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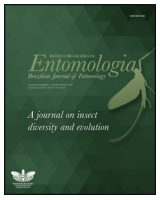

The extant fauna of Neuroptera (Insecta) from Brazil: diversity, distribution and history

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ABSTRACT

This survey presents an overall view of the order Neuroptera from Brazil. A total of 432 valid extant species of Neuroptera divided into ten families, are recorded from the country. Among the Brazilian fauna, 211 species are endemic (48.8%), with the majority belonging to two families: Chrysopidae with 182 species in 19 genera, and Myrmeleontidae with 88 species in 25 genera. The first species discovered from Brazil was *Climaciella semihyalina* (Le Peletier & Audinet-Serville), in 1825, by European authors. In fact, European authors entirely dominated the description of Brazilian Neuroptera during the 19th century. Father Longinos Navás from Spain authored the highest number of species described from Brazil, 98, followed by US-American Norman Penny, with 83 species. Sérgio de Freitas, a Brazilian researcher, ranks third, with a total of 50 species described. It was not until the 21st century that the study of neuropterans from Brazil was primarily led by Brazilian-born authors. Primary type specimens of species described from Brazil are predominantly deposited in non-Brazilian institutions (65.7%). The order Neuroptera is distributed across all Brazilian states, except for Alagoas. The two states with the highest neuropteran biodiversity are Amazonas and São Paulo, with 132 and 124 species, respectively. Among the Brazilian biomes, the Mata Atlântica is the most diverse region with 227 known species, followed by the Amazônia with 192 species. Data on immature stages of Neuroptera are scarce and known for only 47 species recorded from Brazil (10.9%).

Introduction

The Neuroptera are a small order of holometabolous insects that are commonly known as lacewings and is composed of nearly 6,000 extant species, divided into 603 genera (Oswald and Machado, 2018). Neuroptera, together with Megaloptera and Raphidioptera, belong to the superorder Neuropterida. Raphidioptera is consistently recovered as the sister group to the clade Megaloptera + Neuroptera in recent phylogenetic studies (Aspöck and Aspöck, 2008; Wang et al., 2017; Winterton et al., 2018; Vasilikopoulos et al., 2020).

The origin of the order Neuroptera was recently estimated to the Early Permian, nearly 280 million years ago (Ma), with the diversification of the major lineages during the Permian and Triassic periods. However, it was only during the Jurassic and Cretaceous that the order reached its greatest diversity (Winterton et al., 2018; Vasilikopoulos et al., 2020). According to recent phylogenetic studies, Neuroptera is currently divided into 15 families. Myrmeleontidae and Chrysopidae are the most diverse families, comprising together nearly 60% of the known lacewing diversity (Winterton et al., 2018; Machado et al., 2019).

Most of the neuropterans are unknown by non-biologists, except for some lacewing larvae (e.g. green lacewings) that are used in biological control programs against pest populations of aphids, mites, whiteflies, among others. In general, larvae of Neuroptera are predators of small invertebrates and occur in distinct types of habitats, like soil, under rocks, on vegetation, burrowed in sand, associated with hosts like spiders and termites, and even in freshwater (immature stages of Sisyridae, Nevrorthidae, and some Osmylidae). Adults are small to relatively large insects. Despite a high level of morphological diversification within the order, adults are generally recognized by large membranous wings, displaying complex venation. Mirroring their larvae, most adults are also considered predators of small invertebrates (Oswald and Machado, 2018).

Neuropterans have a cosmopolitan distribution, except for Antarctica, and the group is particularly diverse in the tropics. The Neotropical region is one of the most speciose areas for Neuroptera, although some researchers still consider it underexplored. In the Neotropics, Brazil is the most Neuroptera rich country with more than 400 species (Martins, 2019) and is the fourth most diverse country in the world for lacewings, behind China, Australia, and the United States (Oswald and Machado, 2018). Taxonomic studies on the Brazilian neuropterans began during the 19th century, initiated by European authors. It was only near the turn of the 21st century that research intensified, led mostly by authors based in Brazil. There are two researchers to highlight during this period: Norman Penny, United States citizen who lived in Manaus (Amazonas state) during the 1980's and published mostly on

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the Amazonian fauna; and Sérgio de Freitas, Brazilian researcher and expert on Chrysopidae. More recently, the Brazilian Neuroptera fauna has been studied by a series of new researchers, mostly Brazilians, focusing on all families of the order.

Data about the Brazilian fauna are compiled in the "Catálogo Taxonômico da Fauna do Brasil – CTFB" (Taxonomic Catalogue of the Brazilian Fauna), an online catalogue started in 2015 and focusing exclusively on Brazilian fauna. The CTFB database is constantly updated by over 500 zoologists, all experts in their respective animal taxa (Santos et al., 2020). Currently, there are over 120,000 valid extant animal species represented in the CTFB, and information about them can be accessed on the website http://fauna.jbrj.gov.br. The section related to Neuroptera is administrated by the authors of this study and provides a checklist of the Brazilian species, as well as information such as: year of publication, author's name, synonymic listing, hosts and parasites, and distribution for Brazilian states and ecological biomes. In the near future, the type locality and museum repository for all associated type specimens are also expected to be added to the Neuroptera section of the CTFB (Machado and Martins, 2022).

This study is inspired by a recent paper published by CTFB authors responsible for the caddisflies (Insecta: Trichoptera) (Santos et al., 2020). In the publication, the authors presented valuable historical information about the Brazilian species of Trichoptera and this research is now being used to guide future studies on the group. The goal of our study is to similarly analyze data for Neuroptera in the CTFB, along with other taxonomic literature references, to compile available information on the Brazilian neuropteran species in a single resource. By doing so, we will be able to provide analyses highlighting neuropteran species distribution across state and ecological borders, locations of primary type specimens, and a history of how taxonomic studies focused on the Brazilian Neuroptera developed over time, and where they should focus in the future.

Material and Methods

All data analyzed was extracted from the CTFB website (http://fauna.jbrj.gov.br), specifically, the section focused on Neuroptera (Machado and Martins, 2022), which was lastly updated in July 2022. The data contained in the CTFB has been constantly updated and is based on available specialized taxonomic literature, as well as holdings of the Lacewing Digital Library – LDL (Oswald, 2022). The higher-level classification for Neuroptera adopted in the CTFB follows Winterton et al. (2018), with modifications proposed by Machado et al. (2019) and Ardila-Camacho et al. (2021a).

Data were extracted and compiled in an Excel spreadsheet (Supplement 1), which was the basis for all analyses conducted in this study. Our dataset is organized first by family and then contains a list of species for each of these taxa. For each species, the information compiled consists of: author's name and nationality; year of description: year it was first reported from Brazil; location of primary type specimens; whether it is endemic to Brazil or not; if the immature stages are known; and distribution by states and biomes. The nationality of authors was divided into five categories: Brazil, Europe, United States, Asia, and Latin America (except Brazil). The location of the primary type specimens was also divided into those five categories, although the Brazilian institutions were individualized. For species distribution data, the 26 Brazilian states plus the Federal District were considered, as well as the six terrestrial Brazilian biomes – Amazônia (rainforest); Mata Atlântica (rainforest); Cerrado (savanna); Caatinga (arid shrubland); Pampas (fertile lowlands); and Pantanal (tropical wetlands). Neuroptera species reported from "Brazil" without a precise location were included in the species list, but not assigned to any state or biome.

Accumulation curves were generated based on the year that the species was first reported from Brazil and on the nationality of the first author of each species. Graphics were generated in Excel and maps in QGIS, and later edited in Adobe Illustrator CS3.

Results e Discussion

Historical Neuroptera data

A total of 432 valid Neuroptera species in ten families (Fig. 1) are recorded from Brazil, with 211 species (48.8%) endemic to the country (Table 1). Among these ten families, two of them, Chrysopidae (green lacewings) and Myrmeleontidae (antlions and owlflies), constitute 62.5% of the overall Brazilian diversity. Chrysopidae is the most diverse family with 182 species (42.1%) divided into 19 genera (Table 1), including the most diverse neuropteran genus in Brazil, *Leucochrysa* Adams, with 78 species (Table 2). The second most speciose family is Myrmeleontidae with 88 species (20.4%). Despite having half the number of species as found in the Chrysopidae, the Myrmeleontidae is the family with the highest number of genera, 25 (Tables 1 and 2). The least diverse Neuroptera family in Brazil is Osmylidae with only three species (Table 1). This position had historically belonged to Berothidae until early in 2022, when two new cave-associated berothid species were described from Brazil (Machado et al., 2022), increasing its total diversity to four species. Although the number of valid extant species of Neuroptera recorded from Brazil is currently 432, on the CTFB website there are 694 Neuroptera names registered. The additional 262 names are species considered junior synonyms, and information about each of them can be found under their respective senior synonyms on the CTFB website. The Brazilian species with the highest number of synonyms is the green lacewing *Ceraeochrysa cincta* (Schneider), with a total of 18 junior synonyms.

The first Neuroptera species to be recorded from Brazil was the mantispid *Climaciella semihyalina* (Le Peletier & Audinet-Serville) in 1825. However, this is not the oldest name for a Neuroptera from Brazil. This significance belongs to the owlfly (Myrmeleontidae: Ascalaphinae) *Ululodes cajenensis* (Fabricius) described in 1787 but recorded for the first time from Brazil in 1853 (Walker, 1853). The antlion species *Dimarella tarsalis* (Guilding), described in 1829, was not recorded from Brazil until 1977 (Penny, 1977). This difference of 148 years makes *D. tarsalis* the Brazilian Neuroptera species with the longest interval between its original description and its first record from the country. However, this species has a problematic taxonomic history and its status should be reevaluated.

Overall, between the first description of a neuropteran species from Brazil in 1825 until present day, the average rate of annual records has

Table 1
Number of genera, total species and endemic species of Neuroptera families occurring in Brazil.

Family	Genus	Species	Endemic Species
Berothidae	3	4	4
Chrysopidae	19	182	106
Coniopterygidae	4	46	28
Dilaridae	1	11	10
Hemerobiidae	6	26	5
Mantispidae	10	34	13
Myrmeleontidae	25	88	30
Osmylidae	2	3	1
Rhachiberothidae	3	18	9
Sisyridae	2	20	5
TOTAL	75	432	211

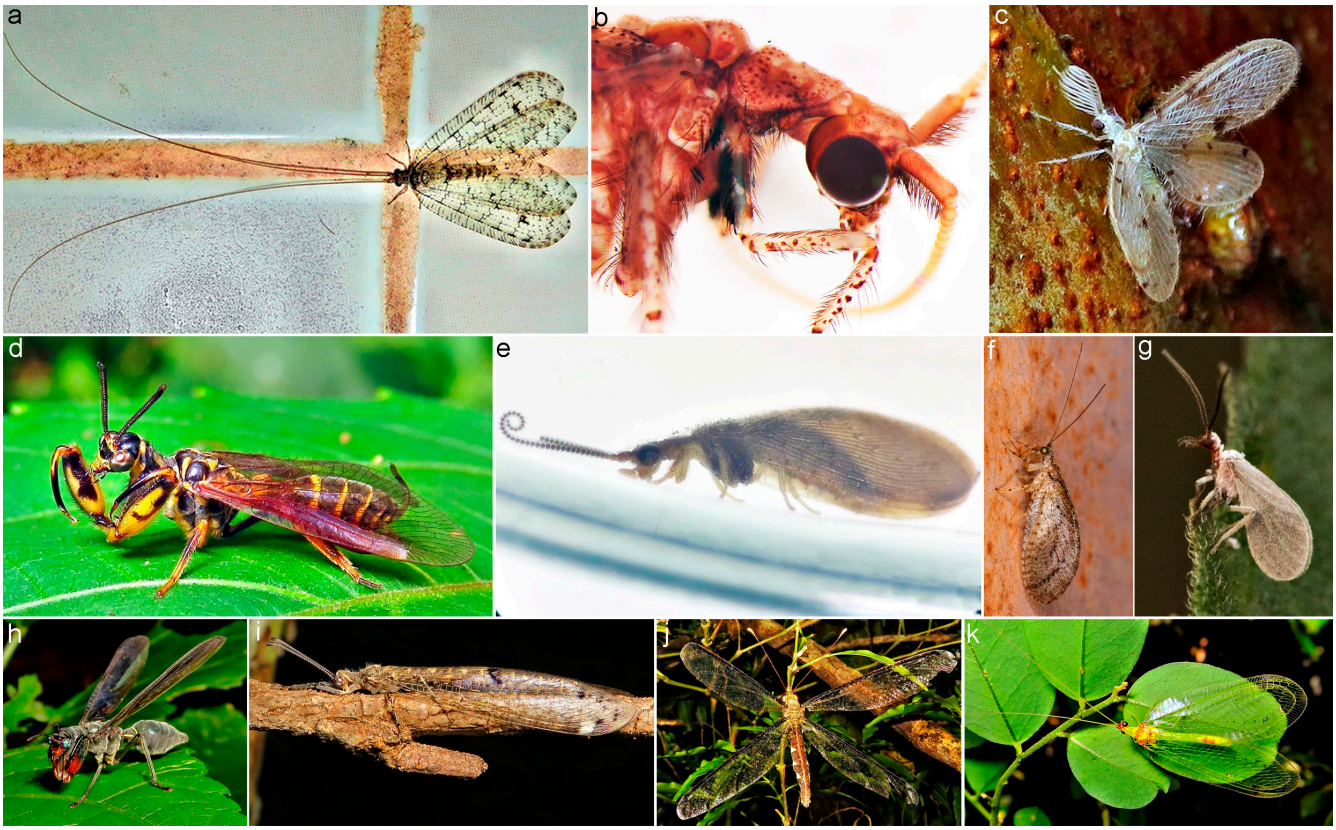

Figure 1 Neuroptera families of Brazil. a) *Gumilla adspersus* Navás (Osmylidae); b) *Spiroberotha tocantinensis* Machado & Krolow (Berothidae); c) *Nallachius* sp. (Dilaridae); d) *Anchieta* sp. (Rhachiberothidae); e) *Sisyra* sp. (Sisyridae); f) *Megalomus* sp. (Hemerobiidae); g) *Coniopteryx* sp. (Coniopterygidae); h) *Climaciella semihyalina* (Le Peletier & Audinet-Serville) (Mantispidae); i) *Eremoleon* sp. (Myrmeleontidae: Nemoleontinae); j) *Haploglenius* sp. (Myrmeleontidae: Ascalaphinae); k) *Leucochrysa* sp. (Chrysopidae). Photos a, c, d, h-k by ©Roger Dias (https://www.inaturalist.org/people/rogerriodias); photo f by ©Vinícius Rodrigues de Souza (https://www.inaturalist.org/people/vinisouza128); photo g by ©Fernando Sessegolo (https://www.inaturalist.org/people/fmiudo), photo e by ©Leon Tavares (https://www.inaturalist.org/people/leontavares); photo b by ©Caleb Califre Martins.

been 2.18 species per year. During the 19th century, 81 species were recorded from Brazil, with an average rate of 1.08 species per year (1825-1900). During the entirety of the 20th century, 2.32 species were recorded from the country per year, totaling 232 records during this period. By the beginning of the 21st century (2001-2022), 119 species have already been recorded from the country for the first time, increasing the rate of annual records to 5.41. This dramatic increase suggests that the total number of Neuroptera species in Brazil is much larger than what has been recorded in previous centuries.

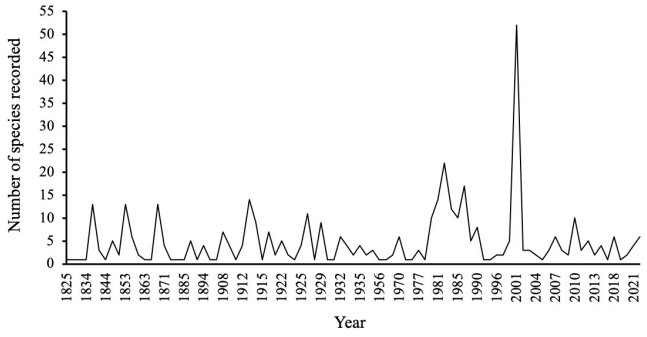

Figure 2 Number of Neuroptera species recorded from Brazil by year (1825-2022).

Authors of Brazilian Neuroptera

The number of species reported to Brazil per year is detailed in Figs. 2 and 3. During the XIX century, the interval between 1839 and 1867 was important for the Brazilian Neuroptera fauna, with many species being registered to the country by different European authors, such as Karl Burmeister, Wilhelm Erichson, Wilhelm Schneider, Francis Walker, and John Westwood. An equally important period was during the early 1900s, primarily due to the publications by Father Longinos Navás and Nathan Banks. A more recent notable period for Brazilian neuropterofauna was the decade of 1980, when Norman Penny was housed at the Instituto Nacional de Pesquisas da Amazônia (INPA), in Manaus, Amazonas, Brazil. During his tenure at INPA, Penny described over 80 neuropteran species from Brazil, particularly from the Amazon basin, with a series of different collaborators, including Martin Meinander, Phillip Adams, and Victor Monserrat. The highest number of Brazilian Neuroptera species described in a single year was 52. All 52 of these species' records originated from a single paper in 2001, de Freitas

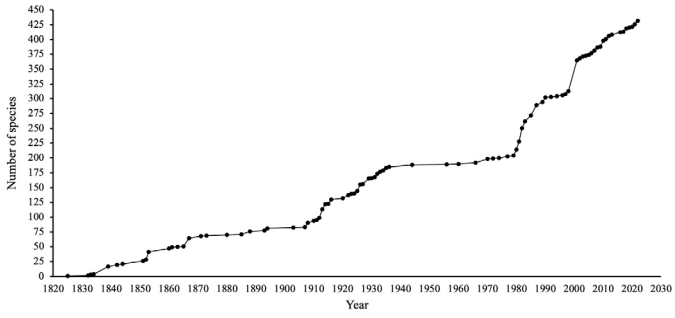

Figure 3 Accumulation curve of Neuroptera species recorded from Brazil by year (1825-2022), based on the first record of each species to the country.

Table 2
Species diversity of each Neuroptera genus occurring in Brazil.

Family	Genus	Number of Species
Berothidae	*Lomamyia* Banks	1
	Spiroberotha Adams	1
	Speleoberotha Machado et al	2
Chrysopidae	*Asthenochrysa* Adams & Penny	1
	Belonopteryx Gerstaecker	1
	Berchmansus Navás	1
	Ceraeochrysa Adams	34
	Chrysopa Leach	5
	Chrysoperla Steinmann	4
	Chrysopodes Navás	21
	Domenechus Navás	1
	Gonzaga Navás	6
	Italochrysa Principi	1
	Leucochrysa McLachlan	78
	Loyola Navás	3
	Nacarina Navás	10
	Nuvol Navás	1
	Plesiochrysa Adams	4
	Santocellus Tauber et al	2
	Titanochrysa Sosa & de Freitas	4
	Ungla Navás	1
	Vieira Navás	4
Coniopterygidae	*Coniopteryx* Curtis	30
	Incasemidalis Meinander	1
	Neoconis Enderlein	6
	Semidalis Enderlein	9
Dilaridae	*Nallachius* Navás	11
Hemerobiidae	*Hemerobius* Linnaeus	5
	Megalomus Rambur	6
	Nomerobius Navás	3
	Notiobiella Banks	4
	Nusalala Navás	4
	Sympherobius Banks	4
Mantispidae	*Buyda* Navás	1
	Climaciella Enderlein	3
	Dicromantispa Hoffman	6
	Entanoneura Enderlein	5
	Gerstaeckerella Enderlein	3
	Haematomantispa Hoffman	1
	Leptomantispa Hoffman	5
	Mantispa Illiger	5
	Paramantispa Williner & Kormilev	3
	Zeugomantispa Hoffman	2
Myrmeleontidae	*Albardia* van der Weele	1
	Ameromyia Banks	10
	Ameropterus Esben-Petersen	9
	Amoea Lefèbvre	4
	Argentoleon Stange	1
	Ascalobyas Penny	3
	Ascalorphne Banks	2
	Austroleon Banks	2
	Brasileon Miller & Stange	2
	Cordulecerus Rambur	6
	Dimarella Banks	7
	Dimares Hagen	1
	Elachyleon Esben-Petersen	1
	Elicura Navás	1
	Eremoleon Banks	1
	Fillus Navás	1
	Glenurus Hagen	3
	Haploglenius Burmeister	6
	Myrmeleon Linnaeus	10
	Navasoleon Banks	2
	Porrerus Navás	2
	Purenleon Stange	5
	Ripalda Navás	1
	Ululodes Smith	6
	Vella Navás	1
Osmylidae	*Gumilla* Navás	1
	Isostenosmylus Krüger	2
Rhachiberothidae	*Anchieta* Navás	5
	Plega Navás	5
	Trichoscelia Westwood	8
Sisyridae	*Climacia* McLachlan	15
	Sisyra Burmeister	5

and Penny (2001), which focused only on Brazilian green lacewings (Chrysopidae), becoming one of the most important studies published to date on the Brazilian neuropterofauna.

Figure 4 shows the accumulation curve for Brazilian Neuroptera species based on their year of publication and the nationality of the first author. Viewing this graph, it is obvious that the earliest years of registration of Neuroptera fauna in Brazil were exclusively comprised of European authors, who dominated neuropteran research during the 19th century. However, the influence of European authors in the accumulation curve was more intense during the 28 years (1908-1936) that Longinos Navás published on the Brazilian fauna. Another important period for European studies of Brazilian neuropterans was during the 1980's, with the publications of Martin Meinander and Victor Monserrat in partnership with Norman Penny. After this period, the influence of European researchers in the description of Brazilian fauna decreased considerably. Nevertheless, European authors still hold the record for number of Neuroptera species described from Brazil, totaling 260 species (60.6%). The domination of European naturalists during the 19th and early 20th century, is certainly related to historical events, and a similar pattern is observable in other groups of insects, such as the caddisflies (Santos et al., 2020).

The first non-European author to describe a species of Neuroptera from Brazil was the US-American Nathan Banks, who described the green lacewing *Ceraeochrysa valida* (Banks) in 1895. During the early 1900's, Banks described a total of 27 species from Brazil that are still valid today. However, it was during the 1980's that authors from the United States had their greatest taxonomic influence on Brazilian Neuroptera (Fig. 4), with multiple papers published by Penny and collaborators playing an important role. With a total of 98 species described from Brazil (22.7%), the US-born are the group of authors to describe the second highest number of Brazilian neuropterofauna.

The third group of researchers with the highest number of described neuropteran species, 66 (15.3%), are Brazilian-born authors. The first Brazilian to be the first author of any Neuroptera species was Sérgio de Freitas, who described 42 species in 2001 (Freitas and Penny, 2001) (Fig. 4) and an additional eight species over the following years. However, de Freitas was not the first Brazilian author to participate in the description of a Brazilian Neuroptera, it was actually José Rafael who described two species of Sisyridae in 1982 as the second author (Penny and Rafael, 1982). Since the publication of de Freitas and Penny (2001), the number of Brazilian first authors increased considerably, now representing the most important group of authors describing Brazilian species. The dominance of Brazilian authors in the 21st century may explain why the annual rate of neuropteran species description (5.41) is higher than ever, reinforcing the importance of local researchers leading to a better understanding of local faunas.

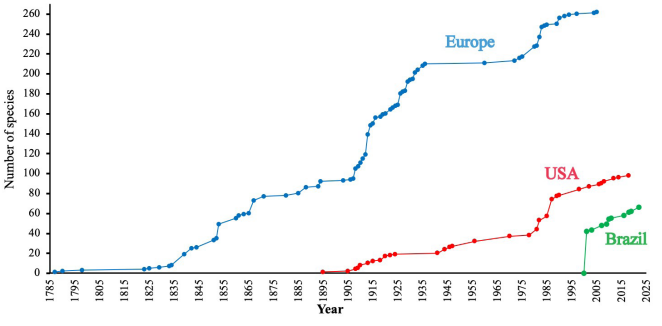

Figure 4 Accumulation curve of Neuroptera species recorded from Brazil by year (1787-2022), based on the year of the description of each species, categorized by the citizenship of the first authors.

Besides the three groups of authors mentioned above, five species of Brazilian Neuroptera were described by three South American first authors, each from a different country (Argentina, Colombia, and Venezuela). A single species, *Hemerobius exceptatus* Nakahara, was described by Japanese author Waro Nakahara in 1965. Nakahara is therefore the only researcher not from the Americas or Europe to be the first author of a Neuropteran species occurring in Brazil. Overall, 57 different authors participated in the description of Brazilian neuropterans (Table 3): 31 (54.4%) from Europe, 12 from the United States (21.1%), 10 from Brazil (17.5%), besides the other four mentioned above. Among all authors, Longinos Navás described the highest number of Neuroptera species, 98, corresponding to 22.7% of the Brazilian neuropterofauna. Norman Penny follows Navás with 83 species described, and Sérgio de Freitas is third, with 50 species described (Table 4). The contributions of these top three authors of Brazilian neuropterans correspond to the highest increments on the accumulation curve presented in Fig. 3. Eleven different authors published more than ten Neuroptera species, while 15 participated in the description of only a single species (Table 4).

Among the 57 authors included in our dataset, only three are females. Catherine Tauber from the United States, who participated in the description of eight Chrysopidae species, Ulrike Aspöck from Europe, with two Berothidae species, and Alice Assmar, the first Brazilian woman to describe a species of Neuroptera, with two Sisyridae species. The latter two female authors only entered this list in early 2022 (Machado et al., 2022; Assmar et al., 2022), spotlighting an extensive gender gap that needs to be addressed in future research endeavors.

Type Specimens

The large number of foreign authors describing Brazilian Neuroptera fauna, particularly Europeans, also reflects where most of the primary type specimens are deposited today (Table 5). Nearly 66% (284) of the primary types of Brazilian neuropterans are currently deposited in foreign institutions, particularly European ones (199 – 46%). Such a high number of primary types in foreign institutions could represent a taxonomic impediment for local researchers, primarily because accessing these specimens via travel or loans can often be very difficult. However, in recent years some of the major institutions have digitalized their insect collections, a very important initiative that facilitates the study of specimens deposited overseas. A secondary problem is that 14 (3.3%) of primary types that were reportedly deposited in European institutions are considered lost today, most of them described by Navás. These type specimens were likely destroyed during the two world wars and several local conflicts that took place in the 20th century (Monserrat, 1985). A total of 147 (34%) primary types are currently deposited in Brazil, and are divided among six institutions (Tables 5 and 6). Within these six institutions, two of them account for 87% of type specimens deposited in Brazil. INPA, in Amazonas state, houses 80 primary Neuroptera types, and UNESP Jaboticabal, in São Paulo state, currently holds 49 neuropteran type specimens (Table 6). Not coincidently, these two institutions employed Penny and de Freitas, two of the most prolific authors of Brazilian Neuroptera, during their careers in Brazil.

Neuropteran distribution across Brazil

The locations of institutions where major neuropterists worked in Brazil also certainly influenced the distribution of species records within the country. The states of Amazonas, with 132 species, and São Paulo, with 124, are the two most speciose states in Brazil (Fig. 5) and correspond to regions where Penny and de Freitas conducted most of their taxonomic research. Among the Brazilian states, only Alagoas

Table 3
Nationality and number of authors who described the Brazilian species of Neuroptera.

Nationality	Number of authors	Percentage
Europe	31	54.4
USA	12	21.1
Brazil	10	17.5
Latin	3	5.3
Asia	1	1.7

Table 4
Name and nationality of authors, and number of Brazilian species of Neuroptera they participated on the original description.

Author	Nationality	Species described
L. Navás	Europe	98
N. Penny	USA	83
S. de Freitas	Brazil	50
M. Meinander	Europe	38
N. Banks	USA	27
P. Adams	USA	22
F. Walker	Europe	19
C. Gerstaecker	Europe	15
V. Monserrat	Europe	14
R. Machado	Brazil	13
J. Westwood	Europe	10
J. Rafael	Brazil	9
H. van der Weele	Europe	9
R. Mclachlan	Europe	8
C. Tauber	USA	8
W. Erichson	Europe	6
O. Flint	USA	6
J. Rambur	Europe	6
G. Albuquerque	Brazil	5
K. Burmeister	Europe	5
G. Enderlein	Europe	5
C. Martins	Brazil	5
W. Schneider	Europe	5
L. Stange	USA	5
H. Hagen	Europe	4
A. Gurney	USA	4
J. Lacroix	Europe	4
S. Parfin	USA	4
F. Sosa	Latin	4
P. Esben-Petersen	Europe	3
K. Hoffman	USA	3
R. Miller	USA	3
D. Amorim	Brazil	2
A. Assmar	Brazil	2
H. Aspock	Europe	2
U. Aspock	Europe	2
C. Blanchard	Europe	2
A. Calor	Brazil	2
F. Guérin	Europe	2
L. Guilding	Europe	2
J. Fabricius	Europe	2
L. Tavares	Brazil	2
A. Ardila-Camacho	Latin	1
F. Brauer	Europe	1
S. Brooks	Europe	1
F. Carpenter	USA	1
E. González	Latin	1
E. Handschin	Europe	1
T. Krolow	Brazil	1
L. le Peletier	Europe	1
W. Nakahara	Asia	1
G. Olivier	Europe	1
J. Oswald	USA	1
J. Perty	Europe	1
M. Sélys	Europe	1
A. Serville	Europe	1
J. Waldheim	Europe	1

Table 5
Location of the collections where the primary types of the Brazilian species of Neuroptera are deposited.

Location	Number of types	Percentage
Europe	199	46.05
Brazil	148	34.3
USA	63	14.5
Latin	8	1.85
Lost	14	3.3

Table 6
Brazilian institutions where the primary types of the Brazilian species of Neuroptera are deposited.

Institutions	Number of types	Percentage
INPA	80	54.05
UNESP	49	33.11
DZUP	9	6.08
MZUSP	6	4.05
MPEG	3	2.03
CZMA	1	0.68

CZMA = Coleção Zoológica do Maranhão, DZUP = Coleção Entomológica Pd. Jesus Santiago Moure, INPA = Instituto Nacional de Pesquisas da Amazônia, MPEG = Museu Paraense Emílio Goeldi, MZUSP = Museu de Zoologia da Universidade de São Paulo, UNESP = Universidade Estadual Paulista, Jaboticabal.

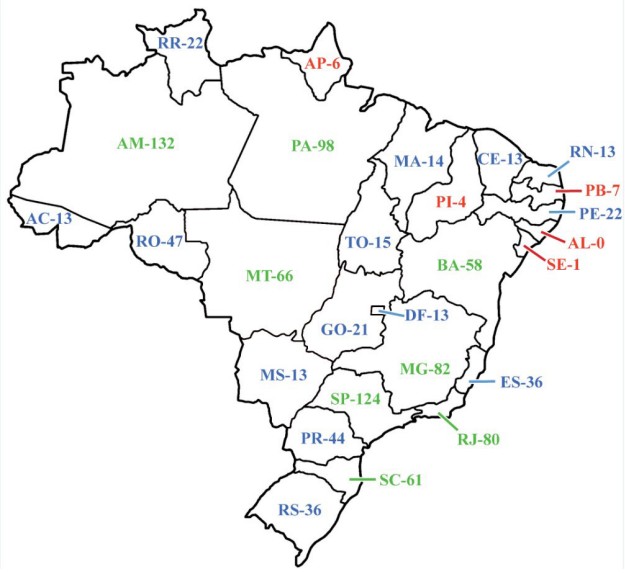

Figure 5 Brazilian map showing the number of Neuroptera species recorded for each one of the states. Numbers in green represent the states with more than 50 species recorded, blue = more than 10 but less than 50 species recorded, and red = less than 10 species recorded. State abbreviations: AC = Acre, AL = Alagoas, AM = Amazonas, AP = Amapá, BA = Bahia, CE = Ceará, DF = Federal District, ES = Espírito Santo, GO = Goiás, MA = Maranhão, MG = Minas Gerais, MS = Mato Grosso do Sul, MT = Mato Grosso, PA = Pará, PB = Paraíba, PE = Pernambuco, PI = Piauí, PR = Paraná, RJ = Rio de Janeiro, RN = Rio Grande do Norte, RO = Rondônia, RR = Roraima, RS = Rio Grande do Sul, SC = Santa Catarina, SE = Sergipe, SP = São Paulo, TO = Tocantins.

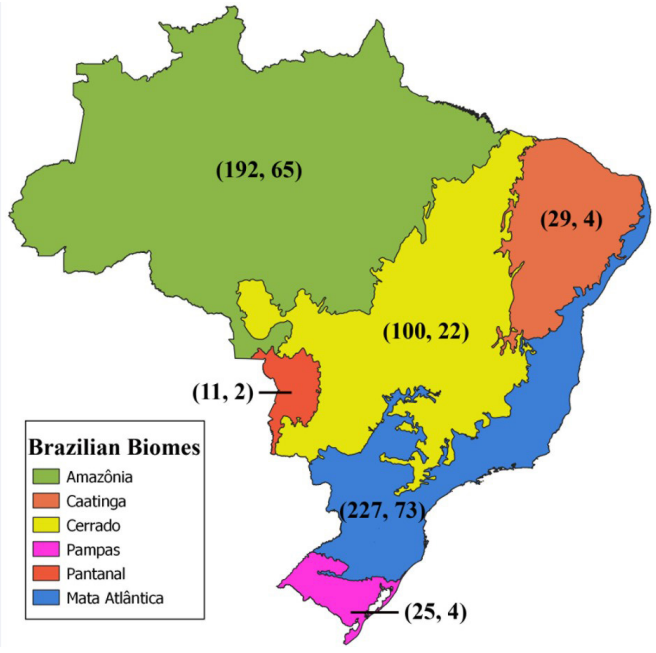

Figure 6 Brazilian map showing the number of Neuroptera species recorded for each one of the Brazilian terrestrial biomes. The first number represents the total of species and second the number of endemic species.

has no official records of Neuroptera. This disparity is certainly the result of a lack of studies targeting local biodiversity, especially because some neighboring states are particularly diverse, including the state of Bahia with 58 species (Fig. 5). In general, the northeastern region in Brazil is the least explored area in the country. Among the five states with less than 10 species recorded, four are located in this region, including Alagoas. Underrepresentation of state biodiversity is undoubtedly a major issue for Brazilian Neuroptera. As indicated by a recent survey in Paraná state which registered an increase of 46% in local neuropterofauna, including the first official records for diverse and commonly collected groups like the owlflies (Myrmeleontidae: Ascalaphinae) (Schuster and Machado, 2021).

Amazonas and São Paulo are also the states with the highest number of endemic species, 25 and 18 respectively. However, in terms of endemic species percentage, the states of Mato Grosso do Sul and Santa Catarina are the highest, with 23% each. Although Mato Grosso do Sul is probably underexplored, with only 13 Neuroptera species recorded from the state, in contrast, Santa Catarina with 61 species, is paramount in emphasizing the existence of endemic neuropteran communities in Brazil. Myrmeleontidae is the most widespread family in the country with records for all states except Alagoas and Acre. The family Osmylidae has the most restricted distribution within Brazil, with records for only seven states, all concentrated in the Mata Atlântica biome (Supplement 1). Among Brazilian species of Neuroptera, the mantispid *Zeugomantispa virescens* (Rambur), recorded in 18 states, is the most widespread neuropteran within the country (Supplement 1), which is not a surprise as the distribution of this species is very large, occurring from Mexico to Argentina, including the Caribbean islands (Ohl, 2004).

Among the six Brazilian terrestrial biomes, the Mata Atlântica is the most diverse with 227 species records, or more than 50% of the total Brazilian neuropterofauna (Fig. 6). The second most diverse biome in Brazil is the Amazônia with 192 known species. These two speciose regions also represent the biomes with the highest percentage of endemicity, with Amazônia (33.8%) and the Mata Atlântica (32.1%) reinforcing the importance of these threatened rainforests in conserving the Brazilian neuropterofauna. Among the smaller Brazilian biomes, the Pantanal and Pampas are also the least diverse ones, with 11 and 25 species respectively. However, the preservation of these ecologically unique regions is still highly important, since 18.2% and 16% of their respective neuropterofauna are endemic (Fig. 6).

Families

Osmylidae, commonly known as the lance lacewings, is the least diverse family of Neuroptera in Brazil, with only three species divided into two genera, *Gumilla* Navás and *Isostenosmylus* Krüger (Tables 1 and 2). The family also displays the smallest distribution within the country. Their range is restricted to the Mata Atlântica, particularly in areas of high elevation or latitude, reinforcing the idea that these insects, particularly *Isostenosmylus*, prefer colder temperatures, as mentioned by Martins et al. (2019). Despite the low species diversity of the family in the country, the Brazilian taxa are very important to the phylogenetic studies of the family evolution, especially due to the presence of *Gumilla*, the sole extant genus classified in the subfamily Gumillinae, and known to possess many plesiomorphic characters (Winterton et al., 2017). The phylogeny of the family was studied recently by Winterton et al. (2017) and a list of all extant and extinct species was presented by Winterton et al. (2019a). The Brazilian species can be identified by the papers by Martins et al. (2016, 2019). Information about Brazilian osmylid larvae can be found in Martins et al. (2016, 2018), however, their behavior and biology remain virtually unknown.

The family Berothidae, or beaded lacewings, is represented in Brazil by four species and three genera, with all described species endemic to the country. Berothidae was the final remaining family of Neuroptera to be reported to the country, and it was only in 1985 with the description of *Lomamyia trombetensis* Penny that the family was recorded from Brazil (Penny 1983). This species remained as the sole Brazilian berothid until 2016, when a new species in the genus *Spiroberotha* Adams was described (Machado and Krolow, 2016). In 2022, the family exceeded the diversity of Osmylidae with the description of two new species in the new genus *Speleoberotha* Machado et al. (2022). The recent increase in the diversity of the family reinforced the idea that the group is currently underrepresented in the country, and phylogenetically important new taxa will likely be discovered in the future. For example, *Speleoberotha*, which is the first Berothidae related to caves ever described, and its taxonomical placement in the subfamily Cyrenoberothinae, represents a rare and key group for the overall understanding of the superfamily Mantispoidea evolution. The Brazilian beaded lacewing species can be identified by the three papers mentioned in this paragraph.

The third least diverse Neuroptera family in Brazil, with eleven described species, is the Dilaridae, or pleasing lacewings. All species of Dilaridae from the country are classified in the genus *Nallachius* Navás, the sole dilarid genus present in the New World. The Brazilian species can be identified using the morphological key provided by Machado and Rafael (2010a). All species recorded from Brazil are endemic, except *Nallachius reductus* Carpenter which was previously known from Paraguay and only recently recorded from Brazil (Schuster and Machado, 2021).

Rhachiberothidae, the thorny lacewings, is the next family in species diversity with 18 species divided into three genera, with 50% of the species endemic to Brazil. The family Rhachiberothidae was historically restricted to Africa, but recent phylogenetic analyses concluded that the subfamily Symphrasinae, traditionally classified in Mantispidae, is instead closely related to Rhachiberothidae (Winterton et al., 2018; Ardila-Camacho et al., 2021a). Based on these results, the Neotropical subfamily Symphrasinae was transferred from Mantispidae to Rhachiberothidae (Ardila-Camacho et al., 2021a), expanding the distribution of this once African endemic family. The Symphrasinae is currently under taxonomic review and the number of species known from Brazil will certainly increase. Rhachiberothid species recorded from the country can be identified using the keys in Penny (1982), Penny and Costa (1983), and Machado (2018), however, it is important to note these publications include the subfamily Symphrasinae still classified in Mantispidae. Information about the biology of the thorny lacewings can be found in the comprehensive study published by Ardila-Camacho et al. (2021b).

The next family, Sisyridae, commonly named the spongillaflies, is represented by 20 species (25% endemic), divided into two genera that occur throughout the New World, *Climacia* MaLachlan and *Sisyra* Burmeister. Sisyrids represent the only truly aquatic neuropterans in Brazil, with the larvae living in association with sponges and bryozoans (Assmar et al., 2022). The group is currently under taxonomic revision and the Brazilian species of spongillaflies can be identified by the keys presented in Assmar and Salles (2017) and Assmar et al. (2022).

Hemerobiidae, brown lacewings, are represented in Brazil by 26 species divided into six genera and five subfamilies. Hemerobiids display the lowest percentage of endemic species for any Brazilian neuropteran family, only 19% (five species). The Brazilian species were listed by Lara and Perioto (2016) and complemented by more recent discoveries by Lara and Perioto (2021). Unfortunately, there is no identification key comprising all Brazilian species of brown lacewings, but there are regional keys available that focus on Amazonian hemerobiid fauna (Penny and Monserrat, 1983). Recommended identification keys at the genus level were presented by Oswald (1993). Specimens of Hemerobiidae are commonly collected and can be found in a variety of different habitats in the country. However, the family has been recorded in only 16 of the Brazilian states. Because of these factors, it is assumed that the distribution & species diversity of the family is underestimated in Brazil.

Based on the current classification, the family Mantispidae, mantisflies, are represented in Brazil by only 34 species (38% endemic) in ten genera. Recently the subfamily Symphrasinae, traditionally placed in Mantispidae, was transferred to Rhachiberothidae (Ardila-Camacho et al., 2021a), resulting in a loss of species diversity for the family. Most of the Brazilian mantispid fauna was last revised by Machado and Rafael (2010b) and can be identified by the keys provided in the study. The few genera not covered in that research, including *Climaciella* Enderlein and *Entanoneura* Enderlein, are now under revision and the results will contribute to an increase in the number of species in the country. One additional taxonomic issue that remains related to the Mantispidae is five species recorded from Brazil that are currently classified in *Mantispa* Illiger, a genus that is now recognized to only occur in the Old World (Hoffman 2002). These five species were described by Longinos Navás or Günther Enderlein in the early the 1900's (Supplement 1) and are only known by their respective brief descriptions based on one or two individuals.

Coniopterygidae, the dustywings, is the third most diverse family of Neuroptera in Brazil, with 46 species (60.9% endemic), divided into four genera. The Brazilian dustywings were recently addressed by Martins and Amorim (2016), who described two new species, including the first record of the genus *Incasemidalis* Meinander to the country, and also provided a checklist & key to the species. The taxonomy of the family in Brazil was heavily influenced by the studies of Meinander, who over 18 years had described a total of 38 species, accounting for 82.6% of the current Brazilian fauna (Meinander, 1972, 1974, 1980, 1983, 1986, 1990; Meinander and Penny, 1982). Despite ranking third in species diversity, coniopterygids are believed to be underrepresented in the country and future studies focusing on unsampled regions will certainly provide new taxa to Brazil. One such example is the species of *Coniopteryx* Curtis that was reported from the archipelago of Fernando de Noronha, which is probably an undescribed, and represents one of only three species of Neuroptera known from this volcanic chain of islands. The other two neuropteran species recorded from Fernando de Noronha belong to the genus *Ceraeochrysa* Adams (Chrysopidae) (Rafael et al., 2020).

The Myrmeleontidae, antlions and owlflies, represent the second most diverse family in Brazil with 88 species (34% endemic) divided

into 25 genera. The family Myrmeleontidae was the focus of several recent phylogenetic studies (Badano et al., 2017; Michel et al., 2017; Wang et al., 2017; Winterton et al., 2018; Jones, 2019; Machado et al., 2019) that culminated in a new classification for the family that now includes the owlflies, the insects traditionally classified in the family Ascalaphidae, as subfamily of Myrmeleontidae (Machado et al., 2019). According to this new classification, the Brazilian fauna includes species classified in three of the four subfamilies and eight of the 17 tribes of Myrmeleontidae. The subfamily Ascalaphinae in Brazil is represented by four tribes, Dimarini, Ascalaphini, Haplogleniini, and Ululodini, with the last three tribes corresponding to the owlflies, traditionally placed in the former family Ascalaphidae. Currently there are 38 species of Brazilian owlflies in nine genera, but the Neotropical fauna of the subfamily Ascalaphinae is in desperate need of revision. Many of the major genera lack modern taxonomic treatments and there are no keys focusing on Brazilian species, hindering identification to the species level in some genera, such as *Ameropterus* Esben-Petersen and *Ululodes* Smith. The genera recorded from Brazil can be identified using the keys provided by Penny (1981).

The remaining Brazilian species of Myrmeleontidae are the traditional antlions and are represented by five tribes and three subfamilies. The Dimarini, with only one species, is placed in Ascalaphinae. With eight genera in Brazil, the Glenurini is the only tribe of Nemoleontinae present in the New World. Finally, the Acanthaclisini (1 species), Brachynemurini (14 species and four genera), and Myrmeleontini (13 species and two genera) are the tribes representing the subfamily Myrmeleontinae in Brazil. Despite the relatively large number of myrmeleontid species present in the country, many of the major lineages of the antlions lack comprehensive taxonomic studies, like *Myrmeleon* Linnaeus, the most commonly sampled genus in Brazil. Species identification in *Myrmeleon* is very difficult, because of a total absence of modern taxonomic treatments. Future research focusing on the Brazilian antlion fauna will certainly result in taxonomic changes and many new taxa assigned to Myrmeleontidae. Antlions can be identified to genus using the world key developed by Stange (2004), but keys focused on species identification are present only for a limited number of genera. These taxa belong to the Glenurini, including *Brasileon* Miller & Stange and *Dimarella* Banks in Miller and Stange (1989), *Eremoleon* Banks in Miller and Stange (2016), *Glenurus* Hagen in Machado (2020), *Navasoleon* Banks in Stange and Miller (2018), *Purenleon* Stange in Machado and Tavares (2020), and *Ripalda* Navás in Badano et al. (2018).

Finally, the most diverse family in Brazil is Chrysopidae, the green lacewings, with 182 species (58% endemic) in 19 genera. The most recent classifications of Chrysopidae (Garzón-Orduña et al., 2019; Winterton et al., 2019b; Breitkreuz et al., 2022) divided the family into three subfamilies, Apochrysinae, Notochrysinae, and Chrysopinae, all of which have representatives in Brazil. Apochrysinae is represented by four species and two genera, *Domenechus* Navás and *Loyola* Navás, and can be identified using Winterton and Brooks (2002). Only one species of the genus *Asthenochrysa* Adams & Penny is classified in the subfamily Notochrysinae, and these taxa can be identified by Adams and Penny (1992). The remaining 177 species are included in the Chrysopinae, the most diverse subfamily of green lacewings in Brazil. Chrysopinae is currently divided into five tribes, but only three occur in the country: Belonopterygini with 16 species and four genera, Chrysopini with 73 species and seven genera, and Leucochrysini with 88 species and five genera. The majority of species classified to Leucochrysini, 78 species, belong to *Leucochrysa* McLachlan, the most diverse neuropteran genus in Brazil. Many of these genera are currently the subjects of revisionary studies and the number of species recorded from Brazil will certainly change, including the likely discovery of other genera from neighboring countries not yet officially collected in Brazil, like *Parachrysopiella* Brooks & Barnard. Many of the Brazilian Chrysopinae can be identified using the keys published in de Freitas and Penny (2001), but more recent studies provided additional information for select genera, including *Ceraeochrysa* Adams (Freitas et al., 2009), *Gonzaga* Navás (Tauber et al., 2008), *Nuvol* Navás (Tauber and Sosa, 2015), *Santocellus* Tauber (2012), *Titanochrysa* Sosa & de Freitas (Tauber et al., 2012), *Ungla* Navás (Tauber et al., 2017), and *Vieira* Navás (Sosa and Tauber, 2017).

Future studies

As mentioned in the sections above, the overall knowledge on the Brazilian neuropterofauna still contains gaps that should be addressed in future studies. One major concern that must be addressed is the high number of undersampled regions in the country. As demonstrated using our dataset, the neuropterofauna of many Brazilian states and biomes are still certainly underrepresented, based on our metrics of species diversity and endemism. Future field research efforts should focus on areas like the Northeast region, the political region with the highest number of states with less than ten Neuroptera species recorded. Similarly, biomes that have been historically undersampled, including Caatinga, Cerrado, Pantanal and Pampas, need to be targeted in future biodiversity projects. However, Brazilian states and biomes that currently display relatively high diversity and endemicity should not be excluded from research efforts, given local fauna is unlikely to be fully catalogued even in these areas. This principle was recently demonstrated by Schuster and Machado (2021), who presented a 46% increase in the neuropterofauna known from the state of Paraná, which is almost entirely located in the Mata Atlântica biome, the most diverse biome for lacewings in Brazil (Fig. 6).

Future field work should also explore unique local microhabitats and use a variety of collecting equipment & techniques, as neuropterans are known for the rich diversity in their life histories. Adults of spongillaflies for example, are easily collected near bodies of water, while some antlions prefer dry regions characterized by sandy soils. The importance of using multiple collecting strategies in different places was demonstrated by the findings of Machado et al. (2022), who described the new beaded lacewing genus *Speleoberotha*, from specimens collected inside or near caves using CDC traps, which are typically not used for collecting adult neuropterans.

Other important aspects that should be prioritized are studies focused on Neuroptera groups that were seemingly historically neglected. As noted in the previous section, many genera classified in the two most diverse families in Brazil, Myrmeleontidae and Chrysopidae, are almost impossible to identify to species, because modern taxonomic treatments are lacking and keys to these groups are unavailable. On the other hand, studies focusing on less diverse neuropteran families should not be avoided, as demonstrated by several recent works that presented some important new records for these families in Brazil, including the description of many new taxa (Machado and Rafael, 2010a; Machado and Krolow, 2016; Martins & Amorim, 2016; Martins et al., 2019; Lara and Perioto, 2021; Assmar et al., 2022; Machado et al., 2022).

Future taxonomic works should preferably be led by local Brazilian researchers, as demonstrated by the data presented in this study. The first quarter of the 21st century marks the time period when the highest number of neuropteran species were recorded from the country per year, and also corresponds to the period that taxonomical studies were mostly headed by Brazilian researchers. This does not mean that international collaboration is not important, we would suggest exactly the opposite, since most of the type specimens of Brazilian species are deposited in foreign institutions (Table 5). Likewise, comprehensive phylogenetic studies must address entire lineages and not only local fauna. Furthermore, another very important aspect that should be taken in consideration in future studies is gender equality and social

Table 7
Current knowledge of the immature stages of Brazilian species of Neuroptera.

Family	Number of Species	Immature Known	Percentage
Berothidae	4	0	0
Chrysopidae	182	27	14.8
Coniopterygidae	46	0	0
Dilaridae	11	0	0
Hemerobiidae	26	3	11.5
Mantispidae	34	2	5.9
Myrmeleontidae	88	13	14.7
Osmylidae	3	0	0
Rhachiberothidae	18	1	5.5
Sisyridae	20	1	5
TOTAL	432	47	10.9

inclusion policies, in order to compensate historical issues, for example, the author gender bias illustrated by our dataset.

Lastly, as indicated by previous studies of Neuroptera (e.g., Martins, 2019) and highlighted by our current dataset, one important aspect that must also be addressed in future studies is the lack of taxonomic & biological data for many immature stages of neuropterans. The data presented in this study is almost entirely based on adult records. In fact, only 47 of the Neuroptera species recorded from Brazil (10.9%) have their respective larva described, or at least illustrated in the literature (Table 7; Supplement 1). Four of the Brazilian families have no larva described, including Coniopterygidae, the third most diverse family in the country. The family with the greatest number of larvae described in the literature is Chrysopidae with 27 species, or 57% of the total neuropteran larvae known from Brazil, undoubtedly due to the importance of the larva of green lacewings in biological control programs. It is clear that studies focusing on the immature stages of Brazilian Neuroptera should be prioritized, since a complete understanding of the larva is crucial for the comprehension of the evolution of the order, their ecological impacts, and for the overall preservation of the group.

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Conflicts of interest

The authors declare no conflicts of interest.

Author contribution statement

Both authors contributed designing the study, analyzing the data, writing the text, and preparing the images and table.

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Supplementary material

The following online material is available for this article:

Supplement 1 - Spreadsheet with information of all extant Neuroptera species recorded from Brazil.