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Analysis of the spatial distribution of Leguminosae species in the state of Maranhão, Brazil

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ABSTRACT

Thousands of plant species are described in the planet. However, little is known about how these organisms are distributed, which is worrying, as species distribution data provide support for the development of conservation strategies. This study aimed to analyze the pattern of distribution of collections of Leguminosae species in Maranhão, determining the priority areas for collection and conservation of species. A database of Leguminosae from Maranhão was built with geo-referencing and taxonomic corrections. Then, the distribution pattern of species, collections and areas of endemism was analyzed, pointing out the main vectors of spatial pressure on this family. The South, East and fragments of the North region of Maranhão had the higher number of collections and species. The Gurupi, North and South regions of Maranhão are suggested as priority for conservation actions because they have high rates of endemism and are subjected to anthropogenic actions, and the domain Cerrado is suggested as priority due to the accelerated advance of agribusiness. This research is relevant to the knowledge of the flora of Maranhão, as it is the first to assess the distribution of Leguminosae collections in the state and suggest key areas for conservation.

Keywords: Distribution of legumes. Spatial pattern. Conservation

Análise da distribuição espacial das espécies de Leguminosae para o estado do Maranhão, Brasil

RESUMO

Dentro da biodiversidade do planeta são descritas milhares de espécies de plantas. No entanto, pouco se sabe sobre como se dá a distribuição desses organismos, o que é preocupante, pois isso fornece suporte para elaboração de estratégias de conservação. A pesquisa teve como objetivo analisar o padrão de distribuição de coletas das espécies de Leguminosae no Maranhão, inferindo as áreas prioritárias para realização de coletas e conservação das espécies. Foi construído um banco de dados de leguminosas do Maranhão com correções de georreferenciamento e taxonômicas. Após isso, realizou-se análise do padrão de distribuição das espécies, coletas e áreas de endemismo, apontando os principais vetores de pressão espacial sobre as leguminosas. As áreas mais ricas em coletas foram Sul, Leste e fragmentos do Norte, assim como foram as regiões mais ricas em espécies para o Estado. Sugere-se que as áreas prioritárias para conservação ocorram no Gurupi, Norte e Sul por possuírem altas taxas de endemismo e sofrerem com as ações antrópicas, e o Cerrado com o avanço acelerado da agroindústria. A pesquisa é relevante para o conhecimento do Maranhão, pois é o primeiro estudo que avalia a distribuição de coletas da leguminosas no estado e infere áreas para conservação.

Palavras-chave: Distribuição de leguminosas. Padrão espacial. Conservação.

Introduction

Biodiversity is distributed heterogeneously across the Earth, with a rich composition of species in some sites and lower richness in others. This biodiversity includes thousands of plant species, which are organisms of great importance for the ecological equilibrium, evolutionary processes, and the survival of human life on Earth. However, little is known about how these organisms are distributed in the environment, which is worrying, since information on distribution, niche and ecology provides support for the development of conservation strategies (Gaston, 2010; Forzza et al., 2012; Meyer et al., 2015; Farinaccio et al., 2018).

The heterogeneity of habitats and the limited dispersion of species are some of the ecological processes or perhaps the main ones driving the distribution of the species and serving as an important mechanism to regulate species aggregation patterns (Hudu et al., 2017). In this sense, the correlation between the occurrence of species and biotic and abiotic data may allow the testing of hypotheses about species distribution patterns (Wiens et al., 2011).

Regarding the diversity of plants in the Americas, Ulloa et al. (2017) recognize 124,993 native vascular plant species, encompassing a total of 6,227 genera and 355 families. This number corresponds to 33% of the 383,671 vascular plant species in the world. In Brazil, a total of 37,066 vascular plant species – of which 19,313 are endemic – distributed in 277 families, 2,886 genera have been recorded. Of these, 32,696 are species of angiosperms, considered a highly diverse lineage, widely distributed throughout the planet (Forzza et al., 2010; Angiosperm Phylogeny Group IV (APG IV), 2016; Brazilian Flora Group (BFG, 2021). According to Flora e Funga do Brasil (2023), 1,410 of ferns and lycophytes, 116 of gymnosperms, and 35,635 of angiosperms are described in the Brazilian territory.

Despite the knowledge of this information and these figures, issues such as spatial and temporal biases, sampling effort deficits, poor quality of geo-referencing of collection data, taxonomic errors, and lack of standardized and effective data storage that may result in the record of samples with inaccurate information, pose difficulties for spatial analyses and consequent biological inferences (Daru et al., 2018; Yost et al., 2018).

One of the main information gaps is the deficient understanding of species ecology and conservation, and particularly the poor of

knowledge on how species are distributed (Wallacean shortfall), which is inadequate at all scales. Most often, the Wallacean shortfall is particularly visible in remote and inaccessible regions. However, understanding and knowing species distribution patterns is fundamental for the accurate understanding of the distribution of the species and underlying processes (Lomolino, 2004; Hortal et al., 2015; Meyer et al., 2016).

Plant groups considered highly diverse and widely distributed are ideal for composition, distribution and conservation studies. Such studies provide the description of the vegetation of a given area, contributing to inferences about the local biodiversity. The family Leguminosae Juss. stands out as one plant group with high diversity among the lineages of angiosperms in Maranhão, Brazil and in the world (LPWG, 2017; Ringelberg et al., 2023, Flora e Funga do Brasil, 2023).

Leguminosae is the third richest family in number of species among angiosperms, behind only Orchidaceae A. Juss. and Asteraceae Bercht. & J. Presl. This family comprises approximately 770 genera and 19,500 species with sub-cosmopolitan distribution and of great importance in the flora of the most diverse phytogeographic domains (Queiroz, 2009; LPWG, 2017, Huges et al., 2022). Plants of this family establish a symbiotic relationship with nitrogen-fixing bacteria on their roots, an important adaptation that allows their growth on nutrient-poor soils and colonization of highly anthropized environments, conferring them diversification and adaptability in the most diverse places (Lewis, 1987; Yahara et al., 2013; De Faria et al., 2022).

In Brazil, Leguminosae is the richest group with about 3,028 species and 253 genera widely distributed across the country and all phytogeographic domains (Flora e Funga do Brasil, 2023). The number of species of this group has increased in the last ten years (BFG 2021). For example, a rich flora of Leguminosae has been described for the Cerrado and Amazon domains, with 1,288 and 1,164 species, respectively (BFG, 2015; Flora e Funga do Brasil, 2023).

In Maranhão, 446 species and 117 genera of Leguminosae have been described. The family has high representativeness in the flora of this state, in fact, it is the richest. It is thus relevant to carry out an analysis of the spatial distribution of collections and species of this family. Leguminosae serves as a model group to determine priority sites for collection and conservation. The knowledge about the distribution pattern of species of this family also allows characterizing the botanical richness of the state, since Leguminosae

is the richest family of angiosperms in number of species in Maranhão.

The present study is based on the problem of where areas of high and low diversity are concentrated in the state of Maranhão, and using Leguminosae as a model we can provide data that can be used to locate areas well sampled, undersampled, and areas that have never been sampled but need to be explored because they have not yet been classified as priority despite being degraded on a large scale, and information on their flora is lacking.

Materials and methods

Study area

The state of Maranhão is located in the Northeast region of the country and has an approximate area of 329,651.496 km² (IBGE, 2017), with 217 municipalities distributed in five geographic mesoregions (North, East, West, Center, and South). The predominant climate in the state is tropical, with mean annual temperature of 22 °C to 30 °C (Stella, 2011; IBGE, 2017). The state encompasses three different phytogeographic

The present work also contributes to future research on the characterization of Leguminosae in the state of Maranhão. Therefore, this study aimed to analyze the distribution patterns of collections of Leguminosae species in Maranhão, providing clues on priority areas for collection and conservation of species. We believe as the main hypothesis that there are several knowledge gaps for the family in the state and that most of the diversity is concentrated in a few areas.

domains and, thus, a high diversity of landscapes. These domains are Cerrado (64.1% of the territory) and its different phytophysiognomies, from the most open (fields) to closed forests; the Amazon (34.8%), with typical tall trees, 'várzea' forests in periodically flooded plains and permanently flooded 'igapó' forests; and a small portion of Caatinga (1.1%), characterized by the presence of shrubby vegetation with twisted branches and deep roots, along with cacti and bromeliads (Stella, 2011; Araújo et al., 2016) (Figure 1).

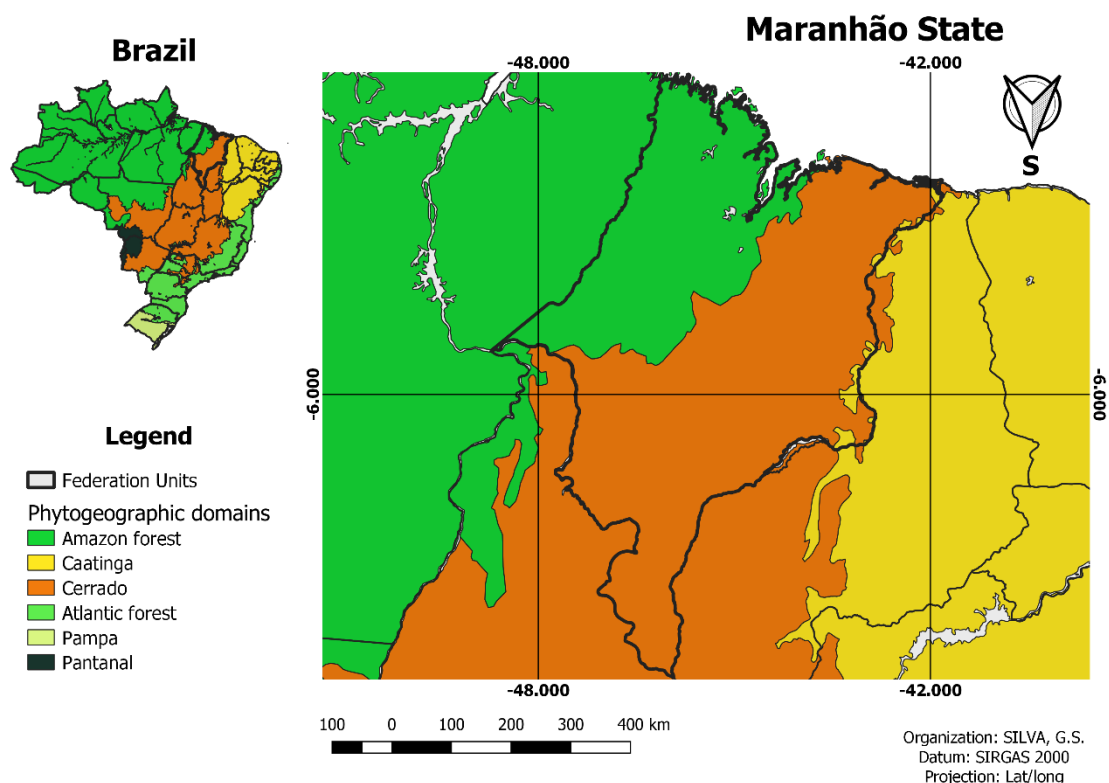


Figure 1. Geographical delimitation of the state of Maranhão in Brazil.

Construction of the collection database

A database was built with records of

Leguminosae occurring in Maranhão using the computerized data management system BRAHMS (Botanical Research And Herbarium Management

System 1990). The data were obtained from the digital platforms Re flora (2020), Specieslink (Reference Center for Environmental Information – CRIA 2020), GBIF – Global Biodiversity Information Facility (2020), SISBBR (Information System on Brazilian Biodiversity), and collections of international herbaria online, such as BM, COL, F, G, GH, K, NY, P, US, and W. The data were obtained in the xlsx, csv, xls, txt formats, managed in a single format and inserted in BRAHMS. Information retrieval policies were respected during the research.

The database also included data on the spatial distribution of collections, with geographical coordinates corrected and validated using Google Maps (www.google.com/maps/preview) to check the precise distribution of records in the territory of Maranhão. Records from sites outside the state,

without voucher number or registration number, and lacking information on collection site and geographical coordinates were excluded. The taxonomic identity of the recorded species was validated by analysis and determination by taxonomists specialized in the family Leguminosae.

Analysis of distribution patterns

The database built with geographic and taxonomic information on the species recorded in Maranhão was the basis to analyze the richness of species, abundance of collections, and the spatial distribution. Species richness and abundance of collections were obtained by delimiting the area of Maranhão in 1×1 longitude/latitude grid system with 44 grid cells (Figure 2).

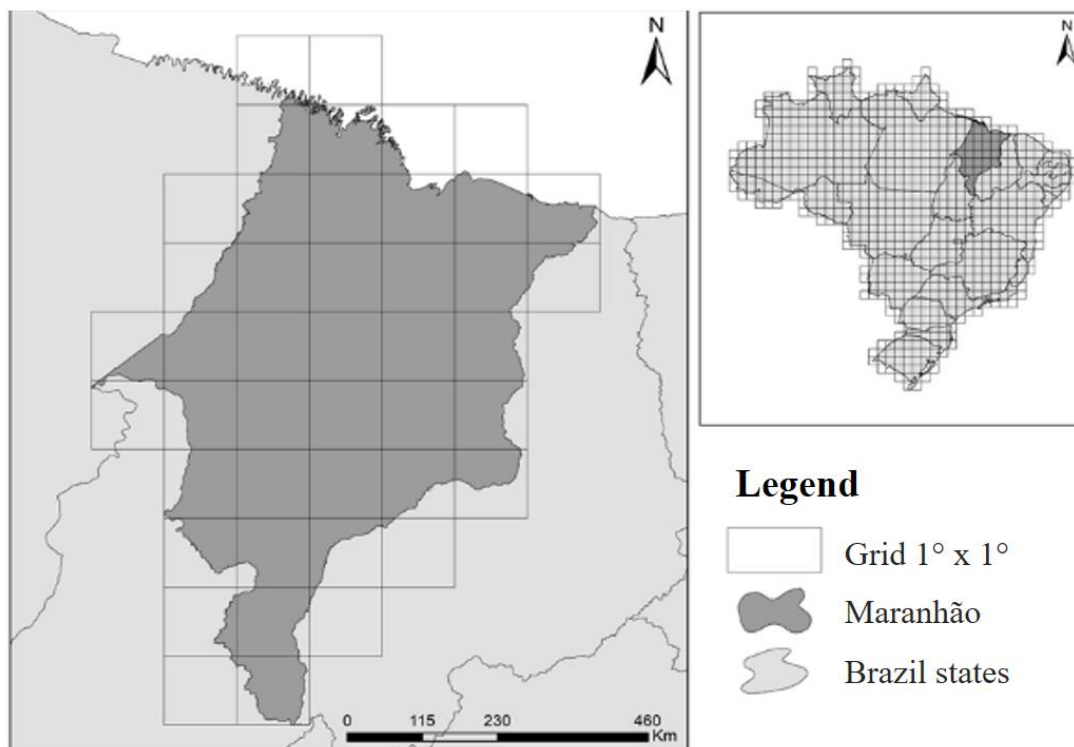


Figure 2. Map with the distribution of grid cells for analysis of the spatial distribution of Leguminosae species in Maranhão.

Each grid cell was named in the results section according to the mesoregion in which it was located and an alphanumeric identifier. Grid cells with higher and lower concentration of species and number of collections were detected so as to determine priority areas for collection (with lower number of species) and for conservation (with higher concentration of species).

The Kernel density estimation-based heatmap tool in QGIS was used to analyze the

density of collections (number of collections per site). This tool calculates a circular area around each point of the sample that corresponds to the radius of influence, and then a mathematical function is applied from 1, at the point position, to 0, between the points. The value in each cell is the sum of the overlapping kernel values divided by the area of each search radius (Souza et al., 2013). The density of collections in each mesoregion and microregion of Maranhão (number of collections

per square kilometer) was calculated using Sobral & Stelman (2009) as a methodological basis.

The species distribution pattern was analyzed using the Geographic Interpolation of Endemism (GIE) method (Oliveira et al., 2015; Castuera-Oliveira et al., 2020). This method estimates a central point (centroid) for the points of occurrence of each species and defines a circular area with a radius produced by the distance between the centroid and the furthest point from it, which corresponds to the estimate of the distribution of each species. The degree of overlap was measured according to a Gaussian function around the centroid of each species. The density of species in each overlap area was converted into interpolated curves, using the Kernel interpolation function (Oliveira et al., 2015).

To perform these procedures, the area of influence of each species was calculated based on the collections, plotting interpolated curves on

maps using Quantum GIS (QGIS 2015; <http://www.qgis.org/en/site/>), where darker colors on the map (tending towards navy blue) corresponded to areas of greater richness. This way it was possible to identify and assess the areas with higher and lower concentration of species and collections and, thus, determine key sites for conservation actions and/or future collections, according to the presence of endemic species, species threatened with extinction and/or low sampling effort.

The main vectors of spatial pressure in the community of Leguminosae of Maranhão were derived from the characterization of areas according to distribution of collections and species. Land use and land cover shapefiles according to IBGE were used in this analysis (2021).

Results

A total of 596 species distributed in 128 genera in five subfamilies of Leguminosae are described for Maranhão, according to the database of Leguminosae species of Maranhão built in this study (Gonçalves et al., *in press*).

Regarding the number of collections, 5,630 records were confirmed in the state, distributed among the five mesoregions as follows: South (1,870 collections, 322 species), East (1,203 collections, 244 species), North (942 collections, 239 species), Center (689 collections, 177 species),

and West (655 collections, 213 species). The South and the West were, respectively, the most and the least sampled regions.

The analysis of the number of collections showed that two of the 44 grid cells (North/C5 and South/H4) (4.5% of the total territory of Maranhão) had 334 to 625 collections, being considered the most collected in the state. Seven grid cells (Extreme North/John/A3, North/B5, North/C3, West/E1, West/I2, fragments of the South/J3, and West/D2) (15.9%) had 1 to 25 collections and were considered the least collected (Fig. 3A).

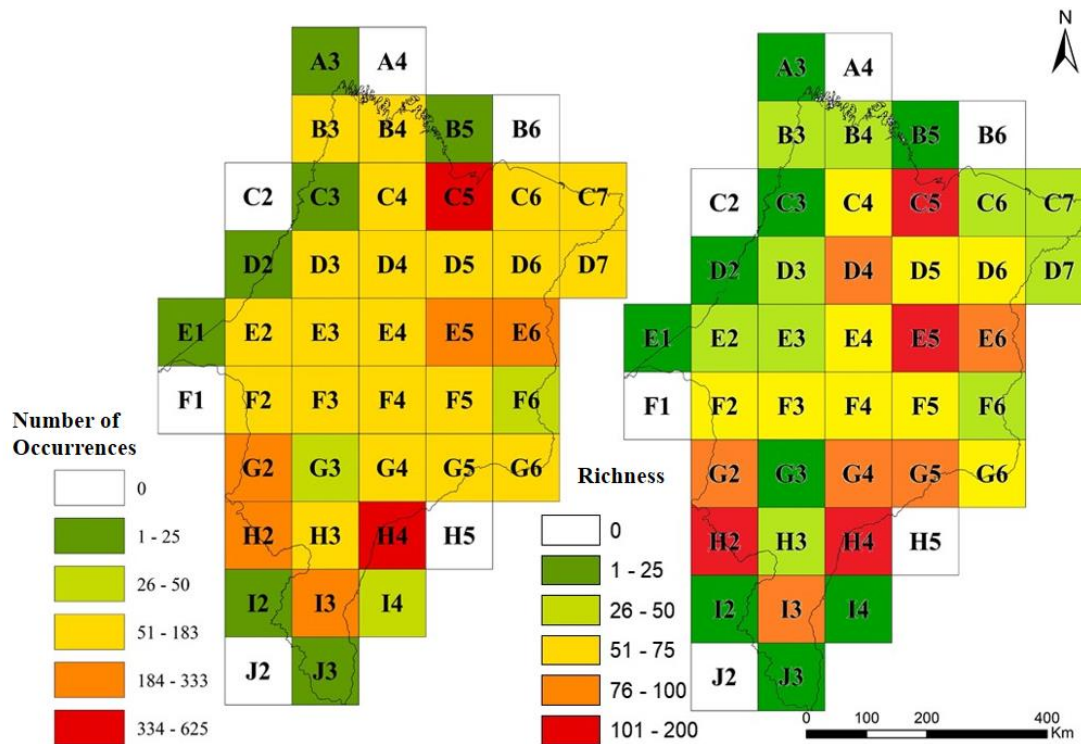


Figure 3. Distribution map of collections and species by grid cells in the state of Maranhão. A) General distribution of collections of Leguminosae species in Maranhão. B) Distribution of Leguminosae species in Maranhão.

It was observed that collection records were absent in only six grid cells (small blank fragments): West/A4, North/B6, North/C2, West/F1, Center/H5, and South/J2. Thus, practically all grid cells in entire state of Maranhão had been sampled in at least one collection, and some of them were intensely sampled, as for example South/H2, North/C5, West/G2, South/I3, South/H4, East/E6 and Center/E5, with 184 to 625 collections (Fig. 3A).

The observation of many grids (10) with few collections and few grids (7) with many collections indicates that the distribution of collections in Maranhão was heterogeneous.

The areas least collected were located in the Amazon (Northwest of Maranhão/D2 and F1), some areas in the North (B5 and C3), and in the extreme South (I2 and J3). Most of the grid cells in the territory of Maranhão, especially in the Center-North part (E5 and C5), had at least between 51 and 183 collections. The largest number of collections took place in the South (H2, G2, H3, H4) and East (E6). It is noteworthy that the number of collections was particularly high in some areas (H4 and C5), in the Center-North region (C5), Baixada Maranhense and Southeast of Maranhão (G4).

Among the phytogeographic domains, the higher numbers of collections were observed in Cerrado (areas of the East, North, and West), in cities such as Carolina, Estreito, and Caxias where this domain predominates, presenting 184 to 625 collections. Caatinga had the lower number of collections (1 to 50).

As for species richness, six of the 44 grid cells had no record of species (the ones without records of collections). This demonstrates the high richness of legume species in the state, since the portion of the territory without records is minimal in relation to the total number of species found per grid cell. The grid cells Center-North/C5, Northwest/D4, East/E6, Center/E5, West/G2, East/E5, South/G2, South/H2, South/H4, and South/I3 had the largest number of species: 101 to 200. Most of the grids with the higher number of collections corresponded to species-rich areas. However, locations such as Northwest/D4 and East/E5 presented high species richness despite low sampling (Fig. 3B).

The analysis also showed six grid cells (13.6%) with 76 to 100 species, nine (20.4%) with 51 to 75 species, 10 (22.7%) with 26 to 50 species, and nine (20.4%) with 1 to 25 species.

The observation of many grid cells with few species and few grid cells with a high number of species (19 grid cells had one to 50 species and 4 had 101 to 200 species) indicate a heterogeneous distribution of species across Maranhão. The largest number of species was observed in places where conservation areas are present, such as the Chapada das Mesas National Park in the South (G2 and H2), the Inhamum Environmental Protection Area in the East (E6), in the Center-North (C5), Baixada Maranhense and Southeast of Maranhão (G4).

Few species were collected in cities that are far from conservation units or do not have protected areas such as the cities in North/C2 and West/F1. Further, low species richness (one to 25 species) was seen in Northwest/G3 despite the presence of a conservation area.

The comparison of the two maps showed that grid cells with the highest number of collections also exhibited the highest number of species in Maranhão. Exceptionally, the grid cells East/D7 and West/D3 had 51 to 183 collections, thus well sampled areas, and yet presented a small number of species.

The heatmap using Kernel density estimation indicated that the South region had the highest density of collections, followed by the East (Fig. 4A). In contrast, a lower density was observed in the Central and Northern portions of Maranhão, with small collection spots, and the West region presented the lower density values. In general, most of the state had low records of species likely resulting from low sampling effort (Fig. 4B).

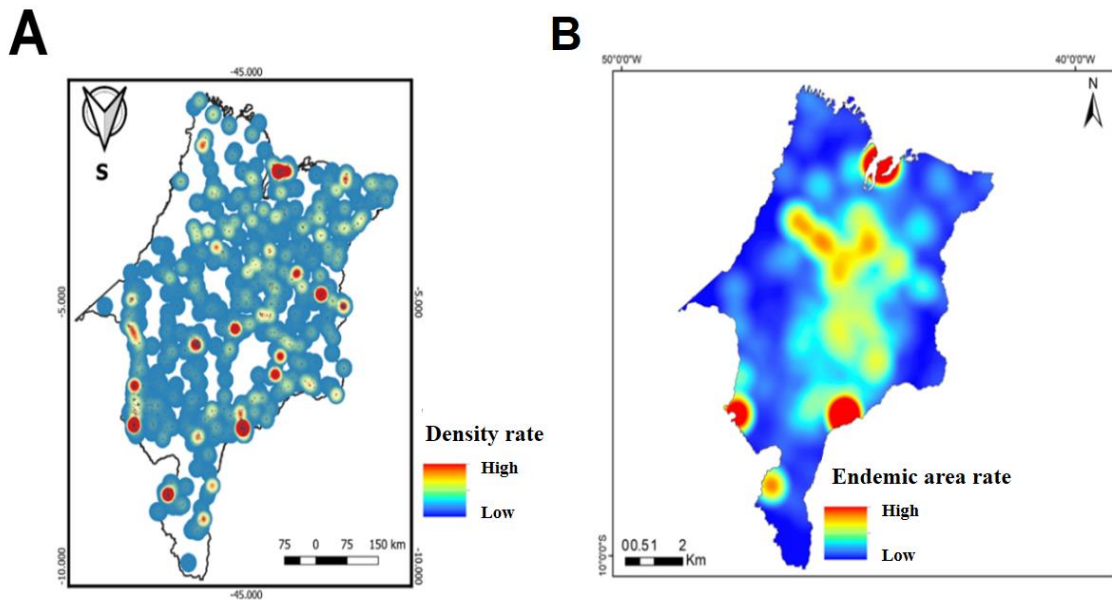


Figure 4. Cartographic representation of the density of collections and areas of endemism of Leguminosae in the state of Maranhão. A) Density of collections. B) Areas of endemism of Leguminosae species.

As for the density of collections in each mesoregion and microregion (Table 1), collection

rates are low in Maranhão and, thus, collections are sorely needed in all mesoregions and microregions.

Table 1. Density of collections of Leguminosae in the mesoregions and microregions of Maranhão.

Mesoregions of Maranhão	Density per km²
South	0.027
East	0.017
North	0.018
Center	0.012
West	0.007
Microregions of Maranhão	Density per km²
Chapada das Mangabeiras	0.0502
Gerais de Balsas	0.0137
Porto Franco	0.0048
Gurupi	0.0006
Imperatriz	0.0008
Pindaré	0.0008
Aglomeração urbana de São Luís	0.0605
Baixada maranhense	0.0015
Itapecuru Mirim	0.0009
Lençóis Maranhenses	0.0013
Litoral ocidental Maranhense	0.0004
Rosário	0.0005
Caxias	0.0023
Chapada do Alto Itapecuru	0.0016
Chapadinha	0.0014
Codó	0.0017
Coelho Neto	0.0011
Médio Mearim	0.0018
Presidente Dutra	0.0012

Regarding areas of endemism, the South of Maranhão presented higher rates of endemism, followed by the North and Center, the latter with intermediate rates of endemism. The western and eastern regions had the lowest rates of endemism. Some similarities were identified when comparing the maps of density of collections and areas of endemism. The Southern region of Maranhão had the highest density of collections and the largest rates of endemism and that the West had the lowest density of collections and smallest rates of

endemism. In contrast, the East had the second highest density of collections but small rates of endemism, while the North had small density of collections but the second largest rates of endemism.

Regarding the key areas for conservation of species, the results obtained showed that the main threats to the conservation of Leguminosae in Maranhão are: cities, extractivism, industrial complexes, crops, and livestock rearing areas (Fig. 5).

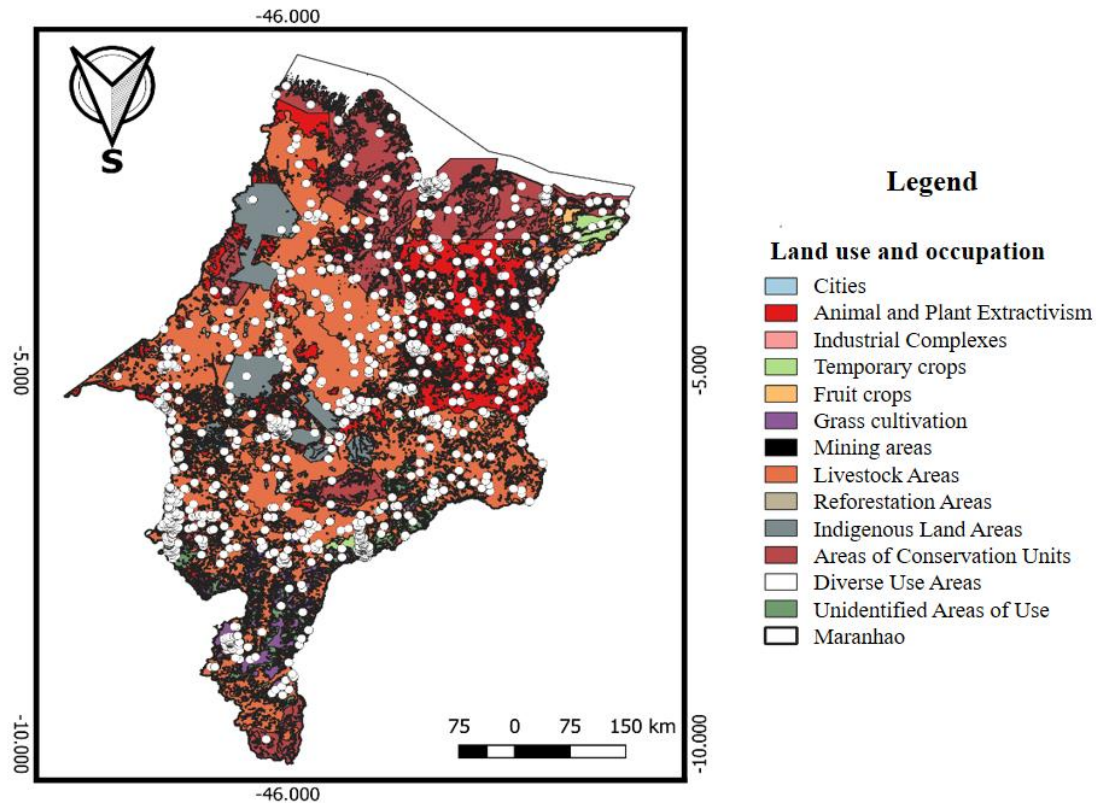


Figure 5. Cartographic representation of the main spatial pressure vectors according to land use and land cover on the community of Leguminosae of Maranhão.

Among them, the latter poses the major menace because it has taken exorbitant proportions, with the implementation of pastures and animal husbandry.

Discussion

The data presented here show that there are clear gaps in the knowledge about Leguminosae in Maranhão probably linked to several factors. One of them is the lack of investments in floristic surveys in Maranhão, because despite the existence of important projects aimed at the the flora of this state, they focus on specific sites, such as large urban centers (São Luís) and/or conservation units. According to Magnusson et al. (2016) and Souza & Castellón (2012), research on biodiversity in strategic places, such as those farther from large urban centers, is still scarce and these sites remain little studied. It is necessary to invest resources that are proportional to the geographic size of the areas and the number of species of the sites to be covered as well as to invest in places of difficult access so as to expand the knowledge of biodiversity (Magnusson et al., 2016).

Problems such as difficult access to some areas preclude the expansion of knowledge of biodiversity. Our study confirms this premise,

since areas in the West, North and Center of Maranhão have low road infrastructure, contributing for them to remain practically unexplored. Hortal et al. (2015) showed that collection gaps are particularly larger in remote and inaccessible areas. Oliveira et al. (2018) argued that the distance to roads in certain places impairs the sampling of remote areas and demonstrated that the number of described species decreases as the inaccessibility to areas increases, contributing to knowledge gaps in specific regions.

The greater exploitation of some areas in relation to others also contributes to what is known as the edge effect in certain places. This problem can be caused by the difficulty people have accessing some collection areas, because plant species may occur in extreme locations. People choose to collect them in more accessible areas, leading to the oversampling of some places (Oliveira et al., 2015) such as roadsides and trails, ultimately causing the edge effect in these places. Silva et al. (2019) argue that the richness and abundance of species within a fragment are more

homogeneous when compared to other areas. Thus, the edge effect reflects on the composition and richness of plant species (Silva & Schmitt, 2015).

It should also be noted that species distribution data usually vary across political units rather than across ecological units because states with better access routes, larger research centers, and consequently greater number of researchers are more sampled and diverse than states without this infrastructure, such as Maranhão. These aspects favor biases in the patterns of collection, analysis and comparison of biogeographic data (Meyer et al., 2016).

Another problem contributing to collection gaps, visibly important in the present data from Maranhão, is anthropization. This factor stands out as a barrier to the knowledge of the species and their distribution. Many areas in the state present signs of degradation and others are highly devastated due to illegal logging, deforestation, important loss of vegetation – including within conservation areas harboring many endemic species – due to anthropogenic activities such as agriculture (Calentano et al., 2018; Pinheiro, 2019).

Areas with a lower number of records of species (Paço do Lumiar, Pinheiro, Matinha, Gurupi region, Buriticupu, Chapada das Mangabeiras) show signs of degradation, with characteristics of altered environments. This is the case of areas of Amazon forest in Maranhão, which have been quite devastated by considerably high fragmentation rates that have caused the loss of 75% of the original coverage (Pinheiro, 2019). These areas undergo blatant exploitation of plant resources and deforestation, with the removal of vegetation for illegal profit, and the region has incorporated other forms of land use, such as pasturelands, tree felling, livestock rearing, and so forth (Silva Junior et al., 2020).

The absence or low numbers of collections in some areas of Maranhão can also be associated with ‘plant blindness’, that is, the inability of people to perceive and observe the plants in their surroundings. The population has a distorted perception of plants and show little appreciation for their diversity (Salatino & Buckeridge, 2016). This contributes to the lack of interest in collecting and studying legume species in Maranhão. Cruz et al. (2021) state that ‘plant blindness’ affects not only the development of botanical research but also the creation and implementation of public policies aimed at the conservation of plant diversity.

The finding of a large number of species collected in the South, East and a small portion of

the North of Maranhão is explained by several factors. The presence of research centers in these regions (Universities, herbaria, and Plant Biology Laboratories) as well as of Conservation Units strongly contributes to these figures. An example is the presence of the Chapada das Mesas National Park in the Southwest region of the state. This is a federal reserve located in an ecotonal region of Maranhão, which is a key aspect for the conservation of plant species since ecotonal areas may encompass a high diversity of species (Saraiva et al., 2020). Further, there are conservation units in the Eastern region of Maranhão, such as the Inhamum Environmental Protection Area and the Buriti do Meio Environmental Protection Area, both located in Caxias, and the Mirador State Park in the city of Mirador. The presence of these protected areas undoubtedly contributes to the high sampling of the East of Maranhão.

Studies with Leguminosae have already been carried out in conservation units in cities of the South and East regions of Maranhão (Inhamum Environmental Protection Area and Chapada das Mesas National Park). Works such as Gomes et al. (2018), Gomes et al. (2019a), Gomes et al. (2020b), Morales et al. (2020), Souza et al. (2022) and Gissi et al., (2023) contributed to a greater density of collections and endemism in these regions.

The study carried out by Masullo et al. (2020) showed that the conservation areas in the North of Maranhão (mainly in the Center-North/São Luís region) had high levels of visitation because they provide pleasant places for the enjoyment of people, thus becoming important for conservation and research. For example, floristic studies have been conducted in the Bacanga State Park in São Luís, influencing the number of species present there.

The significant number of species found in São Luís and Caxias is also related to the presence of herbaria in these cities, such as the Professor Aluizio Bittencourt Herbarium (HABIT) located in the Center for Higher Studies of Caxias; the Rosa Mochel Herbarium (SLUI) of the State University of Maranhão; and the Herbarium of Maranhão (MAR) in the Federal University of Maranhão, located in São Luís. These herbaria promote the collection of more samples and realization of more floristic studies on taxonomy, systematics, botany, mycology, environmental impact, environmental management, public policies, and biotechnology, in addition to being used as an important didactic resource (Silva et al., 2020).

These herbarium collections are composed mainly of species that occur in

Maranhão, with representatives from Cerrado, the Amazon, and ecotonal areas (Silva et al., 2021). Places such as these foster research and enhance the knowledge of the species, as the number of deposited specimens follows the number of collections (Barbosa & Vieira, 2005).

The results show that the distribution of legume collections and species in Maranhão is heterogeneous. One of the factors that explain this unequal distribution is the fact that there are few taxonomists specialized in Leguminosae working in Maranhão. Places where these few taxonomists are based are the ones with the greater number of samples and higher richness of species of the group. For example, there is one taxonomist working in the Eastern region of Maranhão. It is, thus, necessary to train more taxonomists in the state or to build partnerships with taxonomists from other regions, because the identification of plants of this family can be difficult and the development of studies requires qualified professionals. Vieira (2015) states that this challenge is widespread in Brazil, precisely the qualification and increase of plant taxonomists in regions with high knowledge deficits, and this barrier hinders advances in the knowledge of biodiversity.

Taxonomy in Brazil and especially in Maranhão has advanced a great deal in recent years, as biological collections have received support with the development of research as a consequence of the proposition of the National Plans of Botany to meet the goals of the Global Strategy for Plant Conservation (Vieira, 2015). Despite the low number of specialists in Leguminosae, there are many botanists collaborating with the development of knowledge of the flora of Maranhão.

Regarding the distribution of Leguminosae in the phytogeographic domains, one of the reasons that may explain the bias (higher sampling in Cerrado and the Amazon than in Caatinga) may be the fact that the Caatinga covers a smaller area (less than 3% of the territory of Maranhão) compared to the other two domains, which cover more than 98% of the territory (Stella, 2011). It is worth mentioning that there is a heated discussion on whether Maranhão has representative areas of Caatinga or only ecotonal zones or small transition patches between Cerrado and Caatinga (Maranhão, 2021).

Regarding the Amazon in Maranhão, the Gurupi Biological Reserve is one of the places within the state with the highest predominance of this domain. In this study, this area was considered little sampled, with a low number of collections. This shows that even conservation units present a

sampling deficit. This is still an area that can be considered a priority for the conservation of Leguminosae because it undergoes deforestation, burning and illegal logging and is considered one of the Amazon forest areas of Maranhão with higher rates of degradation. Sustainable actions to replace current agriculture and livestock activities and investments in forest restoration in the region are recommended (Celentano, et al., 2018).

The results presented here also indicate that the areas of Maranhão with greater numbers of collections and species of Leguminosae are those located in Cerrado. This is understandable, since this domain and its various phytophysiognomies predominate in the state (64.1% of the territory) (Stella, 2011; Spinelli-Araújo et al., 2016). The Chapada das Mesas National Park and Mirador State Park stand out among the most collected Cerrado areas, presenting a diverse flora and Leguminosae as the richest family (Saraiva et al., 2020; Silva et al., 2022; Silva et al., in press).

The information on the areas of endemism provided in this study is particularly important to guide conservation actions aimed at the flora of Maranhão (Echternacht et al., 2011; Noroozi et al., 2018). It is important to highlight the strong anthropogenic pressure that acts on the regions with the largest rates of endemism, such as the South and North of the state. According to Soares (2008), the flora of the Cerrado of the South of Maranhão is strongly impacted by the constant expansion of the agricultural frontier and disorderly deforestation for the clearing of large areas for soybean cultivation. In turn, factors that act synergistically in the degradation of vegetation, such as agriculture, conversion of forested areas into roads, and urbanization are important pressures in the North of the state (Araújo et al., 2016; Almeida et al., 2020).

In this context, the conservation of endemism areas inserted mainly in these regions is a priority to preserve plant species and ensure the integrity of these areas, especially when considering that less than 19% of Maranhão is protected within conservation units (Spinelli-Araujo et al., 2016). In their evaluation of the effectiveness of conservation units in Maranhão, Masullo et al. (2020) pointed out that in contrast to the North of the state, the conservation units inserted in the South of Maranhão – a region with higher rates of endemism – have unsatisfactory levels of effectiveness, significant landscape change rates, and inefficient planning and management. Thus, we suggest that the creation of new conservation units considering the areas with higher endemism rates indicated in this study and

the application of management plans in existing conservation units are important actions for the conservation of these areas and the maintenance of the flora.

The results showed that livestock activities are the main anthropogenic threat among the land use and land cover categories that affect some species of Leguminosae in Maranhão, especially tree species.

In Maranhão, agribusiness has been advancing rapidly and, as a result, much of the natural coverage has been lost. This activity has been taking on great proportions, even reaching protected areas, demonstrating that public policies are not as effective as they should be with regard to inspection. To solve this problem, better planning is necessary and the protection of these areas must not be deemed to be the responsibility of a single entity, but rather a shared action (Barbosa et al., 2020)

The work carried out by Gerude (2013) stresses that the threats affect not only conservation units, but also the indigenous lands of Maranhão: Alto Turiaçu, Araribóia, Carú, among others. These protected areas contribute directly to mitigate deforestation, since they are the ones that have succeeded to preserve the most intact and uniform remnants of Amazon forest in Maranhão.

Anthropogenic actions such as deforestation, sale of illegal wood, and burning in conservation units and indigenous lands can cause problems and threaten the conservation of species, as they reduce the niche width of the species, cause

biological restrictions, and create the edge effect. The species are also subjected to lower quantity and quality of nutrients (Vezzani & Mielniczuk, 2009). The communities need plenty of space for dispersion and to expand their niches, ensuring greater specialization and greater competitive capacity (Cadotte et al., 2006; Devictor et al., 2010).

Finally, the results presented indicate that more floristic surveys and systematic studies need to be performed in the state of Maranhão, especially in the West and North regions, in areas little sampled, confirming our hypothesis raised for the research. These surveys will reduce the biases that hinder the sampling, identification and conservation of these areas. The present study is relevant for the knowledge of the flora of Maranhão, as it is the first study to evaluate the distribution of legume collections in the state of Maranhão, indicating the areas with the highest sampling deficits and providing a picture of what is known and what yet needs to be explored to enhance the knowledge of the Flora of Maranhão.

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