *Enderleina bifasciata* Hamada, Silva & Pedroza, *E. castro* Almeida & Bispo, *E. plagata* Hamada & Silva, *E. yoshikii* Hamada & Silva
• *Kempnyia couriae* Avelino-Capistrano, Barbosa & Takiya, *K. ocellata* Froehlich, *K. pinhoi* Froehlich, *K. pirata* Froehlich, *K. puri* Avelino-Capistrano, Souza & Nessiman, *K. tupinamba* Froehlich, *K. kaingang* Froehlich
• *Macrogynoplax quadrispina* Menezes, Boldrini & Novaes
Records for Brazil after Froehlich' 2010 list
• *T. misionera* Froehlich – reported from Brazil [by Novaes and Bispo, 2016]
• *A. caraca* Stark and *A. cruza* Stark – reported from Brazil [by Menezes et al., 2020]
• *T. flinti* Froehlich – reported from Brazil [by Duarte, 2019]
• *M. yupanqui* Stark – reported from Brazil [by Almeida et al., 2023]
Species synonymized after Froehlich' 2010 list
• *K. barbiellinii* (Navás) – synonym of *K. flava* [by Froehlich, 2011b]
• *K. petersorum* Froehlich – synonym of *K. neotropica* [by Almeida and Bispo, 2020]
• *P. crassila* (Jewett) – synonym of *P. klapaleki* [by Duarte et al., 2022]
Revision of records for Brazil after Froehlich' 2010 list
• *E. preclara* Jewett – not recorded for Brazil [by Derka et al., 2019]
• *E. flinti* Stark and *E. yano* Stark – not recorded for Brazil [by Hamada and Silva, 2019]

Another notable work on the nature of Brazil was the '*Historia Naturalis Brasiliae*' by Piso and Margrave (1648) and Piso (1948), which resulted from the Dutch occupation of the Northeast in the 17th century.

The three species described by Burmeister, *Semblis gracilis*, *Perla polita*, and *P. dilaticollis*, are found in Vol. 2 (1839) of his *Handbuch der Entomologie* (Handbook of Entomology), published between 1832 and 1855. They were in the Gymnognatha Order, Semblodea Family. The genus *Semblis* was named by Fabricius (1775) for *Phryganea phallaenoides* Linnæus, 1758, which is now classified under Trichoptera: Phryganeidae. The three species are from 'Brasilien' (Brazil) and, even on the original labels, the collector's name is not included. It is likely that these specimens were collected in Rio de Janeiro or nearby areas, as most foreigners arrived in that city. Burmeister later visited the states of Rio de Janeiro and Minas Gerais between 1850 and 1852. In 1857, he moved to Argentina, where he settled, became naturalized, and changed his name to Carlos Germán Burmeister. He was appointed Director of the *Museo Argentino de Ciencias Naturales Bernardino Rivadavia* in 1862 and remained in that position until his death in 1892. During his tenure at the museum, he focused more on paleontology.

François-Jules Pictet de la Rive (1809-1872), a Swiss zoologist and paleontologist, holds a significant position among the authors who contributed to the knowledge of Brazilian Plecoptera. Pictet dedicated his entire career to the Museum of Geneva. In 1841, he published the groundbreaking work '*Histoire Naturelle et Particulière des Insectes Névroptères, Famille des Perlides*'. This two-volume publication consisted of a text volume and a separate volume of illustrations, serving as the first comprehensive study on Plecoptera. Within his work, Pictet meticulously documented 103 species, with 67 of them being described by himself and the remaining 36 described by other authors. He also referenced 28 previously described species that he had not personally observed, some of which might require further validation. In 1843, Pictet released a second volume focused on the '*Famille des Éphémérines*' [Ephemeroptera].

Pictet described eight species from Brazil: *Capnia* (*Gripopteryx*) *cancellata*, and seven in the genus *Perla: P. annularis*, *P. debilis*, *P. hyalina*, *P. longicauda*, *P. brasiliensis*, *P. obscura*, and *P. klugii*. The first four are now classified under the genus *Anacroneuria*, while the last three are assigned to the genus *Kempnyia*. *Perla obscura* was subsequently changed to *P. neotropica* by Jacobson and Bianchi in 1905 (Jacobson and Bianchi, 1905), as it had already been assigned to another species (a preoccupied name). Additionally, *Perla annularis* is *nomen dubium* because the type-specimen lacks the abdomen. Like Burmeister, the Pictet's species have 'Brésil' or 'Brasilien' as their locality. Certain species housed in the Museum of Berlin have their collectors named. For instance, *P. debilis* and *P. obscura* bear the name Sello (or Sellow), while *P. longicauda* is attributed to von Langsdorff, and *P. klugii* to von Olfers. These associations restrict the geographic range of the collections to the Southeast Region (Papavero, 1971). Interested readers can access Pictet's *Histoire Naturelle* books online via the Biodiversity Heritage Library (www.biodiversitylibrary.org) and Google Books (www.books.google.com).

The final noteworthy figure from the 19th century is Friedrich Moritz Brauer (1832-1904), an Austrian entomologist affiliated with the Museum of Natural History in Vienna. Within the institution, he served as the curator of Diptera and Neuroptera and held the position of director (Papavero, 1973). Brauer contributed to the field by describing two species of *Gripopteryx*, *G. reticulata* and *G. tessellata*. It is worth noting that the latter species, now classified as *Tupiperla*, underwent taxonomic reassignment (Froehlich, 1969, 1998). These specimens were collected during the Frigate *Novara* Expedition in Rio de Janeiro. Sponsored by the Austrian imperial government, the expedition embarked from Trieste, which was under Austrian jurisdiction at the time, in April 1857. Its primary objectives encompassed scientific observations and the collection of specimens. On August 5th of the same year, the expedition arrived in Rio de Janeiro, departing on the 31st of that month heading for the Cape of Good Hope and the Indian Ocean.

Early to mid-20th century

Klapálek (1904) documented the male specimen collected in Petrópolis, Rio de Janeiro, as *Gripopteryx cancellata* in the findings of the Hamburg Expedition to the south of South America (*Ergebnisse der Hamburger Magalhaensischen Sammelreise* - 1892/93). Subsequently, in 1905, Jacobson and Bianchi recognized that *Perla obscura* was already a name in use and assigned to Pictet's species the name *Perla neotropica*.

The subsequent noteworthy contributor to the Brazilian fauna is Günther Enderlein (1872-1968), a prolific German entomologist primarily focused on the study of dipterans. Most of his entomological work was conducted during his tenure as the curator of Insects at the Stettin Museum (now Szczecin, Poland). Enderlein published two works that included Brazilian species, Enderlein (1909a, 1909b) [see Zwick (1973)], although many of these specimens were misidentified. Among the valid species identified by Enderlein are *Paragripopteryx klapaleki*, a new name for the aforementioned species *Gripopteryx cancellata* Klapálek (nec Pictet) [see Duarte et al. (2022)], and *Neoperla fuscicosta*, currently classified as *Anacroneuria*.

Nathan Banks (1868-1953) was a renowned North American entomologist who began his career at the USDA (US Department of Agriculture). In 1916, he moved to the Museum of Comparative Zoology at Harvard University. Banks conducted extensive research on various groups of insects, as well as Arachnida. From Brazil, he described two species of *Neoperla*, *N. posticata* in 1913 and *N. remota* in 1920. The former has since been reclassified as *Anacroneuria*, but its status remains uncertain (*species inquirenda*), while the latter was later studied by Stark and reclassified as *Kempnyia*.

In 1916, Navás published his first species from Brazil, *Neoperla egena* (now considered *nomen dubium Anacroneuria egena*). Longinos Navás Ferrer (1858-1938), a Jesuit priest, served as a teacher at the Colegio San Salvador in Zaragoza, Aragon, northern Spain, from 1892. Navás was highly productive in authoring articles on entomology and botany. He was regarded as an expert in Neuroptera (in the broader sense of the term) and received specimens from numerous museums for study, including the *Museu Paulista* (now part of the Museu de Zoologia, Universidade de São Paulo; the specimens examined by Navás are still housed there). Navás' insect descriptions were written in Latin and primarily based on external characteristics, seldom accompanied by illustrations. Unfortunately, during the Spanish Civil War (1936-1939), Zaragoza, including the Colegio San Salvador, suffered bombings, resulting in the loss of a portion of Navás' Collection. He had to flee the city and eventually found himself in a poorhouse in Girona, where he passed away on December 31st, 1938.

František Klapálek (1863-1919) stands as a significant figure in Plecoptera taxonomy. In 1904, this Czech entomologist published the pioneering work that included Brazilian species (as mentioned earlier). Klapálek, in 1896, was the first to emphasize the importance of considering genital characters, especially those of male genitalia, in Plecoptera taxonomy. This innovative approach led Klapálek to revise the genera within Perlidae, particularly *Perla* and *Neoperla*, resulting in the creation of several new genera. Among these, the genera *Anacroneuria*, *Eutactophlebia*, and *Kempnyia* encompassed Brazilian fauna. *Macrogynoplax* Enderlein was also retained but has since been limited in scope. *Eutactophlebia* was later synonymized with *Kempnyia* by Zwick (1983).

Throughout his career, Klapálek worked as a secondary school teacher. He passed away suddenly on February 3rd, 1919. Klapálek bequeathed his collections and library to the Czech Society of Entomology, an organization he had founded. Subsequently, the collection was transferred to the Institute of Zoology at the University of Prague. Prior to his death, Klapálek had been studying the Plecoptera collection of Baron Jean de Sélys Longchamps, a prominent Belgian politician of the 19th century and a distinguished entomologist specializing in Odonata. The insect collections, which included "neuroptera" alongside dragonflies, were partially published, excluding Brazilian species. Klapálek had preliminarily examined specimens from various European museums, assigning names to the species. To prevent their loss, Šámal published them in five parts from 1921 to 1923 in the *Annales de la Societé Entomologique de Belgique*, providing brief descriptions and external characteristics. Parts three to five encompass 33 species of *Anacroneuria*, including 12 from Brazil, ten of which have been redescribed.

Jaromír Šámal (1900-1942), a compatriot and partially contemporary of Klapálek, held the position of Professor at the Technical University of Prague and focused his studies on Ephemeroptera and Plecoptera. During World War II, with the occupation of his country by the Nazis, Šámal joined the Resistance but was eventually captured by the Gestapo and executed. Regarding the Brazilian fauna, he published only one work, describing *Gripoptera brasiliensis*. While the genus was initially considered synonymous with *Gripopteryx*, the species remains valid. Šámal also described a species from Paraguay, *Peltoperla lestagei*. However, since the genus does not occur in South and Central America and the type material is lost, the species is considered dubious.

Lastly, in this brief history, we consider Stanley G. Jewett, Jr. (1917-1991), a North American amateur entomologist who worked as a biologist at the National Bureau of Marine Fisheries and authored 30 papers on Plecoptera. Regarding Brazil, Jewett contributed with three articles. One of them focuses on the *Machris* Expedition in Goiás, where he describes two new species of *Anacroneuria*. The other two articles are more significant. The first one (1959) presents the results of Jewett's study of material collected by Fritz Plaumann and housed at the California Academy of Sciences, covering 15 species, including nine new species of *Anacroneuria*. The second article (1960) mainly deals with material from the Museu Nacional do Rio de Janeiro, Brazil, as well as specimens from Brazil that were held in collections abroad at that time. Notably, Jewett introduces the new genus and species *Enderleina preclara*, with the original type locality attributed to Roraima, Brazil, but later designated as Venezuela by Derka et al. (2019). Unfortunately, the type specimen is lost, although it was believed to be held at the American Museum of Natural History in New York. Jewett often included drawings of the species' genitalia, albeit simplified, focusing mainly on the female terminalia in ventral view for *Anacroneuria*.

Fritz Plaumann (1902-1994), a renowned amateur entomologist of German origin, migrated to Brazil with his parents in 1924. They settled in Nova Teutônia, located west of Santa Catarina State, where Fritz remained until his death. Plaumann compiled extensive collections of entomological material, sending a significant portion to museums abroad, which was the basis for the description of several species of Plecoptera from Brazil. In his locality, he sponsored the construction of a museum that now bears his name, the Museu Entomológico Fritz Plaumann.

Modern age of the Brazilian Plecopterology after the 1960s

From the last third of the 20th century to the present day, Brazilian zoologist Claudio Gilberto Froehlich made extensive contributions to Brazilian plecopterology. Froehlich began his doctoral studies at the *Faculdade de Filosofia, Ciências e Letras* (FFCL) at the Universidade de São Paulo in 1952 and obtained his doctorate in Zoology in 1954 under the supervision of German zoologist Ernst Gustav Gotthelf Marcus (1893-1968), Professor in the FFCL. Prior to studying freshwater macroinvertebrates, Froehlich conducted important research on "land planarians" (e.g., Froehlich, 1955, 1956, 1959, 1967; Froehlich and Froehlich, 1972), as suggested by Professor Marcus, who emphasized the need for taxonomic attention to this understudied group (Carbayo, 2013). Subsequently, Froehlich directed his focus specifically towards Plecoptera, a group that he dedicated his career to studying. In the late 1960s, Froehlich described two new species, *Paragripopteryx anga* Froehlich, 1969, and *P. blanda* Froehlich, 1969, and named the genus *Tupiperla* (Froehlich, 1969), becoming the first Brazilian researcher to publish studies on Brazilian Plecoptera. This keystone study titled "Studies on Brazilian Plecoptera 1. Some Gripopterygidae from the biological station at Paranapiacaba, state of São Paulo" emerged from Froehlich's Associate Professorship Thesis for the FFCL in 1964 (Froehlich, 1964, 1969) and was published in the journal '*Beiträge zur Neotropischen Fauna*' (1956-1971), currently known as 'Studies on Neotropical Fauna and Environment'. Interestingly, another study by Froehlich had already been published in 1960 as part of his postdoctoral studies at Lund University, Sweden, under the supervision of the Swedish zoologist Per Simon Valdemar Brinck (1919-2013) (Froehlich, 1960). In this work, Froehlich introduces several gripopterygids and nemourids from South America (e.g., Argentina, Chile, and Peru), including nine new species. Froehlich joined the faculty at USP in 1952 and remained active even after his retirement, concluding his research activities only in 2019.

Prior to Froehlich's contributions in 1969, taxonomic publications on Brazilian Plecoptera were predominantly led by foreign researchers, reflecting the historical European support for collections in the New World. However, starting from 1984, a significant series of taxonomic and ecological studies were published, largely influenced by Froehlich. Among the 140 species of Plecoptera described in Brazil between 1969 and 2023 (Fig. 2), Froehlich single-handedly described 64 species (31% of the current recorded diversity in Brazil) (Fig. 3). When considering co-authored species, this number increases to 82 species (39.6%) (Table 3). In addition to his taxonomic contributions over the past few decades, Froehlich played a crucial role in training many of the current Brazilian plecopterologists, as well as specialists in other insect taxonomic groups such as Trichoptera, Ephemeroptera, and Diptera. Throughout his career, Froehlich has published approximately 90 papers and has supervised over 60 students at the undergraduate, master's, doctoral, and postdoctoral levels.

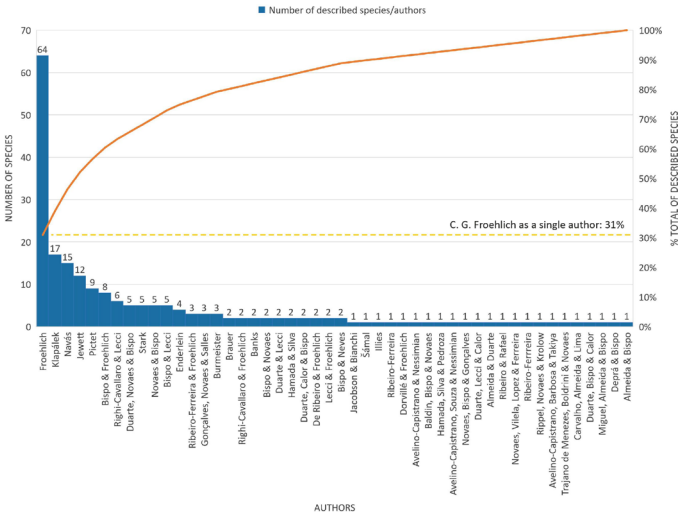


Figure 3 Number of Plecoptera species described for Brazil by author contributions. Cumulative percentage of descriptions represented by the Pareto line (in orange).

In the first decade of the 21st century, Brazilian zoologist Pitágoras da Conceição Bispo made his initial contributions to the ecology and taxonomy of Plecoptera at FFCLRP (Bispo et al., 2002a, 2002b, 2002c; Bispo and Froehlich, 2004a, 2004b, 2004c). Bispo, a student of Froehlich, obtained his doctorate in 2002 and joined the faculty at the Universidade Estadual Paulista (UNESP) in 2004, where he continues to work. Throughout his career, Bispo has authored more than 90 papers on aquatic insects and has described 35 species of Plecoptera (accounting for 16.9% of the Brazilian diversity), some of which were co-authored with Froehlich (Fig. 3). Since starting his studies in Plecoptera, Bispo has actively contributed to training a new generation of Brazilian plecopterologists who are engaged in various research topics.

Currently, eight Brazilian researchers located in different regions are conducting studies on Plecoptera in Brazil. In the North and Center-West Regions, researchers are dedicated to the taxonomy and ecology of perlids: N. Hamada (INPA, Manaus, AM), J.M.F. Ribeiro (MPEG, Belém, PA), K.O. Righi-Cavallaro (UFMS, Campo Grande, MS), and L.S. Lecci (FAR, Rondonópolis, MT). The last two have also made important contributions to the Northeastern fauna, alongside T. Duarte (CIEMEP, Chubut, Argentina). In the Southeast and South of the country, P.C.

Table 3
Authors, their respective nationalities, genders, and the number of currently recognized valid species of Plecoptera from Brazil.

Authors	Authorship in valid species	Nationality	Gender
C.G. Froehlich	82	Brazil	♂
P.C. Bispo	35	Brazil	♂
M.C. Novaes	20	Brazil	♂
F. Klapálek	17	Austria	♂
L.S. Lecci	16	Brazil	♂
L. Navás	15	Catalonia (Spain)	♂
S.G. Jewett Jr.	12	USA	♂
T. Duarte	12	Brazil	♂
F.J. Pictet	9	Switzerland	♂
K.O. Righi-Cavallaro	8	Brazil	♀
A.C. Ribeiro-Ferreira	5	Brazil	♀
B.P. Stark	5	USA	♂
A.R. Calor	4	Brazil	♂
G. Enderlein	4	Germany	♂
L.H. Almeida	4	Brazil	♂
M.C. Gonçalves	4	Brazil	♀
F.F. Salles	3	Brazil	♂
F.S. Avelino-Capistrano	3	Brazil	♀
H. Burmeister	3	Germany	♂
J.O. Silva	3	Brazil	♂
N. Hamada	3	Brazil	♀
C.O. Neves	2	Brazil	♀
F. Brauer	2	Austria	♂
J.L. Nessimian	2	Brazil	♂
N. Banks	2	USA	♂
V.R. De Ribeiro	2	Brazil	♀
A.S. Carvalho	1	Brazil	♂
C. Baldin	1	Brazil	♂
D.M. Takiya	1	Brazil	♀
D.S. Vilela	1	Brazil	♂
E. Trajano de Menezes	1	Brazil	♀
G.G. Jacobson	1	Russia	♂
J. Illies	1	Germany	♂
J. Šámal	1	Czech Republic	♂
J.A. Rafael	1	Brazil	♂
J.M.F. Ribeiro	1	Brazil	♂
L.F.M. Dorvillé	1	Brazil	♂
L.R.C. Lima	1	Brazil	♂
L.S. Barbosa	1	Brazil	♂
M. Miguel	1	Brazil	♀
M. Rippel	1	Brazil	♀
M.K. Pedroza	1	Brazil	♀
M.R. Souza	1	Brazil	♀
R. Boldrini	1	Brazil	♂
R.G.N. Ferreira	1	Brazil	♂
T.K. Krolow	1	Brazil	♂
V.L. Bianchi	1	Russia	♂
V.M. Lopez	1	Brazil	♂
V. Deprá	1	Brazil	♀

Bispo (UNESP, Assis, SP) focuses on ecology and systematics, while F.S. Avelino-Capistrano (FSJ, Rio de Janeiro, RJ), L.H. Almeida (UNESP, Assis, SP), and T. Duarte are dedicated to systematics. Additionally, six students are currently undergoing training in Plecoptera taxonomy at various institutions in the country: M.C. Gonçalves and M. Rippel (UFV, Viçosa, MG) under the supervision of F.F. Salles; M. Miguel and F.R.P. Sarmento (UNESP, Assis, SP) under the supervision of P.C. Bispo; E. Trajano de Menezes (UFRR, Boa Vista, RR) under the supervision of R. Boldrini; and A.S. Carvalho (UEMA, São Luís, MA) under the supervision of L.R.C. Lima.

Author contribution statement

In total, 49 authors have contributed to the descriptions of Brazilian Plecoptera species, either as first authors or co-authors (Table 3). Among these authors, 36 (73%) are from Brazil, 3 (6%) from the USA, 3 (6%) from Germany, 2 (4%) from Austria, 2 (4%) from Russia, 1 (2%) from the Czech Republic, 1 (2%) from Catalonia/Spain, and 1 (2%) from Switzerland. Brazilian researchers have described 65% of Brazil's fauna, while foreign researchers have described 35% (about 26% of the species described by Europeans and about 9% by North Americans). As mentioned earlier, Froehlich has been involved in the description of the most Brazilian species, with 82 contributions, followed by Bispo (35) and M.C. Novaes (20). Additionally, five other authors have participated in the description of more than ten currently recognized Plecoptera species, while 23 authors have contributed to the description of one species (Table 3).

Among the 49 authors involved, 14 (28.6%) are women, all Brazilian. Despite their relatively modest representation, female taxonomists have played a valuable role in contributing to 14.5% of the descriptions of the Brazilian Plecoptera fauna (Supplementary material 1). A remarkable milestone was achieved in 1996 when A.C. Ribeiro-Ferreira became the first woman to describe a Brazilian Plecoptera species, *Enderleina froehlichi* Ribeiro-Ferreira (Ribeiro-Ferreira, 1996). Since 2010, female taxonomists have significantly increased their involvement with Plecoptera, with 13 other women (C. Baldin, D.M. Takiya, E. Trajano de Menezes, F.S. Avelino-Capistrano, K.O. Righi-Cavallaro, M. Miguel, M. Rippel, M.C. Gonçalves, M.K. Pedroza, M.R. Souza, N. Hamada, V. Deprá, and V.R. De Ribeiro), most of them as first authors, contributing to 22 species descriptions (Supplementary material 1).

Out of the 49 taxonomists involved, five have Afro-Brazilian origins. These taxonomists have collectively contributed to 23% of the descriptions of Brazilian species, with a significant increase in engagement, particularly since the 2010s. Notably, P.C. Bispo was the first Afro-Brazilian taxonomist to describe Plecoptera species in 2004, documenting two *Kempnyia* species (Bispo and Froehlich, 2004c) and five *Anacroneuria* species (Bispo and Froehlich, 2004a, 2004b). The first Afro-Brazilian female taxonomist to describe a Plecoptera species was M.C. Gonçalves, who described *A. ruschii* Novaes, Bispo & Gonçalves (Novaes et al., 2016). Subsequently, she also described as the first author, *A. rotunda* Gonçalves, Novaes & Salles, *A. pitii* Gonçalves, Novaes & Salles, and *Gripopteryx caparao* Gonçalves, Novaes & Salles (Gonçalves et al., 2017a, 2017b).

Among the Brazilian taxonomist of Asian origin, N. Hamada and D.M. Takyia stand out, participating in the descriptions of three and one species, respectively. N. Hamada became the first Brazilian taxonomist of Asian origin to describe a Plecoptera species in 2016, namely *E. bifasciata* Hamada, Silva & Pedroza (Hamada et al., 2016). Subsequently, she described another two species: *E. plagata* Hamada & Silva, and *E. yoshikii* Hamada & Silva (Hamada and Silva, 2019). Currently, there are no Brazilian taxonomist of Indigenous origin who have published in the field of Plecoptera taxonomy.

Type-specimens and institutions

Foreign researchers studied the first Brazilian Plecoptera species mainly from 1839 to 1964, and as a result, all the specimens studied were housed in foreign institutions. Currently, 67 type-specimens (32.4% of the total) are still held in foreign institutions, with 20.3% located in Europe and 12.1% in the USA (Fig. 4). Six type-specimens are considered lost in foreign institutions, while another five are lost in Brazilian institutions, amounting to 5.3% of the total type-specimens. The lost type-specimens include six *Anacroneuria*, three *Kempnyia*, and two *Gripopteryx* (Supplementary material 1).

The *Anacroneuria* type-specimens are particularly dispersed across various institutions, with 43 located in foreign institutions and 49 in Brazil. Most of the *Anacroneuria* type-specimens outside Brazil were described before the 1960s from Brazilian material, authored by different researchers such as Banks (1 species), Burmeister (2), Pictet (5), Enderlein (1), Klapálek (10), Navás (4), and Jewett (8). Additionally, 12 *Anacroneuria* species, described more recently by Stark (1995, 2001) and Froehlich (2002), are found outside Brazil. Stark's species were originally described from Venezuela (3) and Ecuador (1), but were later recorded in Brazil (Froehlich, 2003; Menezes et al., 2020). On the other hand, Froehlich's species (8) were described based on Brazilian material (Supplementary material 1).

Since the late 1960s, most type-specimens described for Brazil have been housed in national institutions, including the MZSP in São Paulo, the INPA in Manaus, and the MNRJ in Rio de Janeiro.

Figure 4 Percentage of Brazilian type-specimens of Plecoptera housed in institutions worldwide.

In total, Brazilian institutions house 129 Plecoptera type-specimens, accounting for 62.3% of all type-specimens (Fig. 4). The MZSP has received the highest number of specimens, with 103 (79.8%), primarily due to Froehlich's studies conducted in the Southeast Region, particularly in São Paulo State. Of the 49 type-specimens of Gripopterygidae housed in Brazilian institutions, 47 are located at the MZSP, while the same institution provides access to 56 out of the 80 types of Perlidae. The INPA (11 type-specimens; 8.5%) is the second institution with the most type-specimens housed, especially Perlidae. The MNRJ had the potential to establish itself as the third national institution holding a significant collection of type-specimens, encompassing five types. However, following the unfortunate fire incident in September 2018 (as reported by https://www.nationalgeographic.com), there is a notable absence of information regarding the status of the specimens housed within the institution. Therefore, we are currently compelled to consider them as lost (Supplementary material 1). Additionally, there are 15 type-specimens (11.6%) distributed among other aquatic insect's smaller collections (Table 4).

It is of paramount importance to ensure that biological material collected in Brazil will be deposited within national institutions. This practice guarantees the preservation of the country's scientific heritage and facilitates access for researchers, students, and other interested individuals. Moreover, by depositing the material in Brazilian institutions, we can strengthen the scientific and technical capacities of national organizations, fostering the training of local experts and promoting research and knowledge generation within the country. Specimens collected within Brazilian territory are instrumental in taxonomic, ecological, evolutionary, and conservation studies, offering valuable insights for comprehending and managing Brazilian biodiversity. However, it is essential to allocate funding to these institutions, aiming to improve general working conditions and provide suitable infrastructure for long-term storage. Indeed, such investments are crucial not only for the preservation of biological material but also for preventing unfortunate incidents like the one that occurred at the MNRJ from becoming commonplace. By allocating resources towards improving infrastructure, implementing appropriate safety measures, and ensuring proper maintenance, we can minimize the risks of accidents and protect valuable scientific specimens from harm. This proactive approach will contribute to the long-term preservation of Brazil's scientific heritage and ensure the continuity of research efforts in the field of biodiversity. By doing so, we can enhance the accessibility and utilization of the material by both the national and international scientific communities.

Distribution of Brazilian Plecoptera

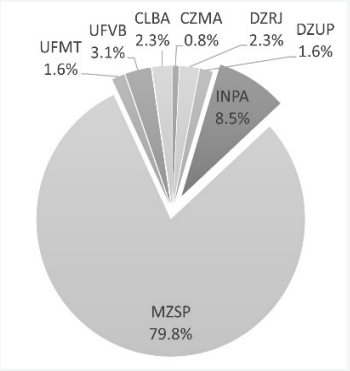
The vast expanse of the Brazilian territory results in asymmetrical records of Plecoptera, due to its wide range of latitudes, vegetation cover, and altitudinal variations. Historically, research efforts and funding have exhibited an uneven concentration, which primarily favored the Southeast and South Regions of the country while comparatively neglected the states within the North, Northeast, and Center-West administrative regions (Froehlich, 2011a). Consequently, these regions, particularly the Southeast, boast the highest number of Plecoptera species recorded (Fig. 5). Among them, São Paulo stands out with 67 recorded species, followed by Rio de Janeiro and Santa Catarina, both with 47 species each (Fig. 5). Froehlich (2011a) listed 56 Plecoptera species to São Paulo, and since then, there has been a slight increase of 11 species, likely due to improved knowledge and understanding of Plecoptera in the state. Except for *Enderleina*, all other genera with known localities are documented in São Paulo. Gripopterygidae encompasses 32 species (Fig. 5a), while Perlidae is represented by 35 species in the state (Fig. 5b). The significant number of records in São Paulo can be attributed to the diligent efforts of researchers such as Froehlich (USP), Bispo (UNESP), and associated researchers engaged in programs like Biota/FAPESP (https://www.biota.org.br), which has supported fauna studies in the state since 1999.

Among the Brazilian states, Alagoas, Paraíba, and Rio Grande do Norte currently lack official records of Plecoptera. These states are located in the Northeast Region of Brazil, an area that has historically been neglected and received limited investment in research on aquatic insect fauna (Froehlich, 2011a; Duarte and Lecci, 2016). Currently, out of the nine states in the Northeast, seven have fewer than three records each, with the exceptions being Maranhão, which has six species, and Bahia, the state with the highest number of recorded species (26 species) in the region (Fig. 5c).

Until 2011, only two *Anacroneuria* species (*A. lacunosa* (Navás) and *A. parilobata* Klapálek) were known to occur in Bahia. However, since then, new records and species descriptions have significantly increased the number of known species in the state (Lecci and Froehlich, 2011; Righi-Cavallaro et al., 2013; Duarte et al., 2014a, 2014b; Duarte and Lecci, 2016; Almeida and Duarte, 2017). This increase in knowledge can be attributed to the efforts of the research group led by A.R. Calor (UFBA) since 2010, which has laid the foundations for training new students and researchers in taxonomy. Additionally, funding for research programs such as the Semiarid Biodiversity Research Program (PPBio semiarid), has contributed to enhanced collection efforts in the Northeast (Lecci et al., 2014; Duarte and Lecci, 2016; Duarte and Calor, 2017).

Table 4
Type-specimens of Plecoptera housed in Brazilian institutions.

Brazilian Institutions	Gripopterygidae	Perlidae	Total of type-specimens
CZMA	0	1	1
DZRJ	1	2	3
DZUP	0	2	2
INPA	0	11	11
MZSP	47	56	103
UFMT	0	2	2
UFVB	1	3	4
CLBA	0	3	3
Total	**49**	**80**	**129**



In terms of species diversity, São Paulo, Rio de Janeiro, and Santa Catarina are not only the states with the highest number of recorded species but also have the highest number of endemic species, with 21, 16, and 12, respectively (Fig. 5c). In contrast, when considering the ratio between species diversity and endemism, Amazonas stands out as the state with the highest percentage of endemic species at 38%, while Bahia and Goiás both have 35%. In Amazonas, there are eight recorded species of *Anacroneuria*, with one being endemic, four species of *Enderleina*, of which three are endemic, and four species of *Macrogynoplax*, with two being endemic. In turn, Bahia (26 species) and Goiás (23 species) have nine and eight endemic species each (Supplementary material 1). Among the three endemic genera in Brazil, *Kempnyia* is found in 10 Brazilian states. On the other hand, *Guaranyperla* is the most geographically restricted genus among Brazilian Plecoptera, being recorded in the Southeast states (Froehlich, 2001, 2015). As previously mentioned, the locality of *Onychoplax* in Brazil remains uncertain.

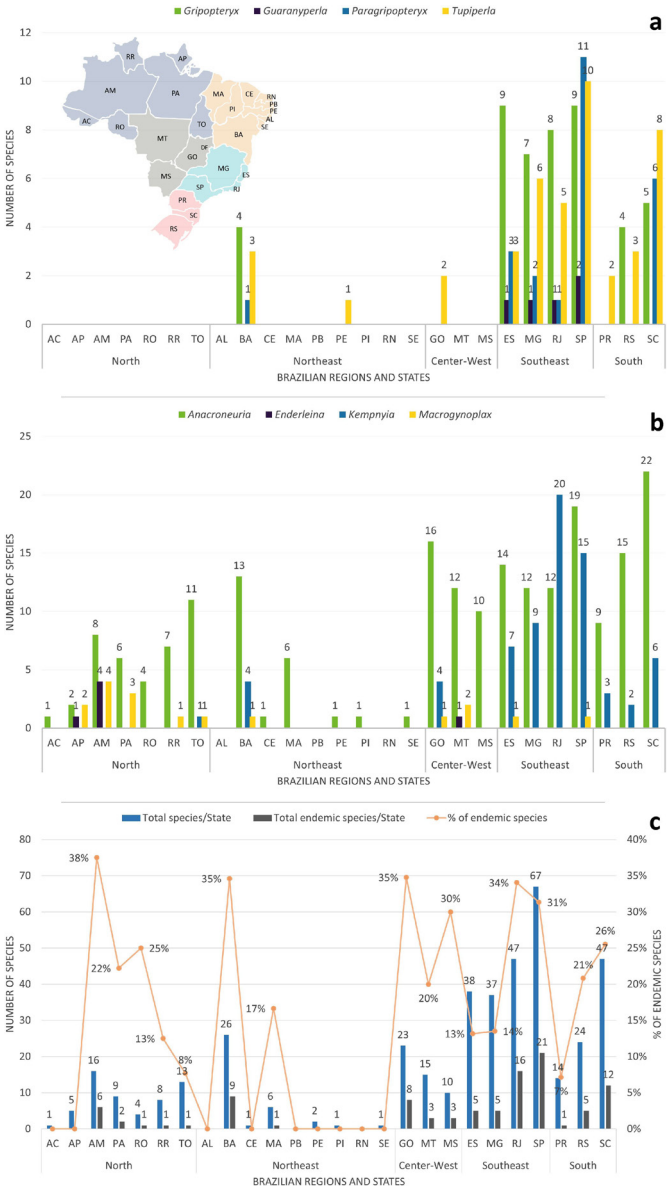


Figure 5 Number of Plecoptera species recorded in each Brazilian political region and state: a) Gripopterygidae; b) Perlidae; c) total recorded species per state, including endemic species, along with their respective percentages. Note: The data excludes the *Onychoplax* genus and other species lacking information regarding their records' locality in Brazil. Brazil state codes are derived from ISO 3166-2: BR (ISO, 2023).

Anacroneuria is the most diverse and widespread Neotropical genus of Plecoptera (Froehlich, 2010; Pessacq et al., 2019). One species, *A. debilis* Pictet, is found in 13 out of the 26 states of Brazil, with additional records in Argentina (Provinces of Misiones and Entre Rios) and Paraguay (Department of Paraguarí) (Froehlich, 2010). Two other Brazilian species, *A. atrifrons* Klapálek and *A. dilaticollis* Burmeister, have broad distributions beyond Brazil. The former occurs in Argentina, Colombia, Ecuador, Paraguay, and Peru, while the latter is also found in Bolivia, Colombia, Guatemala, Mexico, and Panama (Supplementary material 1).

In terms of Brazilian terrestrial biomes, the Atlantic Forest stands out with 140 recorded species, from which 114 are endemic (Fig. 6a). The Brazilian Savanna has the second highest number of recorded species, with 57 records, followed by the Amazon Forest with 28 records. Although Brazilian Savanna has 23 endemic species, the Amazon Forest has a higher ratio of recorded species to endemic species, reaching 64% of endemic species, compared to 40% in the Brazilian Savanna. These three threatened biomes form a diversity corridor, with at least 30 shared species (Supplementary material 1), emphasizing the importance of conservation efforts in these regions.

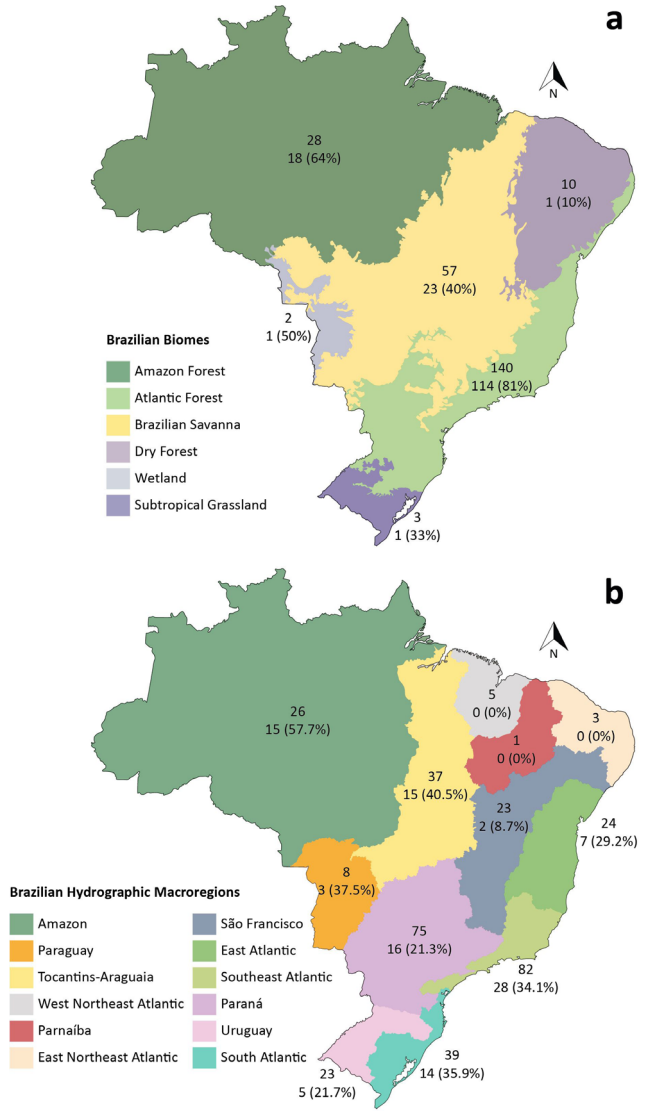


Figure 6 Number of Plecoptera species and endemic species recorded in each terrestrial biome (a) and Hydrographic Region (b) of Brazil. Note: the number in parentheses represents the percentage of endemic species.

Among the six Brazilian terrestrial biomes, the Wetland has the lowest number of recorded species. However, it has a higher level of endemism (50%), with only two recorded species, one of which is endemic. The Dry Forest exhibits the lowest level of endemicity, at 10% (Fig. 6a). *Anacroneuria* is also the genus with the most records in all biomes, except for the Subtropical Grassland, where it has not been recorded (Supplementary material 1). In the Atlantic Forest, 54 species of *Anacroneuria* have been recorded (41 endemic), while the Brazilian Savanna and the Amazon Forest have recorded 38 (15 endemic) and 18 (8 endemic) species of this genus, respectively. The second most widespread genus across biomes is *Gripopteryx*, recorded in four biomes, followed by *Tupiperla* and *Macrogynoplax*, both recorded in three biomes (Supplementary material 1).

Moving on to HR, among the 12 Brazilian regions (Fig. 6b), the Southeast Atlantic HR stands out as having the highest number of recorded species, with 82 species, covering 2.5% of the national territory. Following closely is the Paraná HR, covering 10% of the national territory, with 75 species (Fig. 6b). The proximity of important national and state parks along the border of these two HR (such as Itatiaia National Park, Serra do Mar State Park, Intervales State Park, Alto Ribeira Tourist State Park, Campos do Jordão State Park, Carlos Botelho State Park) results in a significant overlap of species. Forty-six recorded species are shared between these two HR, establishing a critical biodiversity corridor in the South and Southeast regions of the country (Supplementary material 1).

In terms of the percentage of endemic species, the Amazon HR, covering 40% of the national territory, exhibits the highest endemism at 57.7%. The Tocantins-Araguaia HR, covering 10.8% of the national territory, follows closely with 40.5% endemism. The Paraguay HR, covering 4.3% of the national territory, displays 37.5% endemism, while the South Atlantic HR showcases 35.9% endemism (Fig. 6b). Despite Southeast Atlantic HR exhibits the highest number of recorded species, it appears as the fifth in percentage endemism, with 34.1%. The genus *Anacroneuria* is the only genus recorded in all HR (Supplementary material 1).

Life stages

When it comes to taxonomic studies of Plecoptera, like many other insect groups, the focus has predominantly been on the adults. While the number of described females is approximately like that of males, a different reality exists for larvae/exuviae. Among the 207 Brazilian Plecoptera species, approximately 85% have described males, while this proportion is 72% for females and 24.6% for larvae/exuviae (Table 5). The genera *Tupiperla* and *Enderleina* have the fewest described immatures in Brazil, each with only one known immature stage. In contrast, *Anacroneuria* stands out with the highest number of described immatures, totaling 16. However, when considering the ratio between the number of species per genus and the number of described immatures for each genus, *Guaranyperla* emerges as the genus with the highest percentage of immatures described, approximately 66.7%, followed by *Gripopteryx* with around 64.7%.

The scarcity of associated larvae and adults for most groups can present several challenges for their taxonomy. It results in an incomplete understanding of the organism's life history, including its development, feeding habits, and habitat preferences (Faria et al., 2020). The absence of knowledge about the larvae can also make species identification difficult, ultimately hindering our understanding of the organism's ecological role in an ecosystem. Furthermore, for species conservation efforts, having a comprehensive understanding of an organism's life cycle is crucial, as it can influence decisions related to habitat preservation and management. Additionally, the limited availability of larval specimens can restrict research opportunities and impede scientific advancements in specific subjects, contributing to the well-known taxonomic impediment (Lipscomb et al., 2003; Scotland et al., 2003; Wheeler, 2004; Carvalho et al., 2005; Crisci, 2006). This hindrance has constrained broader studies on Brazilian Plecoptera, such as the inference of phylogenetic relationships based on morphological data or the development of more comprehensive diagnoses for genera and species using larval characters, which is a crucial step for ecological investigations. Overcoming this taxonomic impediment is essential for advancing our understanding of Plecoptera and facilitating ecological research (Faria et al., 2020).

Nucleotide information

The lack of molecular information on Brazilian Plecoptera species is another significant gap that needs to be addressed. Currently, only 20 out of the 207 Brazilian species have available molecular data in databases like GenBank (https://www.ncbi.nlm.nih.gov/genbank/). Among these, Perlidae has the highest representation, with molecular data available for 19 species. However, for Gripopterygidae, only one species of *Gripopteryx* has molecular information accessible. These data account for a mere 9.7% of the potential total molecular information that could be accessible for Brazilian Plecoptera species (Table 5).

South America, particularly Brazil, still harbors a substantial portion of its biodiversity awaiting description, while facing escalating threats from human activities (Agostinho et al., 2005; Ribeiro et al., 2009). Consequently, the incorporation of molecular data in environmental monitoring, taxonomy, and ecology would offer numerous benefits.

Table 5
Status of life stage descriptions and nucleotide availability in Brazilian Plecoptera genera.

Families	Genera	Species	Life stage described			Nucleotide information
			Males	Females	Larvae/Exuviae	
Gripopterygidae	*Gripopteryx*	17	16	15	11	1
	Guaranyperla	3	3	2	2	0
	Paragripopteryx	13	13	10	7	0
	Tupiperla	25	25	18	1	0
Perlidae	*Anacroneuria*	98	76	68	16	6
	Enderleina	5	4	2	1	0
	Kempnyia	36	31	27	9	9
	Macrogynoplax	9	9	6	4	1
	Onychoplax	1	0	1	0	0
Total		**207**	**177**	**149**	**51**	**20**
%			**85.5%**	**72%**	**24.6%**	**9.7%**

This approach would enable the association and description of immature stages, enhancing the accuracy of ecological, biogeographical, and phylogenetic studies (Sharma et al., 2017; Almeida and Bispo, 2020). Moreover, it would facilitate the monitoring of freshwater ecosystems. By bridging this knowledge gap and expanding molecular studies, we can significantly contribute to a more comprehensive understanding of Brazilian Plecoptera species and their ecological dynamics.

Journals

During the interval from 1969 to 2023, a total of 61 papers were published, featuring new descriptions and records of Brazilian Plecoptera species (Fig. 7). From 1969 to 2008, most manuscripts were submitted to the journal Aquatic Insects (12). However, Brazilian researchers published in various scientific journals during this period, including Studies on Neotropical Fauna and Environment (4), Acta Amazonica (1), *Mitteilungen der Schweizerischen Entomologischen Gesellschaft* (Journal of the Swiss Entomological Society) (1), Proceedings of the Biological Society of Washington (1), Zootaxa (5), Annales de Limnologie (1), and Trends in Research in Ephemeroptera and Plecoptera (1) (the latter as part of the proceedings of the IX International Conference on Ephemeroptera and the XII International Symposium on Plecoptera, held in Tucuman, Argentina, 1998).

From the second decade of the 21st century, taxonomic traditional journals such as Aquatic Insects and Studies on Neotropical Fauna and Environment experienced decreased interest in Plecoptera taxonomy. This shift was primarily due to the emergence of Zootaxa, a New Zealand journal established in 2001 as an alternative platform for rapid publication of high-quality papers on systematic zoology. In 2004, Bispo and Froehlich authored the inaugural paper in Zootaxa featuring Brazilian Plecoptera species (Bispo and Froehlich, 2004c).

The most prolific period for taxonomy of Brazilian Plecoptera was the 10-year span from 2009 to 2018, during which 26 papers were published, with an impressive 23 of them featured in Zootaxa (Fig. 7). This period included the description of 46 new species along with noteworthy addition of *Tupiperla misionera* Froehlich as a new country record (Novaes and Bispo, 2016). Among the years within this period, 2011 witnessed the highest number of new species described, totaling 12 species (Fig. 2b), including two *Gripopteryx* and two *Kempnyia* species published in Zootaxa (Froehlich, 2011b; Lecci and Froehlich, 2011), three *Paragripopteryx* and two *Tupiperla* in Annales de Limnologie (Bispo and Lecci, 2011), and three *Kempnyia* in Illiesia (Froehlich, 2011c). Worth mentioning is the esteemed reputation of Illiesia as an international journal with comprehensive coverage of plecopteran research. Alongside the descriptions by Froehlich (2011c), three other seminal papers on the taxonomy of the Brazilian fauna have been published in this journal: (i) Froehlich (2010) presented the famous catalogue of neotropical Plecoptera (as aforementioned), a crucial reference for researchers and enthusiasts studying the diverse plecopteran species in the region; (ii) Avelino-Capistrano et al. (2011) contributed with the description of larvae and female of *Kempnyia*, providing valuable insights into the life stages and sexual dimorphism of these insects; and (iii) Froehlich (2015) provided taxonomic notes on *Guaranyperla*, further enhancing our understanding of this particular group within the Brazilian Plecoptera fauna. For additional information, interested readers can visit the journal's website at http://illiesia.speciesfile.org.

The subsequent years, 2014 and 2016, emerged as remarkably prolific periods with an abundance of published papers containing descriptions of new species, each boasting six different papers, all featured in Zootaxa (Bispo et al., 2014; Duarte et al., 2014a, 2014b; Novaes and Bispo, 2014a, 2014b, 2014c; Avelino-Capistrano et al., 2016; Duarte and Lecci, 2016; Froehlich, 2016; Hamada et al., 2016; Novaes and Bispo, 2016; Novaes et al., 2016).

Despite the challenges posed by the Covid-19 health emergency, between 2019 and 2022, seven papers containing new species were published: six in Zootaxa (Duarte et al., 2019; Hamada and Silva, 2019; Rippel et al., 2019; Carvalho et al., 2020; Menezes et al., 2020; Miguel et al., 2022) and one in PlosOne (Duarte et al., 2022). In 2023, two additional papers were published in Studies on Neotropical Fauna and Environment (Deprá et al., 2023) and in Neotropical Entomology (Almeida et al., 2023). The publications from 2019 to 2023 introduced 15 new species and reported two new country records (Supplementary material 1).

Next steps

Over the past two decades (2001-2023), significant advancements have been made in our understanding of the Brazilian Plecoptera fauna. The description of 26 gripopterygids and 72 perlids, accounting for almost half of the known species in Brazil, represents substantial taxonomic progress. These achievements are a testament to the investments in fundamental scientific research, which have not only enriched our knowledge of the Plecoptera order but also expanded our understanding of other orders of aquatic insects, including Ephemeroptera, Odonata, and Trichoptera (Shimano et al., 2013; Miguel et al., 2017; Santos et al., 2020).

It is worth noting that vast regions of Brazil remain unexplored, indicating that numerous new species and unrecorded occurrences can still be found. Conducting comprehensive species descriptions, encompassing detailed morphological, ecological, and distributional data, is crucial for providing an accurate representation of Plecoptera diversity in Brazil. Furthermore, ongoing taxonomic revisions are necessary to refine and update the classification of these species. This involves morphological examinations, examination of type-specimens, and potential integration of molecular techniques to gain a comprehensive understanding of species boundaries and relationships.

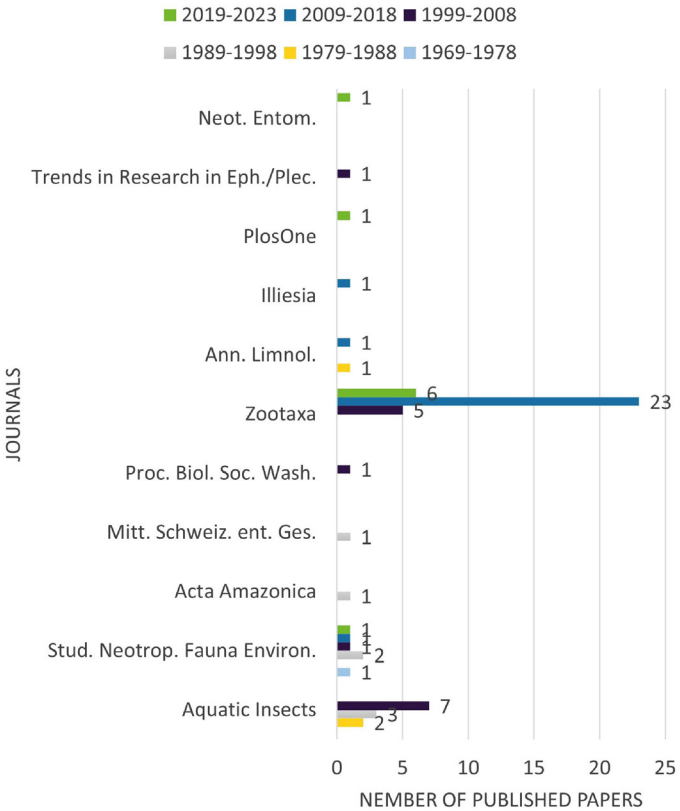


Figure 7 Cumulative number of papers describing Brazilian Plecoptera published in journals over 10-year intervals from 1969 to 2023.

The incorporation of molecular data into Plecoptera taxonomy can offer valuable insights into evolutionary relationships, species delimitation, and population genetics. Future studies could focus on generating molecular markers, such as DNA barcoding, to complement traditional morphological approaches.

Another vital avenue of research is the investigation of biogeographical patterns of Plecoptera species in Brazil. Such studies can shed light on historical dispersal events, regional endemism, and the influence of environmental factors on species distribution. Understanding the evolutionary history of Plecoptera in the region and their ecological roles and functional significance within freshwater ecosystems can be achieved through these investigations. Furthermore, research can delve into their interactions with other organisms, nutrient cycling dynamics, and responses to environmental stressors, providing valuable information for conservation and ecosystem management. Given the sensitivity of Plecoptera to environmental changes, it is essential to assess their conservation status and monitor their populations. Investigating the impacts of habitat degradation, pollution, and climate change on Plecoptera communities can contribute to their effective conservation and management.

An important aspect of the taxonomy of Plecoptera in Brazil is that, historically, Caucasian men have been predominant in the field. However, the contribution of women and the diversification of ethnic groups have been increasing over the last decade. This trend could reflect the growing presence of women in Brazilian universities and their increasing interest in the taxonomy of aquatic insects, as observed in groups like Odonata, Trichoptera, and Ephemeroptera. The greater ethnic diversity among taxonomists also can be aligned with the adoption of affirmative action policies in Brazilian universities over the past two decades, which have contributed to increased ethnic heterogeneity within the academic environment. The enrollment and retention of these students in postgraduate programs are expected to further expand the ethnic diversity working in various fields of biology. Consequently, in the coming decade, we anticipate a more diverse group of taxonomists, including professionals of indigenous origin who have not yet been included in Plecoptera taxonomy.

Lastly, fostering collaborative efforts among researchers and institutions is paramount for the sharing of data, specimens, and knowledge related to Brazilian Plecoptera. Establishing networks and databases for data sharing and collaboration can greatly enhance the progress of Plecoptera taxonomy. By focusing on these next steps, researchers can advance the knowledge and understanding of Brazilian Plecoptera. This contribution will not only benefit their conservation and ecological understanding but also foster a greater appreciation for their importance within aquatic ecosystems. Ultimately, such efforts can help mitigate the shortfalls in our large-scale knowledge of biodiversity (Hortal et al., 2015; Faria et al., 2020).

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Conflicts of interest

The authors declare no conflicts of interest.

Author contribution statement

TD and LSL conceived the study, collected distributional data for the species listed, updated the CTFB website, and co-authored the paper. TD was responsible for performing the statistical analyses, as well as creating the tables and figures.

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Supplementary Material

The following online material is available for this article:
Supplementary material 1.