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ECOSYSTEMS

Distribution and Endemism Areas of *Bonamia* Thouars (Convolvulacea) in Brazil

FLAVIA KATERINE DA SILVA, EDUARDO T. AMORIM, GABRIEL HENRIQUE O. CAETANO, MARIA ROSA V. ZANATTA, ROBERTA KEYLA KOJIMA & ANDRÉ LUIZ C. MOREIRA

Abstract: Brazil harbors the highest richness of Convolvulaceae with 424 species recognized mainly distributed in the Amazon, Atlantic Forest, *Caatinga* and *Cerrado* phytogeographic domains. Seventeen of these species are representatives of *Bonamia*, with ten endemic to the country. The aim of the study was to map the distribution of this group to understand its richness, its sampling and detecting areas of endemism, valuable information for conservation. We collected data gathered from herbaria and from the online database. The data were refined (1) excluding of records not at the species level; (2) records with no identification of collection site or with only the identification of the state of collection. There was calculated the richness, the number of records and an estimate of richness per cell. We conducted a parsimony analysis of endemism for distribution analysis. Finally, the knowledge of richness for the species was analyzed. There were gathered 420 occurrence records, in 87 grid cells. Most grid cells observed in the study presented one species. Two endemic areas were found for the genus. The results contribute to the understanding of the distribution of the group in Brazil, highlighting shortfalls in collections.

Key words: Cerrado, conservation, Convolvulaceae, distribution, endemism areas.

INTRODUCTION

Convolvulaceae contains approximately 1.900 species in 60 genera concentrated in tropical and subtropical regions (Staples 2012, WFO 2024). Brazil harbors the highest number of taxa: 24 genera and 424 species, in open phytogeographic domains such as *Cerrado* and *Caatinga*, and in the border of the Atlantic Forest and Amazon (Austin & Cavalcanti 1982, Simão-Bianchini et al. 2024).

Despite its richness, the environmental and ecological importance of this family has been insufficiently explored for Brazil (Buril & Alves 2011), even though it is cited as one of the richest components of the *Caatinga* flora (Giulietti et al. 2002) and is well represented in both total number and endemic species of the *Cerrado* domain (Simão-Bianchini & Pirani 2005). It is of great importance to understand that the distribution and abundance of species might explain other important patterns in communities, such as the slope of the species-area relation (Preston 1960), and the positive association between abundances and patch occupation frequency (Gaston 1996). Furthermore, the distribution of species abundance has many potential applications as it allows us to understand the causes of rarity, which is one of the main tasks of conservation biology (Hubbell 2001).

Bonamia Thouars is a genus of Convolvulaceae, and has 65 species with a huge distribution, ranging from South and North

America to Africa (including, Madagascar), South and Southeast Asia and Australia (Staples 2019, Moreira et al. 2017, 2018, 2019, 2021). Its representatives are mainly herbaceous, rarely climbing vines or subshrubs, characterized by free or partially free styles, non-accrescent sepals, dehiscent fruits, and ovate, obovate, or ovate-cordate cotyledons (Myint & Ward 1968, Austin & Staples 1985, Breteler 1992, Moreira et al. 2021) (Figure 1).

In Brazil, the genus occurs in the Amazon, Atlantic Forest, *Caatinga* and *Cerrado* phytogeographic domains, and has 18 species (Moreira et al. 2021, Moreira & Simão-Bianchini 2024), ten of them are restricted to the country (Moreira & Simão-Bianchini 2024).

In recent years, many species have suffered from habitat fragmentation, as consequence of urban development and expansion of agriculture, especially in open vegetations (Tilman et al. 2017, Prakash & Verma 2022). Based on the MApBiomas Platform (Souza et al. 2020), ca. 33% of natural areas in Brazil have been transformed into agricultural and livestock activity zones in 2020. These activities lead to loss of habitat and might cause the extirpation of local populations due to interruption of ecological interactions. The sum of these factors makes the choice of conservation areas a strategic step for biodiversity conservation (Carvalho & Almeida 2011).

According to Sylvestre (2002) the analysis of geographic distribution patterns is an important tool for the assignment of priority areas for conservation. This analysis gives us information about how species are distributed in phytogeographic domains and locates areas of endemism, which contain exclusive taxa (Szumik & Goloboff 2004). It highlights the specific biodiversity of those locations and priority sites for conservation (Carvalho & Almeida 2011).

The aim of the study was to map the distribution of this group to understand its patterns under quantitative analysis of richness

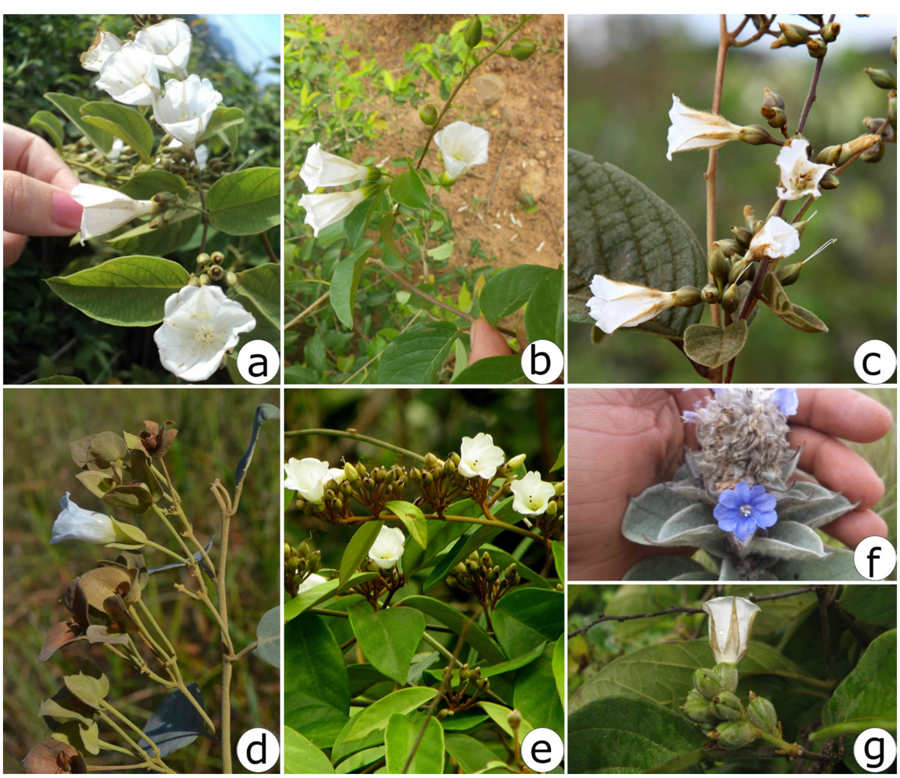

Figure 1. Inflorescences of *Bonamia* representatives. a) B. agrostopolis (Vell.) Hallier f. b) B. balansae Hallier f. c) B. cerradoensis J.R.I.Wood. d) B. kuhlmanii Hoehne. e) B. maripoides Hallier f. f) B. sphaerocephala (Dammer) Ooststr. g) B. subsessilis Hassl. (Photographs: a. R.S. Bianchini; b. J. Wood; c. H. Moreira; d. T. Almeida; e-g. A.L.C. Moreira).

and records of species, and to detect areas of endemism, which is a valuable information for conservation.

MATERIALS AND METHODS

Data collection and refinement

Data was gathered from visits to herbaria and from the online database *SpeciesLink* (https://specieslink.net/) and *Reflora* (https://reflora.jbrj.gov.br/) for herbaria that could not be visited. The original data set included 774 occurrence records identified at the species level by the experts in the group.

The following criteria were used for data cleaning: (1) exclusion of records not at the species level; (2) records with no identification of collection site or with only the identification of the state of collection. In the case of duplicate records, only one was used in the analysis. Synonyms were checked through tropicos.org (Missouri Botanical Garden – http://www.tropicos.org/), as well as specialized literature, and only valid names were kept. For each record we checked if geographical coordinates were present. If not, coordinates were obtained from Google Maps (https://www.google.com.br/maps), and when they could not be found we used the coordinates for the county recorded as the collection site. After cleaning, the samples were reduced to 420 records from the following herbaria: ALCB, BHCB, CEN, CEPEC, CESJ, CGMS, COR, CENTRAL, ESA, FUEL, HB, HEPH, HJ, HRB, HST, HUEFS, HRCB, HURB, HUEM, IAN, IBGE, IPA, INPA, IPA, MBM, PEL, PEUFR, R, RB, SJRP, SP, SPF, UB, UEC, UFG, UFP, BM, COL, DUKE, GH, HBG, K, L, MEXU, MO, NY (acronyms according to Thiers 2024).

Distribution

The geographical distribution of *Bonamia* was inferred from the known coordinates for each species of the genus. We constructed a record csv file which was overlaid with the shapefiles maps of Brazil and Brazilian phytogeographic domains (Fiaschi & Pirani 2009), through the software QGIS 2.0 (Qgis Development Team 2019).

Quantitative analysis

The species records were overlaid in a grid file with a 2° × 2° grid (OGU – Operational Geographical Units) through *software* DIVA-GIS 7.5 (http://www.diva-gis.org/). We plotted the richness and number of records of each grid cell to assess the distribution and sampling effort for the genus in Brazil. To verify the representativity of grid cells, we estimated their species richness using a Jackknife 2 estimator (Magurran 2011). We fit a linear regression model between records and estimated richness, in order to understand if the local richness is influenced by sampling effort. All analysis were performed in *software* R (R Core Team 2021).

Parsimony Analysis of Endemicity

We performed a Parsimony Analysis of Endemicity (PAE) to detect areas with species restricted to certain localities (Rosen 1988, Rosen & Smith 1988). For that, we constructed a presence absence matrix through software Past 2.17b (Hammer et al. 2001), using a 2° × 2° grid. The matrix was then analyzed on *software* Nona 2.0 (Goloboff 1993), WinClada 1.00.08 interface (Nixon 2002), to generate an area cladogram through the parsimony algorithm. We considered monophyletic clades as endemic areas, defined as two or more grid cells with one or more exclusive taxa.

Analysis of knowledge of richness

To map the areas with better sampling of *Bonamia* richness in Brazil, we calculated the proportion between observed and estimated richness in each sampled grid cell. If observed richness was close to estimate, we considered local richness as well-known. The proportion of knowledge in unsampled grid cells was estimated using the species turnover between sampled grid cells. For each sampled grid cell, hereafter referred as focal grid cell, we calculate the proportional species turnover to the three closest sampled grid cells, and then divided it by the distance between the focal grid cell and each of those three. Next, we averaged the three values generated, estimating a turnover over distance rate for each focal grid cell. This rate was multiplied by the distance between each focal grid cell and all other grid cells on the map, creating an estimate of proportional species turnover for each grid cell which increased proportionally to the distance to the focal grid cell. This estimate was then multiplied by the proportion of known species richness of the focal grid cell, generating an estimate of proportional richness knowledge for each grid cell in relation to the focal grid cell. This procedure was repeated for each sampled grid cell and the highest value was retained for each grid cell.

RESULTS

Distribution

We verified through literature records that six species in the genus were distributed outside Brazil, in other South American countries – *Bonamia agrostopolis* (Vell.) Hallier f. (Brazil: Midwest, Northeast, South and Southeast region, Bolivia and Paraguay), *B. balansae* Hallier f. (Midwest Brazil to Eastern Bolivia and Paraguay), *B. cerradoensis* J.R.I.Wood (North and Midwest Brazil to Bolivia), *B. maripoides* Hallier f. (North and South America to North, Northeast and Southeast Brazil), *B. rosiewiseae* J.R.I.Wood (Midwest Brazil to Eastern Bolivia), and *B. subsessilis* Hassl. (North, Northeast, and Midwest Brazil, Bolivia to Paraguay).

Nine species occur only in Brazil, and are considered restricted endemics according to geographical range: (1) species known for more than five localities – *B. austinii* A.Moreira & Sim.-Bianch. (Midwest and Northeast Brazil), *B. ferruginea* (Choisy) Hallier f (North, Midwest and Southeast Brazil), *B. krapovickasii* A.Moreira & Sim.-Bianch.(Midwest and Southeast Brazil), *B. kuhlmannii* Hoehne (North and Midwest Brazil), *B. sphaerocephala* (Dammer) Ooststr. (Midwest, Northeast and Southeast Brazil), *B. linearifolia* A.Moreira & Sim.-Bianch. (North and Midwest Brazil), and *B. umbellata* (Choisy) Hallier f. (Southeast Brazil); (2) comprises species known from one phytophysiognomy in less than five close localities – *B. campestris* A.Moreira & Sim.-Bianch. (North Brazil).

Species richness and distribution

Overall, 14 species are distributed in all Brazilian phytogeographic domains, except the Pampa (Figure 2). The *Bonamia* species richness map overlaid with the phytogeographic domains are shown in Figure 3. The number of species by grid cell is ranged from one to four (Figure 3).

Only a single grid cell showed 4 species and nine showed 3 species. Most grid cells observed in the study presented one species. The *Cerrado* is the richest phytogeographic domain (13 species – *Bonamia agrostopolis*; *B. austinii*; *B. balansae*; *B. campestres*; *B. cerradoensis*; *B. ferruginea*; *B. krapovickasii*; *B. kuhlmannii*; *B. linearifolia*; *B. maripoides*; *B. rosiewiseae*; *B. sphaerocephala*; and *B. subsessilis*), followed by the Amazon Forest (5 species – *B. agrostopolis*; *B. cerradoensis*; *B. ferruginea*; *B. kuhlmannii*, and *B. maripoides*), Atlantic Forest (4 species – *B. agrostopolis*; *B. ferruginea*; *B. maripoides*; and *B. umbellata*.), and *Caatinga* (2 species – *B. agrostopolis* and *B. sphaerocephala*).

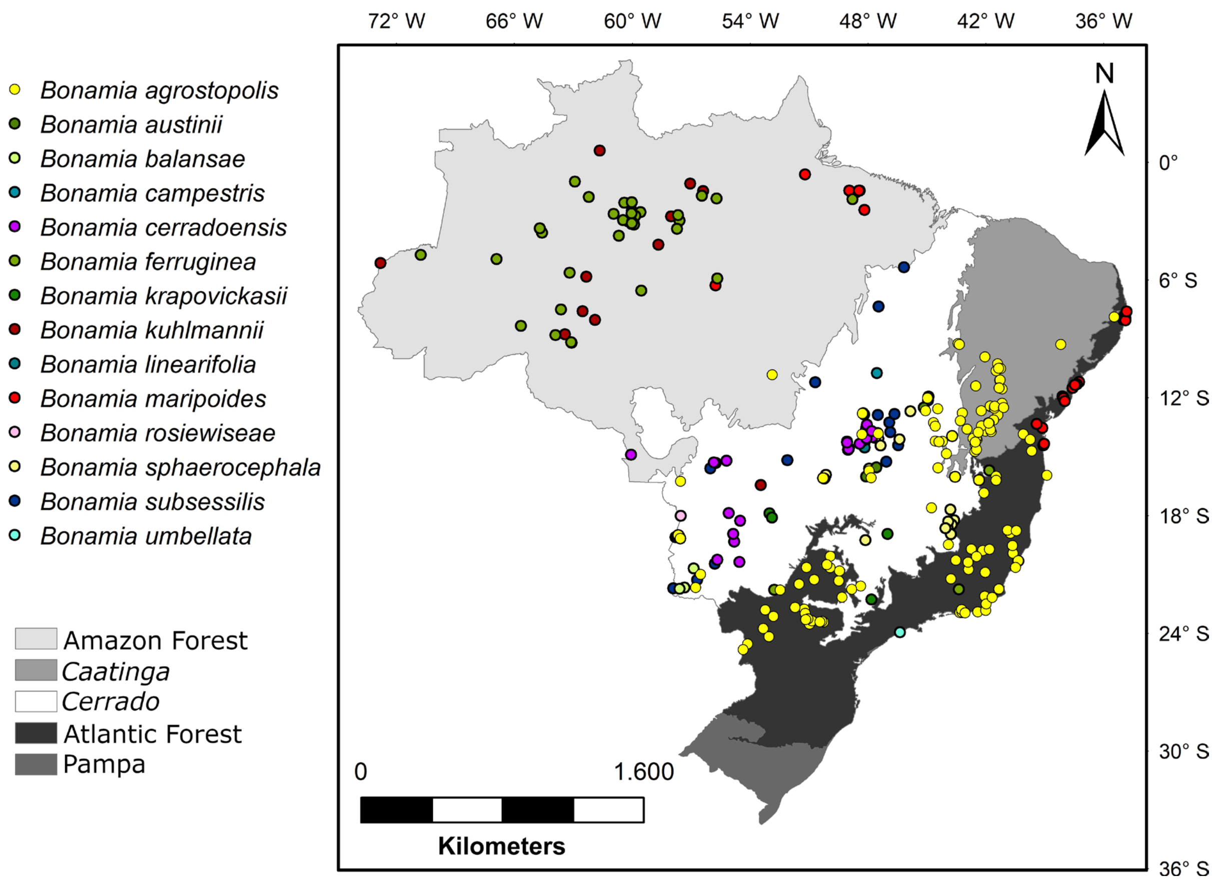

Figure 2. Geographical distribution of the genus *Bonamia* in Brazil, with phytogeographic domains.

Occurrence records

The occurrences compiled a dataset comprising 420 occurrence records distributed across 87 grid cells. Subsequently, we categorized the number of records per cell into five distinct classes: high (29 – 35), average (22 – 28), low (15 – 21), minimal (8 – 14), very low (2 – 7), and insufficient (1) (Figure 4a).

Only two grid cells showed more than 29 occurrence records. The most sampled Brazilian states were *Amazonas* and *Bahia*, with 78 records each of them. The states having deficient sampling (less than 10 records) were: *Distrito Federal*, *Maranhão*, *Pernambuco*, *Piauí*, *Rondônia*, *Sergipe*, and *Tocantins*.

Richness estimation

The Jackknife 2 estimator showed potential high richness when compared to the number of species observed (Figure 4b). The resulted values were divided in five classes. The grid cell with highest estimated richness had 7 – 9 species potentially. Grid cells with insufficient estimated richness had 0 – 2 species.

The linear regression did not show a significant relationship between the number of records and the estimated richness by grid cell. Therefore, areas having higher sampling do not present higher richness, not showing possible biases.

Richness knowledge analysis

We observed that the richness of the genus *Bonamia* is better known in the center and

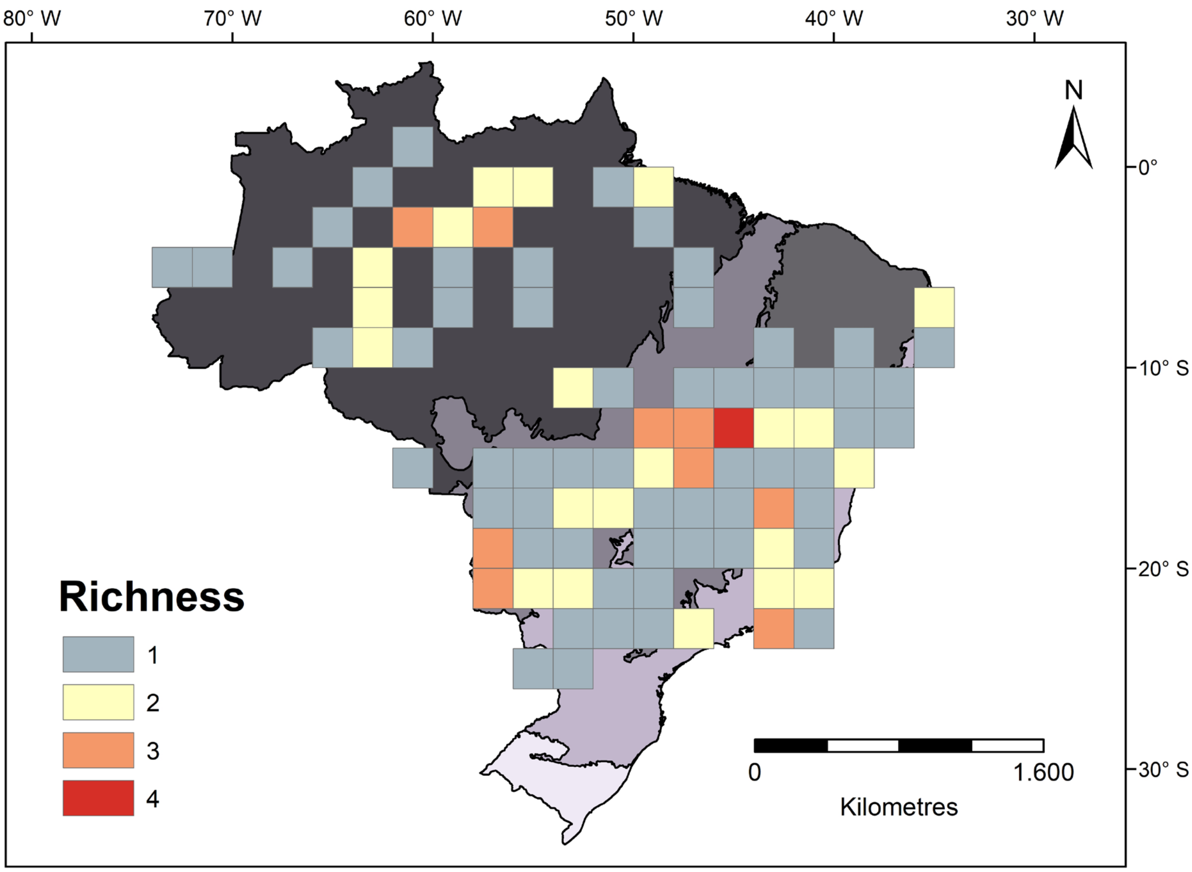

Figure 3. ***Bonamia*** **species richness per grid cell in Brazil, ranging from 1 to 4.**

coastal regions of the Amazon, in the central Atlantic Forest and in the far East region of Northeast Brazil (Figure 6). There are knowledge gaps in the *Cerrado*, the South Brazil and some Atlantic Forest regions. The average richness knowledge was 0.65 with a standard deviation of 0.09.

Parsimony analysis of endemism

The PAE generated a consensus tree and detected 2 areas of endemism (Figure 5). The first area on the central region of Brazil, in the *Cerrado* phytogeographical domain, at the *Chapada dos Veadeiros* National Park (Q38 and Q50), and the second area is in the state of *Mato Grosso do Sul*, on *Pantanal* domain. (Q65 and Q73).

DISCUSSION

Distribution

The *Serra do Espinhaço* Mountain Range, on the states of *Bahia* and *Minas Gerais* (North to South regions), is an important area of distribution for the genus, since the species show uneven distributions along the range, with a center of diversity in the states of *Bahia* and another in the *Minas Gerais*. The species *Bonamia agrostopolis* occurs predominantly at the *Bahia* portion of *Serra do Espinhaço*, similar to *Marcetia* DC. (Melastomataceae), *Calliandra* Benth. (Leguminosae), and genera from tribe Gyptidinae, such as *Lasiolaena* R.M.King & H.Rob., *Agrianthus* Mart. ex DC. and *Stylotrichium* Mattf. (Asteraceae) (Rapini et al. 2008).

Bonamia sphaerocephala is distributed on the state of *Minas Gerais*, portion of *Serra do*

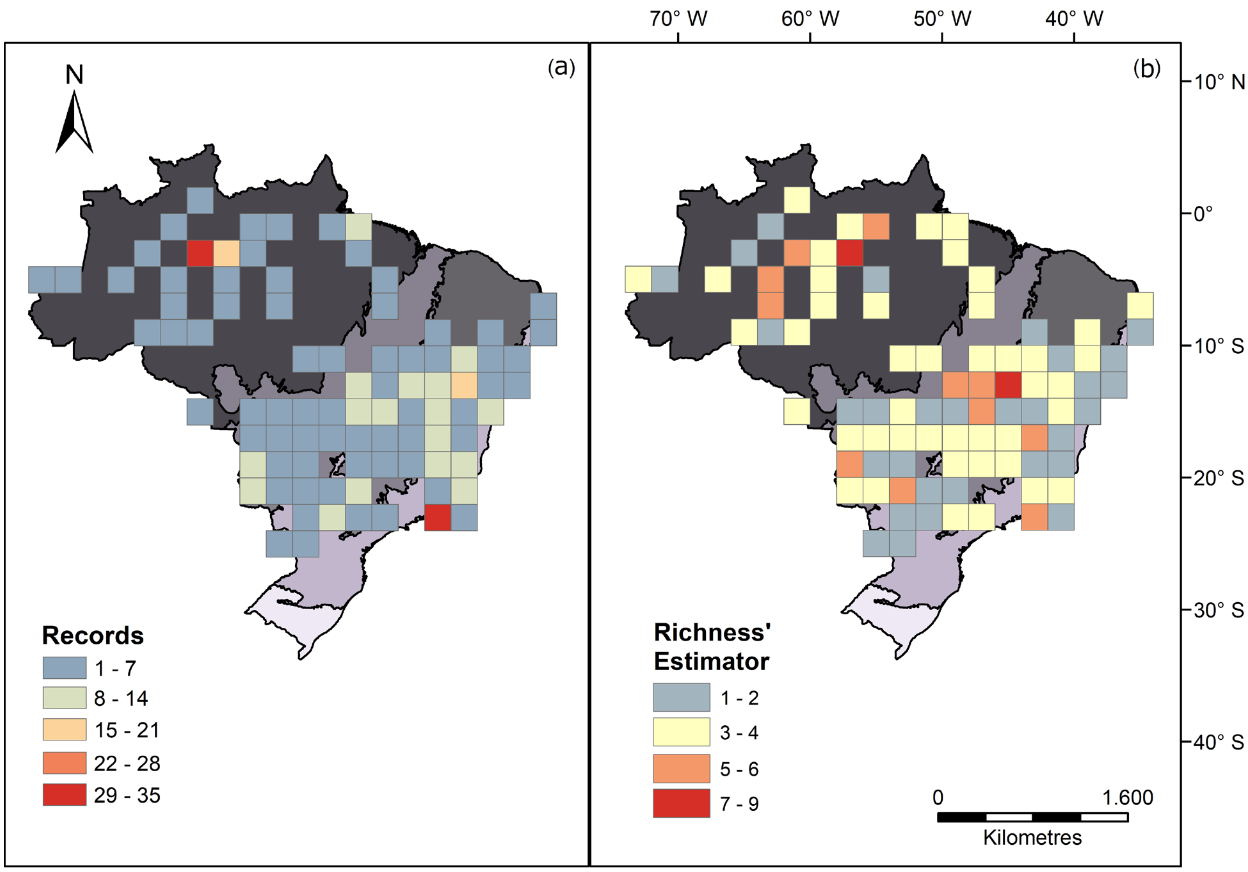

Figure 4. a) *Bonamia* record values in Brazil per cell divided into five classes – high (29-35), medium (22-28), low (15-21), minimal (8-14), very low (2-7) and insufficient (1). b) Estimated *Bonamia* richness values using the Jackknife 2 estimator.

Espinhaço, similar to *Jacquemontia decipiens* Ooststr. and *J. revoluta* Sim.-Bianch., from Convolvulaceae (Buril et al. 2015). It occurs in rocky fields, and the intimate association of the species with this phytophysiognomy suggests that individuals require specific conditions to survive (Alves & Kolbek 1994). The high floristic richness and degree of endemism found on rocky fields is due to the insular nature of the mountains where they occur and to especial environmental conditions that they are subject to (Giulietti et al. 1997, Lohmann & Pirani 1996, Rapini et al. 2008).

Another explanation for its diversity were climatic oscillations during the Quaternary. It is known that the climate became milder during interglacial periods, with reduction in ice layers and expansion of rainforests (Pennington et al. 2004). The distribution of *B. maripoides* reinforces previously held notions about a past link between forest formation during the Quaternary interglacial periods. Its distribution in the Amazon and Atlantic Rainforests shows apparent disjunction, similarly to *Besleria flavovirens* Nees & Mart. and *B. laxiflora* Benth. (Gesneriaceae) (Lopes et al. 2007).

During glacial periods, there was a generalized reduction in temperature and rainfall and an expansion of seasonally dry vegetations (Pennington et al. 2004). During this period, some part of Amazon Forest was replaced by Savanna vegetation (Gottsberger & Silberbauer-Gottsberger 2006). We believe that *B. ferruginea* and *B. kuhlmannii* are found in

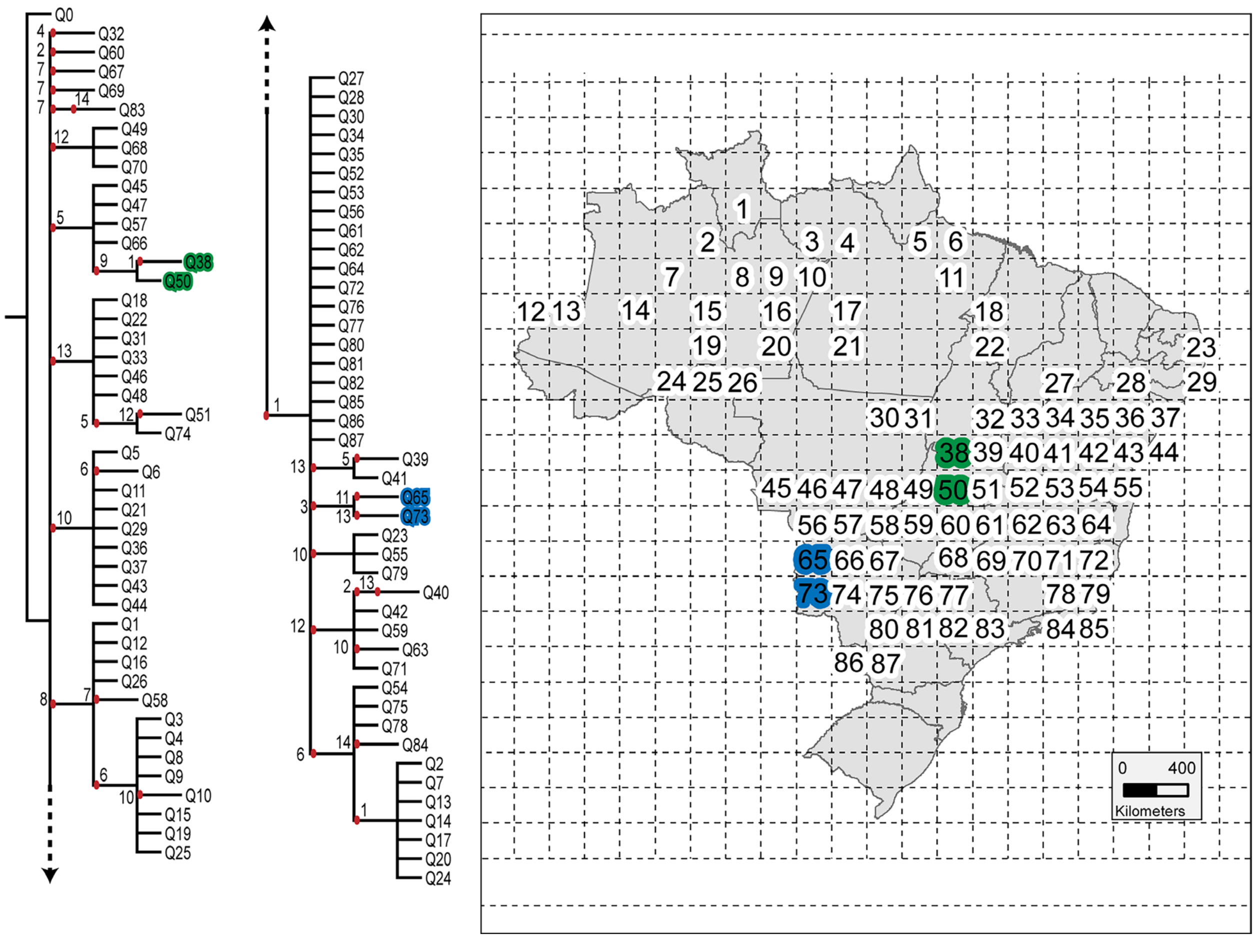

Figure 5. Cladogram of *Bonamia* distribution in Brazil and map of numbered grid cells, highlighting endemic areas. Green represents grid cells in *Chapada dos Veadeiros*, and blue represents those in sthe tate of *Mato Grosso do Sul*.

dryland forests in the state of *Amazonas* (Austin & Cavalcante 1982) because of such vegetation replacement.

The distribution of the genus *Bonamia* supports the hypothesis of expansion of Seasonally Dry Tropical Forests during the glacial periods on the Quaternary (Werneck 2011). Pennington et al. (2011) suggested that this kind of vegetation imposes more restrictions to the dispersal of species than other types of neotropical vegetations. This could be an explanation for many species having genetic structures strongly related to the geographical distribution of Seasonally Dry Tropical Forests (Buril et al. 2015). Eight species of *Bonamia* are exclusive to the Brazilian *Cerrado*: *B. austinii*, *B. balansae*, *B. campestris*, *B. cerradoensis*, *B. krapovickasii*, *B. linearifolia*, *B. rosiewiseae* and *B. subsessilis*.

The species *Bonamia austinii*, *B. campestris*, *B. krapovickasii* and *B. linearifolia* are exclusive to the *campo limpo* phytophysiognomy. *Bonamia austinii* can be found on burned *Cerrado* and is recorded to *Distrito Federal* and state of *Goiás*. *Bonamia krapovickasii* are recorded to states of *Goiás*, *Minas Gerais* and *São Paulo*. *Bonamia campestris* has one record at state of *Tocantins*, in the *Jalapão* region. *Bonamia linearifolia* can also be found in sites with strong anthropic action and exposed to periodic fires.

In the Amazon domain, *B. cerradoensis* occurs in an ecotone region, where lower altitude areas present Amazon vegetation, and higher altitude areas present Savanna vegetation. This record was made in higher altitude areas, so it is considered a species exclusive to the *Cerrado*. *Bonamia subsessilis* can be found in poor, sandy and rocky soils, phytophysiognomies characterized by being subject to fires (SEMA 2012). The ability to survive in such fire and drought conditions is related to adaptative strategies of *Cerrado* species (Durigan & Ratter 2016). This fact collaborates to high endemism of this domain.

Bonamia balansae grows in short and seasonal woodlands and has an extensive area of occurrence in Brazilian Midwest, Eastern Bolivia and Paraguay. Studies revealed that *B. rosiewiseae*, previously known only from Bolivia, also occurs at the *Pantanal* region in the state of *Mato Grosso do Sul* (Moreira et al. 2017, Moreira & Simão-Bianchini 2024).

Oliveira Filho & Fontes (2000) showed that the Atlantic Forest has two distinct floristic zones on North and South of a transition zone located on Southern region of state of *Bahia*. Such distinction was probably caused by temperature variations and rainfall regimes. *Bonamia umbellata* is an exclusive species of the Southern floristic zone of the Atlantic Forest, having records to *Rio de Janeiro* county, at the *Catumbi* and *Morro da Nova Cintra* neighborhoods, which form the *Maciço da Tijuca* formation at the *Santa Teresa/Laranjeiras* region.

Species richness

We found that *Cerrado* is the richest domain for *Bonamia*, which could be due to its horizontal complexity, containing forests, Savanna and fields. These conditions provide the heterogeneity that able strong association of plants and animals with local ecosystems (Machado et al. 2004). This phytogeographic

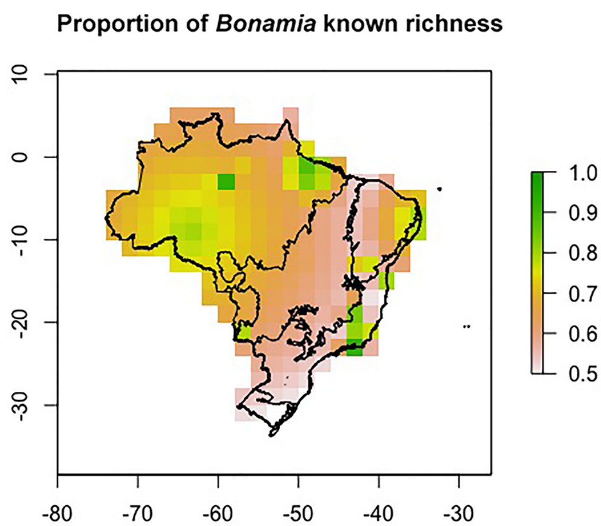

Figure 6. Proportion between observed and estimated richness of *Bonamia* in Brazil for each sampled grid cell.

domain is composed mostly by open areas, with low and irregular precipitation. An important fact is the occurrence of natural periodic fire that influence on the plant populations and the structure of communities (Hoffmann 1996, Munhoz & Amaral 2010). The fire also controls ecological process and is crucial to maintenance of the *Cerrado* ecosystem (Durigan & Ratter 2016). Since Convolvulaceae is composed mostly of herbs and climbers, which are favored in open areas, it is likely that its representatives are able to colonize and to persist in this environment (Moreira & Pigozzo 2015). Furthermore, those are opportunist species that predominate in environments subject to periodic changes such as rainfall seasonality in the *Cerrado* (Lewis 1987).

The richest grid cell was in the *Cerrado-Caatinga* ecotone, on the border between the states of *Bahia*, *Goiás* and *Tocantins*, at a physiogeographic formation known as *Espigão Mestre do São Francisco* or *Chapadão Central* (Cochrane et al. 1985). The *Cerrado* predominates in this landscape which some patches of *Caatinga*, having more than 1,273 known species. Despite being considered an area of high species richness, few floristic studies have been conducted there or in nearby areas, and it has been undergoing rapid replacement by monocultures (Mendonça et al. 2008).

Our results show that sampling for *Bonamia* in Brazil is low, with many sampling gaps in the East and South of the Amazon, in the North of *Cerrado* and *Caatinga* and in the South of the Atlantic Forest.

The localities presenting higher sampling efforts were closest to the *Manaus* and *Rio de Janeiro* counties, home of large research centers such as *Instituto Nacional de Pesquisas da Amazônia* – INPA (Amazon Research National Institute), and *Instituto de Pesquisas Jardim Botânico do Rio de Janeiro* (Rio de Janeiro Botanical Garden Research Institute). This pattern can be explained by the phenomenon named as “the museum effect” and occurs due to efficiency, logistics and convenience factors. This factor causes an over botanical samples closer to teaching and research institutes (Werneck 2011). Some authors have shown that uneven sampling activities affect the perception of centers of endemism (Ponder et al. 2001), and the selection of priority areas for conservation (Grand et al. 2007). Therefore, more representative inventories should be directed to less sampled areas to correct the geographic bias in sampling effort (Werneck et al. 2011).

Parsimony Analysis of Endemism

We detected two areas of endemism for *Bonamia* in Brazil (Figure 5). The first is in the center of the *Cerrado*, in the *Chapada dos Veadeiros* region. This local is considered one of the endemism centers for plant species, which can be explained by the abiotic features of the region, containing a protected conservation unit (Munhoz & Proença 1998, Ribeiro & Walter 2008). Although this, the area is under anthropic disturbance, mainly the touristic unregulated pressure, resulting in threat to the preserved flora.

The second area of endemism is in the state of *Mato Grosso do Sul*, at *Pantanal* domain, an area including the *Maciço do Urucum* formation (known for mining exploration) and the *Corumbá* limestone hills. This is an area of residual hill formation, with a great variety of phytophysiognomies, and has species of fauna and flora from three phytogeographic domains: *Pantanal*, *Cerrado*, and Amazon.

Richness knowledge analysis

The Amazon Forest showed higher indexes of richness knowledge, despite having several sampling gaps. This is due to few regions which had intense sampling, especially in the center and East of the domain. The regions of high richness knowledge at the Atlantic Forest also matches with areas of high sampling, but this knowledge cannot be extrapolated to nearby regions as extensively as on the Amazon, due to higher species turnover at this region.

Unlike Amazon, *Cerrado* showed extensive sampling but low knowledge indexes. This is due to few numbers of samples at most areas, and to areas where estimated richness is much higher than observed, especially to the East, on the border with the *Caatinga*. It indicates that many of the species are still not recorded to this region. At the Atlantic Forest, low knowledge areas are due mostly to the lack of sampling. The genus does not occur in the extreme Southern Brazil.

Surprisingly, a high knowledge index was estimate to the far East of Northeastern Brazil region, where there was low sampling. This is due to the high number of species sampled, which is close to the estimated richness. It suggests that most of the species in the area have been sampled. To better understand the richness of *Bonamia* in Brazil, we recommend the intensification of sampling on the *Cerrado-Caatinga* transition and on the less sampled regions of the Atlantic Forest.

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FLAVIA KATARINE SILVA[1]
https://orcid.org/0000-0002-5609-4697

EDUARDO T. AMORIM[2]
https://orcid.org/0000-0003-4253-1339

GABRIEL HENRIQUE O. CAETANO[3]
https://orcid.org/0000-0003-4472-5663

MARIA ROSA V. ZANATTA[4,5]
https://orcid.org/0000-0002-6471-0875

ROBERTA KEYLA KOJIMA[6]
https://orcid.org/0000-0002-8538-8694

ANDRÉ LUIZ C. MOREIRA[4,7]
https://orcid.org/0000-0003-0862-0135

[1]Universidade de Brasília, Departamento de Engenharia Florestal, Campus Darcy Ribeiro, Asa Norte, 70910-900 Brasília, DF, Brazil

[2]Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Centro Nacional de Conservação da Flora, Rua Pacheco Leão, 915, Jardim Botânico, 22460-030 Rio de Janeiro, RJ, Brazil

[3]Ben-Gurion University of the Negev, Jacob Blaustein Institute of Desert Research, David Ben Gurion Blvd, 1, 8410501 Be'er Sheva, Israel

[4]Programa de Pós-Graduação em Botânica, Universidade de Brasília, Departamento de Botânica, Campus Darcy Ribeiro, Asa Norte, 70910-900 Brasília, DF, Brazil

[5]Jardim Botânico de Brasília, Superintendência Técnico-Científica, Diretoria de Gestão Integrada da Biodiversidade e Conscientização Pública, F-035, s/n, Jardim Botânico, 71680-001 Brasília, DF, Brazil

[6]Instituto de Pesquisas Ambientais, Grupo de Pesquisa do Herbário de São Paulo, Avenida Miguel Estéfano 3687, Água Funda, 04301-902 São Paulo, SP, Brazil

[7]Universidade Federal da Bahia, Faculdade de Educação, Avenida Reitor Miguel Calmon, s/n, Canela, 40110-100 Salvador, BA, Brazil

Correspondence to: **Roberta Keyla Kojima**
E-mail: keylakoji@gmail.com

Author contributions

Silva, KF: Data production, text drafting. Amorim, ET; Caetano, GHO; Zanatta, MRV; Kojima, RK: text drafting, revision, data refinement. Moreira, ALC: advisor, leadership of the work.