



Anais da Academia Brasileira de Ciências (2017) 89(3): 1543-1553
(Annals of the Brazilian Academy of Sciences)
Printed version ISSN 0001-3765 / Online version ISSN 1678-2690
<http://dx.doi.org/10.1590/0001-3765201720150378>
www.scielo.br/aabc | www.fb.com/aabcjournal

Spider species richness and sampling effort at Cracraft's Belém Area of Endemism

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Manuscript received on June 19, 2015; accepted for publication on March 18, 2016

ABSTRACT

A list of spider species is presented for the Belém Area of Endemism, the most threatened region in the Amazon Basin, comprising portions of eastern State of Pará and western State of Maranhão, Brazil. The data are based both on records from the taxonomic and biodiversity survey literature and on scientific collection databases. A total of 319 identified species were recorded, with 318 occurring in Pará and only 22 in Maranhão. About 80% of species are recorded at the vicinities of the city of Belém, indicating that sampling effort have been strongly biased. To identify potentially high-diversity areas, discounting the effect of variations in sampling effort, the residues of a linear regression between the number of records and number of species mapped in each 0.25° grid cells were analyzed. One grid, representing the Alto Turiaçu Indigenous land, had the highest deviation from the expected from the linear regression, indicating high expected species richness. Several other grid cells showed intermediate values of the regression residuals, indicating species richness moderately above to the expected from the model.

Key words: Amazon, araneae, diversity, fragmentation.

INTRODUCTION

Spiders are both highly abundant and diverse organisms. There are above 46.000 species described (World Spider Catalog 2017), but these figure is presumed to represent only a fraction of the actual species diversity of the group (Costello et al. 2012). Additionally, the taxonomic and biogeographic knowledge on the spiders is biased both taxonomically and geographically (Brescovit

et al. 2011a). The Amazon Basin in particular is still largely unknown regarding spider species richness and composition and the available samples from this region came mostly from easily accessible areas (Heyer et al. 1999, Oliveira 2011), as already observed for Amazonian plants (Nelson et al. 1990, Hopkins 2007) and birds (Vale and Jenkins 2012). Several spider inventories have been done in recent years in Brazilian Amazonia (Bonaldo et al. 2009a, b, Ricetti and Bonaldo 2008, Bonaldo and Dias 2010, Dias and Bonaldo 2012, Venticinque et al. 2007). However, despite these efforts, large

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portions of the Amazon Basin remain undersampled and the checklists provided were mostly based in the recognition of morphospecies, a situation that severely limits the study of biogeographic patterns.

The Amazon Basin presents high landscape heterogeneity, with several distinct phytophysionomies that offer a myriad of different habitats (Silva et al. 2005). Studies on biogeography of vertebrates (Haffer 1978 [birds], Ávila-Pires 1995 [lizards], Silva and Oren 1996 [primates], Ron 2000 [amphibians]) indicated that the distribution of several species in the Amazon Basin is not continuous and proposed that the similar patterns of limited distribution of these vertebrates could lead to the recognition of areas of endemism. According to these authors, eight to ten areas of endemism can be delimited within the Amazon Basin. These areas of endemism are separated by the main river systems, which supposedly acted as effective physical barriers for these animals and lead to vicariant events of speciation (Haffer and Prance 2002 – but see Oliveira et al. 2015).

The Belém Area of endemism (BAE), proposed by Cracraft (1985) based on historical biogeography of avifauna, represent unique homogeneous ecoregion, originally covered by dense ombrophylous Amazonian forest. This is the most threatened of the areas of endemism proposed by Cracraft (1985) for the Amazon Basin, suffering with habitat loss caused by deforestation, fire and fragmentation (Silva et al. 2005). In the last 400 years, the BAE has undergone great landscape transformations, being currently formed by a mosaic of forest remnants. Most of these remnants are covered by relatively young secondary forest, since nearly half the deforestation within the BAE occurred in the last 30 years. The primary forest remnants are restricted to a few large blocks, represented by indigenous reservations, the Gurupi Biological Reserve and a few private areas (Almeida and Vieira 2010). The BAE also comprises the northern portion of the “arc of deforestation”, a

large region stretching from the State of Maranhão to the State of Acre (Ferreira et al. 2005), which concentrates most of the logging and agricultural activities in the Brazilian Amazonia (Costa and Pires 2010).

As indicated above, the delimitation of Amazonian areas of endemism is based on vertebrate distribution data. The distribution of lesser-known taxonomic groups, like arthropods, is still virtually unknown for the entire Amazon basin, except for studies based on butterflies (Brown et al. 1995, Racheli and Racheli 2004). Considering that arthropods represent the majority of animal species on Earth, filling this knowledge gap seems to be an urgent task for the effective conservation of Amazonian biota. Thus, this study provides a faunistic list of spiders from the BAE, with data compiled from all available sources, including ordinary material from museum collections as well as data from primary taxonomic and biodiversity survey literature. Furthermore, we map the species richness and sampling effort of spiders in the BAE. We restrict the list to the specimens that were identified down to species, since non-identified morphospecies distribution could not be accessed in large geographic scale without examining primary specimens. Thus, the list represents only a portion of the sampling at hand, and is obviously just a fraction of the actual spider species richness in the area. Considering that the rate of success of species identification in structured inventories carried on in east Amazonia fluctuates between 25% and 35%, we estimate that the list below represents nearly 30% of all species of the BAE available in the studied collections. However, that small portion is the only one that is readily comparable to similar lists from other regions, reflecting the current knowledge on taxonomy of Amazonian spiders. Gathering these data progressively for each of the areas of endemism recognized for the Amazon basin could prove to be a necessary step towards

understanding how spiders are distributed in the region.

MATERIALS AND METHODS

The BAE is totally inserted in Brazilian territory, located in the physiographic zone that lie on east of State of Pará and west of State of Maranhão, comprising 243.753,18 Km², located between 00° 30' and 06° 00' S and 44° 00' and 50° 00' W (Figure 1a). The BAE includes 27 conservation units and 14 indigenous lands in 149 municipalities, 69 of which in Pará and 80 in Maranhão (Almeida and Vieira 2010). The vegetation is composed mainly of Dense Ombrophylous Forest and areas characterized by different types of use. It also has two main climate areas, the humid equatorial with annual average rainfall greater than 2.000 mm, and the tropical equatorial zone with annual average rainfall of 1.500 mm. The relief is composed by plateaus, depressions and plains (Almeida et al. 2013).

A list of spider species recorded in the BAE were compiled from the databases of Museu Paraense Emílio Goeldi (MPEG, curator: A.B. Bonaldo), Instituto Butantan, São Paulo (IBSP, curator: A.D. Brescovit) and Museu de Zoologia da Universidade de São Paulo (MZSP, curator: R. Pinto da Rocha). These collections were chosen because they hold greater representation of the BAE spider fauna. Records from the taxonomic and biodiversity survey literature were gathered from a database of Brazilian spider distribution (see Brescovit et al. 2011a). The list is arranged taxonomically as in the World Spider Catalog (2017).

To determine which species were considered potentially endemic, first we reviewed the primary literature of all species and we identified which had distribution restricted to BAE. Then, we checked whether these species were present in other localities in the collection databases, and also

verified the presence of these species in important species lists of the Neotropical region, especially in Amazon (Dias and Bonaldo 2012, Höfer and Brescovit 2001, Ricetti and Bonaldo 2008, Venticinque et al. 2008, Bonaldo et al. 2009a, b, Brescovit et al. 2011a, Buckup et al. 2010). Thus, a species was only considered potentially endemic if recorded so far only for the BAE, being absent in the verified databases and species list.

To access the current state of knowledge of spider species richness in the BAE, the number and density of distribution records were used as indicators of sampling effort. The spatial variation of the sampling effort and species richness was expressed in maps with 0.25° grid cells. This size of grid cells was considered ideal because raster maps with larger grid cells would not reveal collecting gaps. Grid cells were classified regarding the number of records and species into five categories according to the natural gaps in their distribution, which ranks values in ranges with the greatest variation, calculated using DIVA-GIS (Hijmans et al. 2004) and ArcGIS 10.1 (ESRI 2012).

The relationship between species richness and sampling effort in the sampled area was analyzed through a least-squares linear regression. To identify potentially high-diversity areas, discounting the effect of variations in sampling effort, we analyzed the residues of the linear regression between the number of records and number of species in each grid cell. The potential diversity of each cell was expressed as the difference between the species richness observed and expected according to the regression model, composing an index of potential species richness, which were plotted on a map. All statistical analyses were done in Statistica 7.0 (StatSoft 2004).

RESULTS AND DISCUSSION

A total of 319 species distributed in 163 genera and 39 families were recorded for the BAE (Appendix

– Supplementary Material). These figures represent an underestimation, since much of the material in collections are from unrevised groups and was therefore not included. This taxonomic deficit is reflected even in the representation of families known to occur in the region: the number of families listed should be 46, but Anapidae, Caponiidae, Deinopidae, Dictynidae, Filistatidae, Mimetidae, Philodromidae and Symphytognathidae are recorded only from specimens identified, at best, to genus level. On the other hand, the families Araneidae (99 spp.), Salticidae (52 spp.) and Theridiidae (36 spp.) are the most representative, with about 60% of total identified species. It is not a coincidence that the majority of recent revisions of Neotropical genera are from these families, which are also the groups with more nominal species in the lists of states of São Paulo (Brescovit et al. 2011a) and Rio Grande do Sul (Buckup et al. 2010).

This paper records the occurrence of spiders in about 25% of the BAE municipalities, seven belonging to the state of Maranhão and thirty-one to the state of Pará (Table I). All listed species were recorded in Pará, except *Micrathena macfarlanei* Chickering, 1961. Only 22 species were recorded in Maranhão. This odd pattern may be explained by a differential sampling effort, much more intense in the state of Pará. The city of Belém, capital of the state of Pará, contributed with about 80% of all species recorded in the entire BAE (Figure 1b). The municipality of Belém was an important collecting point of XIX century naturalist expeditions to Brazil, and it was reported in old literature as “Le Para” (Levi 1964a). As a result, the BAE presents great historic significance to taxonomy, harboring the type localities of at least 40 spider species, all of them from state of Pará, 29 of which from Belém. Additionally, the fact that Belém presently harbors one of the most important Brazilian spider collections (MPEG) and an active spider taxonomy and ecology study group also explains this pattern. The contribution to the BAE spider samples for

the list of the state of Pará as a whole is also very expressive. Brescovit et al. (2011a) recorded 3,203 nominal species from Brazil, in 659 genera and 72 families. From the state of Pará, there are 696 nominal species recorded, distributed in 291 genera and 46 families (Brescovit et al. 2011b). About 40% of these species are recorded in the BAE.

The linear regression model indicated a strong relationship between species richness and sampling effort, expressed by the number of records ($R^2=0.96$, $p<0.01$) (Figure 1b, c). The greatest concentration of sampling effort is in the northwestern BAE and, as mentioned above, the surroundings of the city of Belém is particularly diverse, with 247 species. The second more diverse region was the Alto Turiaçu Indigenous land, with 78 species. However, this region had the highest deviation from the expected from the linear regression model, indicating expected species richness highly above the observed. The relationship between the observed species richness and sampling effort in this grid was comparatively weak, and no recent records were obtained from that area (all records from the region were produced in a single locality – Canindé, municipality of Paragominas, in the state of Pará (2°31'50"S 46°25'19"W) - sampled in the 60's by B. Malkin). Thus, the Paragominas vicinities may be elected as a priority area for further spider inventories within the BAE. Several grid cells showed intermediate values of the regression residuals, indicating a species richness moderately above the expected by the regression model (Figure 1d).

Due to the large sampling gaps across the Amazon Basin, which impose several limitations to the knowledge of actual distribution patterns of Amazonian spiders (Oliveira et al. 2015), as well as several taxonomic limitations, which prevent the input of data, determining species that may be endemic to a given region is not an easy task. The situation is further complicated by the scanty and poorly informative historical literature, as well as

by the lack of experts who could provide reliable identifications. Nevertheless, it was possible to identify 18 species with potentially endemic distribution within the BAE (Table II). This figure probably do not represent the actual fauna of BAE endemics, since at least some groups that were reported in the literature to be microdistributed, as Oonopidae (Platnick et al. 2013, Bonaldo et al. 2014), were severely misrepresented in the present data set. However, many spider species present a wide distribution and some species are capable to occupy synanthropic habitats (e.g. Brazil et al. 2005). In the current study, 27 synanthropic species were recorded. The most common ones are

Hasarius adansoni (Audouin, 1826), *Menemerus bivittatus* (Dufour, 1831), *Nesticodes rufipes* (Lucas, 1846), *Oecobius concinnus* Simon, 1893, *Plexippus paykulli* (Audouin, 1826), *Physocyclus globosus* (Taczanowski, 1874) and *Zosis geniculata* (Olivier, 1789). Two species, *Cithaeron praedonius* O. Pickard-Cambridge, 1872 and *Zimiris doriai* Simon, 1882, were recently recorded for the first time in western Amazonian region (Ruiz and Bonaldo 2013).

The data here presented depicts the state of knowledge of spider taxonomy and the sampling effort applied so far in one of the most impacted areas of Brazilian Amazon, highlighting great sampling gaps in the area, especially in the Amazonian portions of the state of Maranhão, from

TABLE I
Total of identified spider species recorded in municipalities from the Belém Area of Endemism.

State	Municipalities	Nº Species
Maranhão	Açailândia	1
Maranhão	Bom Jardim	7
Maranhão	Centro Novo do Maranhão	16
Maranhão	Mirinzal	2
Maranhão	Peri-Mirim	1
Maranhão	Pindaré-Mirim	2
Maranhão	São Bento	2
Pará	Abaetetuba	1
Pará	Acará	2
Pará	Ananideua	14
Pará	Barcarena	8
Pará	Belém	247
Pará	Benevides	20
Pará	Bragança	19
Pará	Breu Branco	5
Pará	Bujarú	4
Pará	Capanema	1
Pará	Capitão-poço	2
Pará	Castanhal	2

TABLE I (continuation)

State	Municipalities	Nº Species
Pará	Dom Eliseu	1
Pará	Goianésia do Pará	1
Pará	Igarapé-Açu	8
Pará	Irituí	1
Pará	Jacundá	11
Pará	Marapanim	1
Pará	Marituba	3
Pará	Mocajuba	2
Pará	Moju	16
Pará	Nova Ipixuna	18
Pará	Paragominas	76
Pará	Primavera	1
Pará	Santa Bárbara	4
Pará	Santa Isabel	5
Pará	Santo Antônio do Tauá	5
Pará	São Domingos do Capim	1
Pará	Tailândia	21
Pará	Tomé-Açu	2
Pará	Vigia	2

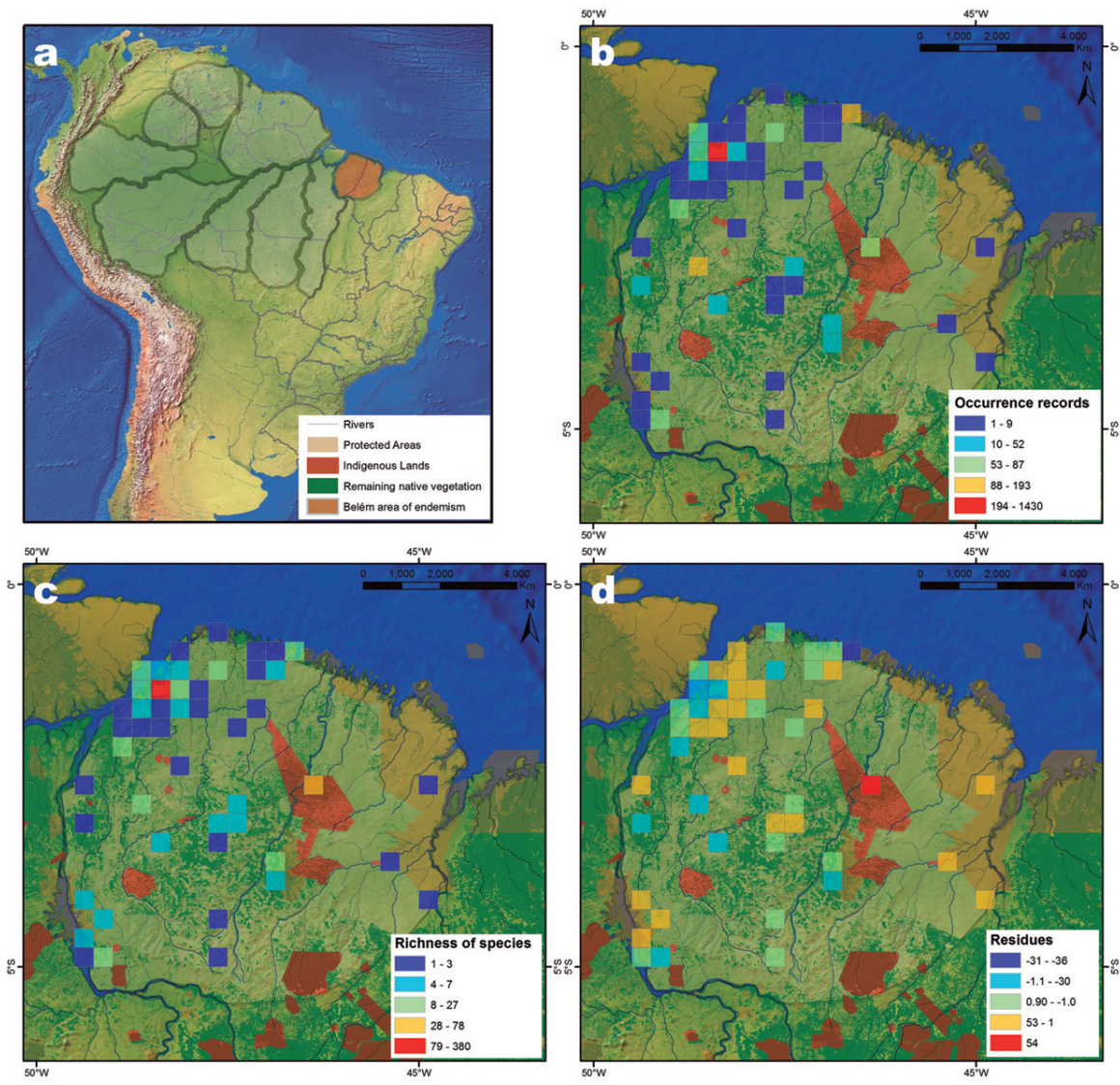


Figure 1 - a, Localization of the Belém Area of Endemism; **b,** number of distribution records per grid cell; **c,** observed species richness and, **d,** residues from species richness X distribution records linear regression (see text for details).

where only 22 species were recorded. We expect that replicating the present approach to other areas in the Amazon Basin can contribute to a better understanding of the patterns of spider distribution in the region. Addressing the question to how congruent are these patterns with those presented by other groups could ultimately lead to a refinement of the current recognized areas of endemism.

The preservation of forest remnants has been an increasingly important concern, since the fragmentation compromises the natural populations,

resulting in the disappearance of species even before they are known to science. For this reason, some areas should be considered priority for structured inventories. In the BAE region, the central Dense Ombrophyllous Forest remnants would be the most important, since they still have continuous patches of primary forest. These areas have the greater potential species richness values, but are largely undersampled regarding spider fauna, presenting few records of either identified or unidentified individuals. Some of these remnants are small (less

TABLE II
Potentially endemic species of spiders from the Belém Area of Endemism.

Family	Potentially endemic species
Araneidae	<i>Metazygia aldela</i> Levi, 1995
Araneidae	<i>Taczanowskia trilobata</i> Simon, 1897
Corinnidae	<i>Abapeba echinus</i> (Simon, 1896)
Idiopidae	<i>Idiops siolii</i> (Bücherl, 1953)
Linyphiidae	<i>Paraletes timidus</i> Millidge, 1991
Oonopidae	<i>Aschnaonops caninde</i> Platnick et al., 2013
Oonopidae	<i>Aschnaonops belem</i> Platnick et al., 2013
Oonopidae	<i>Scaphiella capim</i> Platnick & Dupérré, 2010
Palpimanidae	<i>Otiotrops baculus</i> Platnick, 1975
Palpimanidae	<i>Otiotrops facis</i> Platnick, 1975
Salticidae	<i>Freya rubiginosa</i> (C. L. Koch, 1846)
Salticidae	<i>Lyssomanes sylvicola</i> Galiano, 1980
Senoculidae	<i>Senoculus plumosus</i> (Simon, 1880)
	<i>Rhomphaea velhaensis</i> (González & Carmen, 1996)
Theridiidae	<i>Theridion agrarium</i> Levi, 1963
Theridiidae	<i>Theridion paraense</i> Levi, 1963
Thomisidae	<i>Titidius gurupi</i> Esmerio & Lise, 1996
Thomisidae	<i>Tobias epicadoides</i> Mello-Leitão, 1944

than 15 ha) and largely surrounded by pastures or other human-modified landscapes, a situation that makes them particularly vulnerable to habitat destruction. Furthermore, the surroundings of these remnants also depicts small patches of poorly sampled primary forest that also deserve attention, a situation that makes the central portion of BAE to be considered the top priority for the conducting future spider inventories within the region.

ACKNOWLEDGMENTS

This paper is a contribution of the Project “Instituto Nacional de Ciência e Tecnologia em Biodiversidade e Uso da Terra na Amazônia” (INCT - CNPq Proc.: 574008-2008-0). Field and laboratory work was also sponsored by the Programa de

Pesquisa em Biodiversidade (PPBio/NLP, CNPq Grant 558202/2009-8). The support from various grants was greatly appreciated: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). ABB, CNPq-PQ grant #304965/2012-0; ADB, CNPq-PQ grant #301776/2004-0 and FAPESP 2011/50689-0; AJS, CNPq grants #475179/2012-9 and #308072/2012-0. AJS also thanks FAPEMIG (PPM-00335-13), CNPq (475179/2012-9, 407288/2013-9, 308072/2012-0) and Instituto Nacional de Ciência e Tecnologia dos Hymenoptera Parasitóides da Região Sudeste Brasileira (<http://www.hympar.ufscar.br/>). BVBR received a Doctoral fellowship (CAPES). UO was sponsored by FAPEMIG and CAPES fellowships.

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SUPPLEMENTARY MATERIAL

Appendix - List of spider species recorded in the Belém Area of Endemism, with their respective data sources, municipalities and type-localities (when within the BAE). *Potentially endemic species; **Synantropics species.