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Taxonomic Diversity and Threat Levels of the Arboreal Flora of the Brazilian Amazon

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Abstract

The Brazilian Amazon has one of the highest diversities of tree species in the world; however, knowledge of its flora is limited by significant taxonomic and geographic gaps. This study aimed to analyze the taxonomic diversity and conservation status of the arboreal flora in the Legal Amazon using official databases (*Flora e Funga do Br*asil). A total of 4249 tree species were recorded, with Fabaceae, Melastomataceae, and Apocynaceae showing the greatest species diversity. The states of Amazonas and Pará contained the largest datasets, indicating a sampling bias toward areas with stronger institutional infrastructure. A crucial finding was the high proportion of species classified as "Not Evaluated" or "Data Deficient," indicating a dangerous level of conservation invisibility. Nevertheless, species in high-risk categories ("Critically Endangered," "Endangered" and "Vulnerable") were found in all states, reflecting widespread human pressure across the biome. We conclude that conserving Amazonian flora requires urgent attention to gaps in risk assessment and to the integration of taxonomic data into territorial planning and environmental licensing policies.

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Keywords: Legal Amazon; Tree richness; IUCN; Sampling biases; Conservation status.

1. Introduction

The Brazilian Amazon is the largest continuous tropical forest in the world, hosting biodiversity essential to maintaining the balance of the biosphere. Recent estimates indicate that the Amazon basin may support more than 16,000 tree species, of which approximately 6700 have already been formally described (ter Steege et al., 2013; Cardoso et al., 2017). This forest not only functions as a major global carbon reservoir but also drives complex biogeochemical and hydrological cycles that influence climate on a continental scale.

The complexity of the Amazonian flora is maintained by a remarkable variety of habitats, ranging from terra firme forests and floodplains to campinaranas and savanna enclaves. This environmental heterogeneity, shaped by edaphic gradients and complex geological histories—such as the uplift of the Andes—has resulted in high levels of endemism and pronounced taxonomic turnover (beta diversity), which substantially limit ecological generalizations across Amazonia (Antonelli et al., 2018; ter Steege et al., 2020). Understanding how this diversity is distributed therefore represents a fundamental step toward the development of effective and sustainable management strategies.

Despite its biological importance, taxonomic knowledge of the Amazon remains constrained by the so-called Wallacean shortfall, defined as the gap between known species and accurate information on their geographic distributions. Historically, botanical collection efforts have been concentrated along river channels and road networks, leaving extensive interfluvial areas largely unexplored (Hopkins, 2007). This spatially biased sampling obscures the true magnitude of Amazonian plant diversity and suggests that the number of rare and threatened species may be considerably higher than currently documented in official databases.

Over the past two decades, Brazilian botany has undergone a major digital transformation driven by the development of large-scale biodiversity platforms such as *Flora e Funga do Brasil* and SpeciesLink. These initiatives, coordinated primarily by the Rio de Janeiro Botanical Garden, have enabled the integration of national and international herbarium collections, reducing nomenclatural inconsistencies and expanding access to occurrence data (Brazil Flora Group [BFG], 2015; *Flora e Funga do Brasil*, 2024). Nevertheless, the growing availability of botanical "big data" also introduces new challenges, particularly those related to data curation, as records with imprecise geographic coordinates or outdated taxonomic identifications require rigorous filtering before being used in conservation assessments.

Assessing the conservation status of arboreal plant species is a complex process that depends critically on the quality and spatial resolution of georeferenced occurrence data. Application of the International Union for Conservation of Nature (IUCN) Red List criteria requires robust estimates of Extent of Occurrence (EOO) and Area of Occupancy (AOO) (IUCN, 2024). In the Amazon, however, the scarcity of collections for rare or poorly known species frequently results in their classification as Data Deficient (DD), effectively excluding them from conservation planning and public policy priorities despite their potential vulnerability (Martinelli & Moraes, 2013).

The conservation scenario in the Amazon is further aggravated by intensifying human pressures, particularly within the so-called "Arc of Deforestation." Forest fragmentation and the expansion of the agricultural frontier not only lead to the direct loss of tree individuals but also disrupt key ecological processes, such as pollination and seed dispersal mediated by large vertebrates. Projections indicate that if current deforestation trends persist, up to 50% of Amazonian tree species may be classified as threatened by the middle of this century (ter Steege et al., 2015; Gomes et al., 2019).

In addition to land-use change, climate change has emerged as a synergistic threat. The increasing frequency of extreme drought events and the expansion of savanna-like conditions in eastern and southern Amazonia may push tree species adapted to humid environments beyond their physiological tolerance limits (Esquivel-Muelbert et al., 2019). Identifying species already categorized as Vulnerable, Endangered, or Critically Endangered is therefore essential for the design of ecological corridors that facilitate gene flow and lineage migration in response to ongoing climate change.

The integration of classical taxonomic approaches with geospatial analysis tools allows contemporary botany to move beyond simple species inventories. Analyses that incorporate conservation threat categories help identify "hotspots of vulnerability" within the Amazon. Taxonomic groups characterized by long life cycles or naturally low population densities deserve particular attention, as their recovery following disturbance is slow, increasing their susceptibility to local extinction (Stevens et al., 2020).

In this context, producing syntheses that integrate taxonomic diversity with officially recognized conservation status is essential. Such syntheses directly support international biodiversity commitments, including the Kunming–Montreal Global Biodiversity Framework, to which Brazil is a signatory. Botanical science must therefore provide robust, policy-relevant evidence to ensure that the establishment of Protected Areas and Indigenous Lands prioritizes the conservation of unique evolutionary lineages and threatened tree species.

2. Materials and Methods

2.1. Study Area

The spatial scope of this study includes the Brazilian Amazon, defined by the legal boundary of the Legal Amazon, as established by Law No. 1806/1953. This boundary encompasses the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins, and the western portion of Maranhão. The region covers more than 5 million km² and does not constitute a uniform ecological unit but rather a heterogeneous mosaic of phytophysiognomies (Figure 1). This diversity is shaped by soil gradients, hydrological regimes, and climatic variation, which collectively influence regional patterns of biological diversity (Instituto Brasileiro de Geografia e Estatística [IBGE], 2012; ter Steege et al., 2013).

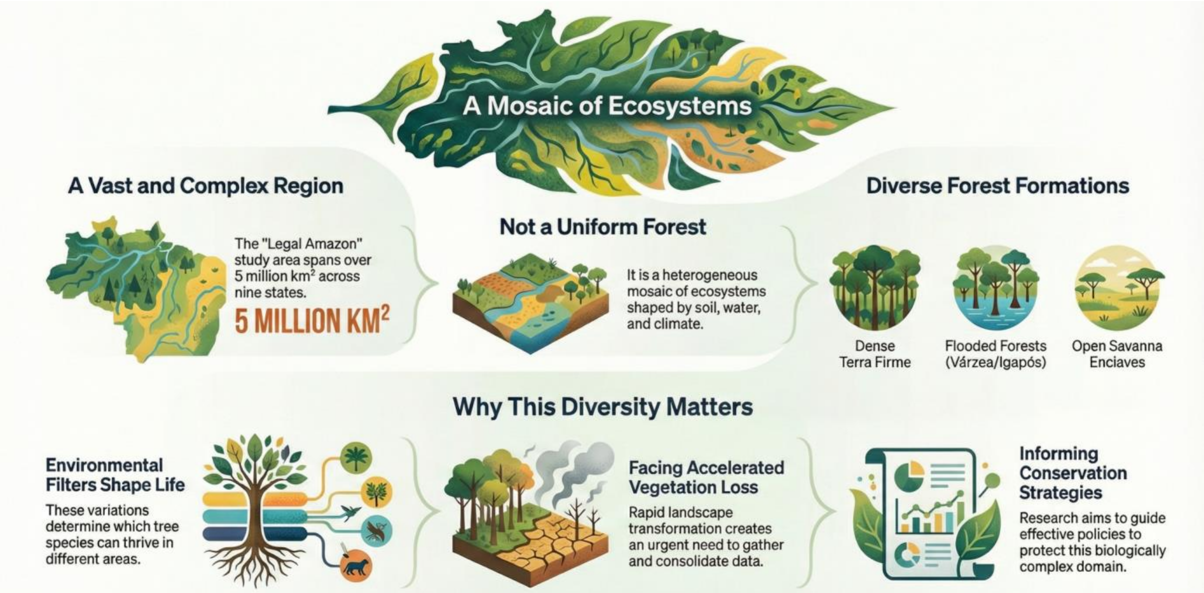

Figure 1. Legal Amazon: a mosaic of ecosystems

In 2004 the Brazilian Institute for Geography and Statistics (IBGE) divided the country into six regions and designated them as “biomes.” These “biomes” are defined by the predominant vegetation that was present before European colonization; they include areas where the original vegetation has been cleared for agriculture and other uses, as well as enclaves of other types of native vegetation. This differs from the meaning of the term “biome” in the ecological sciences, where it refers to broad groups of vegetation that is still standing anywhere in the world. The Amazon forest, for example, is part of the “tropical forest” biome that also includes the remaining Atlantic forest and other tropical forests around the world.

Environmental variation within the study area is expressed through a succession of ecosystems, ranging from dense terra firme forests to periodically flooded environments such as várzea and igapó forests. In addition to these formations, the region includes edaphically distinct physiognomies, such as campinaranas and savanna enclaves, which support highly specialized plant lineages. These environmental contrasts act as strong ecological filters, driving species turnover and shaping arboreal diversity at regional and continental scales (Antonelli et al., 2018). The choice of this spatial scope is motivated by the urgent need to integrate floristic information within a rapidly changing landscape, in order to support conservation planning in one of the most biologically complex regions on Earth.

2.2. Data Sources and Selection Criteria

Floristic and conservation data were obtained from authoritative secondary databases, primarily the *Flora e Funga do Brasil* platform, coordinated by the Rio de Janeiro Botanical Garden. This database represents a collective effort by taxonomic specialists

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and provides the official nomenclature and conservation status for Brazilian plant species (Brazil Flora Group [BFG], 2015; *Flora e Funga do Brasil*, 2024). In addition, the SpeciesLink network, maintained by the Centro de Referência em Informação Ambiental (CRIA), was used to assess the spatial density of georeferenced occurrence records.

Tree species belonging to botanical families recognized for their dominance and ecological relevance in Amazonian forests—such as Fabaceae, Malvaceae, Sapotaceae, and Lecythidaceae—were selected. Priority was given to taxa with recent and consistent taxonomic revisions, in order to avoid biases associated with unresolved species complexes or outdated nomenclature (Cardoso et al., 2017). For each taxon, the following attributes were recorded: botanical family, genus, species epithet, state-level occurrence, and official conservation category.

Strict eligibility criteria were applied: only taxa confirmed as native to the Amazon "biome" were included in the dataset (Figure 2). Note that this includes non-forest enclaves, such as the savannas of Roraima and Amapá. Exotic species, cultivated taxa, and records with uncertain occurrence within Brazilian territory were excluded. This procedure aimed to minimize analytical noise associated with identification errors in historical collections and to ensure that the resulting dataset reflects the current state of validated scientific knowledge (ter Steege et al., 2020).

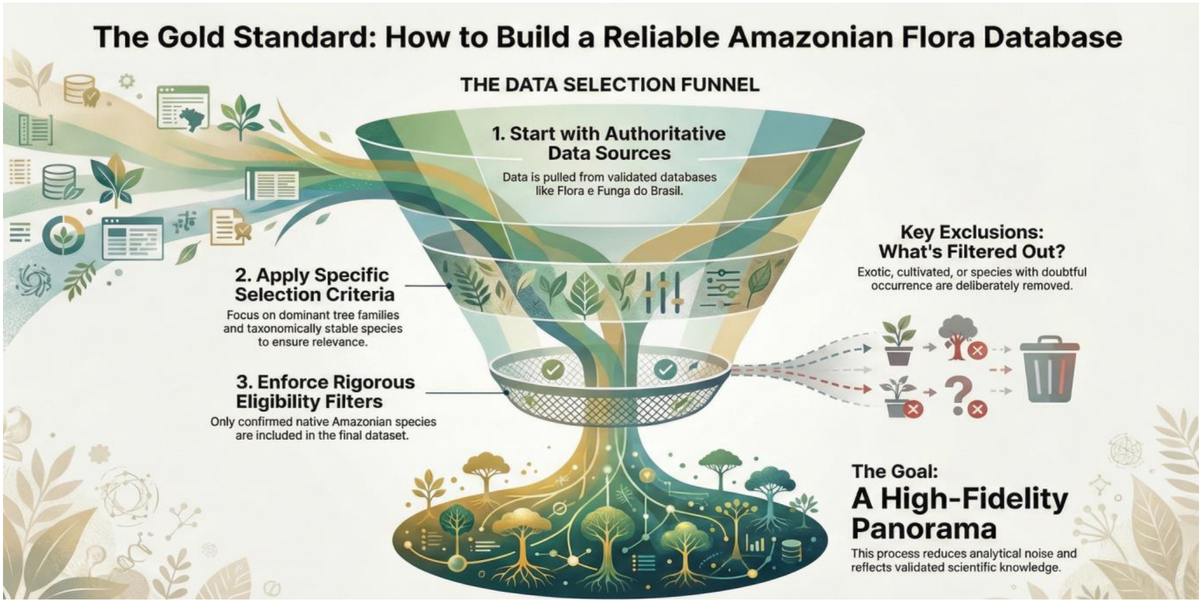

Figure 2. Methodological framework underlying the Amazonian flora dataset

It is important to emphasize that this study focuses exclusively on arboreal species, as defined by the growth form classification adopted in the Flora e Funga do Brasil database. Although the Amazon biome includes non-forest native vegetation types—such as savannas, campinaranas, and open formations—the present analysis does not aim to represent total plant diversity. Instead, it provides a descriptive synthesis of the documented arboreal flora recorded in herbarium-based databases, without inferring complete floristic composition or true species richness at the ecosystem level. Therefore, this study should be understood as a synthesis of documented arboreal species diversity based on official botanical databases, rather than as an ecological assessment of vegetation completeness across the Amazon biome.

2.3. Data Organization and Processing

Data processing followed a systematic nomenclatural standardization workflow designed to reduce artificial inflation of species richness caused by synonymy. All scientific names were validated against the *Flora e Funga do Brasil* index, adopting the

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Angiosperm Phylogeny Group IV (APG IV) system for family-level classification. This step is essential in large-scale floristic studies, where orthographic variation and divergent taxonomic concepts can compromise result comparability (Brazil Flora Group [BFG], 2021).

After nomenclatural validation, the data were organized into a matrix linking each species to its confirmed occurrence within the federative units of the Legal Amazon. Records lacking reliable state-level information or presenting geographic coordinates outside the Amazon "biome" were excluded. This spatial filtering ensured that inferences regarding diversity and endemism were specific to the Brazilian Amazon.

Conservation status was assessed using categories established by the Brazilian Red Book of Flora and CNCFlora, which are fully aligned with the criteria of the International Union for Conservation of Nature (IUCN). Species were classified as "Least Concern" (LC), "Near Threatened" (NT), "Vulnerable" (VU), "Endangered" (EN), "Critically Endangered" (CR), or "Data Deficient" (DD), allowing quantification of the proportion of arboreal species at varying levels of extinction risk (Martinelli & Moraes, 2013).

Species richness was summarized at both the botanical family and federative unit levels, enabling identification of centers of documented diversity as well as regional gaps in floristic knowledge. Descriptive statistical metrics were used to characterize the distribution of threat categories and to support the identification of conservation priorities (Gomes et al., 2019). Although the analyses are primarily descriptive, the robustness of the dataset allows for meaningful spatial interpretations relevant to Amazonian biogeography. The methodological procedures adopted are summarized in Figure 3.

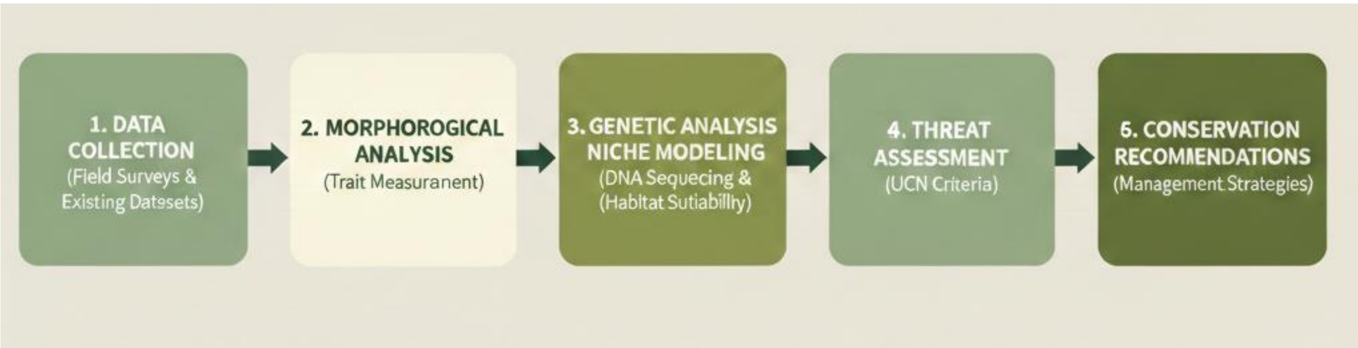

Figure 3. Methodological flowchart for species assessment

2.4. Methodological Limitations

The use of secondary data inevitably introduces "collector bias," whereby areas close to rivers, roads, and research institutions exhibit disproportionately high recorded density (Hopkins, 2007). This accessibility effect may lead to underestimation of species richness in remote interfluvial regions of Central and Western Amazonia. Consequently, the diversity patterns presented here should be interpreted as reflecting documented knowledge rather than the absolute magnitude of biological diversity.

Another important limitation concerns the prevalence of the "Data Deficient" (DD) category. Many Amazonian tree species are naturally rare or have restricted distributions, limiting the application of quantitative IUCN criteria and hindering accurate risk assessment (Martinelli & Moraes, 2013). Including these species in the analysis is nonetheless essential, as the lack of georeferenced data constitutes, in itself, a significant obstacle to effective conservation planning.

Despite these constraints, the official databases used in this study undergo continuous expert curation, substantially reducing systematic taxonomic errors. The application of strict filtering criteria and the exclusion of synonyms ensures that the conclusions are based on the best available evidence. Transparency in data processing further facilitates reproducibility in future floristic and conservation studies. In summary, the methodological approach balances large spatial scale with taxonomic rigor, offering a reliable

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overview of arboreal biodiversity in the Legal Amazon and supporting environmental planning initiatives aimed at identifying plant groups with elevated extinction risk (Stevens et al., 2020).

3. Results

3.1. Taxonomic Diversity and Floristic Composition

The comprehensive analysis revealed an extraordinary level of arboreal diversity in the Brazilian Amazon, totaling 4249 species (Table 1). This figure confirms the biome as one of the largest repositories of tree diversity worldwide, supporting estimates that place the Amazon Basin at the center of tropical lineage diversification (Cardoso et al., 2017; Antonelli et al., 2018). The floristic composition reflects a taxonomic structure typical of Neotropical forests, in which diversity is not evenly distributed but rather concentrated in a limited number of highly diverse families that shape regional physiognomy and ecosystem functioning.

Fabaceae emerged as the most species-rich family, with 1178 species, representing approximately 27% of the total inventory. This dominance is associated with the ecological versatility of the group, which includes pioneer and late-successional species, as well as its capacity for biological nitrogen fixation, conferring a competitive advantage in the predominantly acidic and nutrient-poor soils of the Amazon *(Flora e Funga do Brasil*, 2025; ter Steege et al., 2013). Melastomataceae (528 species) and Apocynaceae (322 species) were the next most diverse families, occupying a wide range of ecological niches from the understory to the forest canopy.

A clear taxonomic asymmetry was observed in family-level contributions. While families such as Lauraceae (248 species) and Malvaceae (255 species) showed a broad and consistent presence, other groups, including Myristicaceae (58 species) and Lecythidaceae (113 species), although less diverse in absolute terms, exhibited strong ecological specialization. Lecythidaceae, in particular, is recognized as one of the most structurally important families in Central Amazonia, comprising large-statured species that store substantial amounts of aboveground biomass (ter Steege et al., 2020).

Analysis of Amazonian affinity revealed distinct biogeographic patterns among families. Myristicaceae and Lecythidaceae presented Amazonian affinity indices of 87.9% and 84.3%, respectively, indicating that most Brazilian representatives of these families are restricted to, or centered in, the Amazon "biome." In contrast, families such as Euphorbiaceae and Apocynaceae exhibited Amazonian proportions below 35%, reflecting lineages with broader ecological tolerance or diversification centers distributed across other IBGE "biomes," including the Atlantic Forest and the Cerrado (Brazil Flora Group [BFG], 2021).

This disparity highlights the importance of conserving Amazonian integrity for the persistence of entire botanical lineages. The loss of Amazonian habitats would likely result in the near-complete national extinction of families such as Myristicaceae, underscoring that regional taxonomic diversity comprises both continental generalists and basin-restricted specialists whose evolutionary histories are closely linked to the geological and climatic dynamics of the tropical forest (Antonelli et al., 2018).

Table 1. Diversity of arboreal species by botanical family in the Brazilian Amazon

Botanical family	No. of species in Brazil	No. of species in the Amazon	% of Brazilian species in the Amazon	% of total Amazonian species
Fabaceae	3,160	1,178	37.3%	27.7%
Melastomataceae	1,575	528	33.5%	12.4%
Apocynaceae	1,041	322	30.9%	7.6%
Malvaceae	647	255	39.4%	6.0%
Lauraceae	507	248	48.9%	5.8%
Euphorbiaceae	1,047	261	24.9%	6.1%

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Botanical family	No. of species in Brazil	No. of species in the Amazon	% of Brazilian species in the Amazon	% of total Amazonian species
Lecythidaceae	134	113	84.3%	2.7%
Moraceae	241	140	58.1%	3.3%
Myristicaceae	66	58	87.9%	1.4%
Overall total	–	**4,249**	–	**100%**

3.2. Spatial Distribution of Species in the Brazilian Amazon

The spatial distribution of arboreal diversity revealed a pronounced gradient, with the state of Amazonas harboring the highest richness (3124 species), followed by Pará (2295 species). This pattern reflects both the larger territorial extent of these states and the presence of key centers of endemism, such as the interfluvial regions between the Negro and Solimões rivers (Hopkins, 2007).

Mato Grosso, with 1477 species, stood out due to the strong influence of ecotonal transitions with the Cerrado, incorporating floristic elements from distinct morphoclimatic domains. Acre (1713 species) and Rondônia (1605 species) showed intermediate richness values, reflecting the influence of Andean-derived floristic elements and southern Amazonian lineages, respectively.

Roraima (1410 species) exhibited relatively high richness considering its smaller area, a pattern attributed to its location within the Guiana Shield, one of the oldest geological formations in South America and a region characterized by high endemism (ter Steege et al., 2020).

In contrast, Maranhão (1,165 species) and Tocantins (852 species) displayed the lowest arboreal species richness. This pattern is largely explained by the smaller extent of Amazonian forest cover within these states, which are predominantly composed of ecological transition zones at the southern and eastern margins of the biome. As a result, the reduced forest area naturally limits the number of arboreal species recorded. In these regions, Amazonian forest elements are interspersed with taxa adapted to seasonal environments, resulting in structurally distinct and less species-rich forest formations (Instituto Brasileiro de Geografia e Estatística [IBGE], 2012).

It is important to note that the observed spatial patterns also reflect historical biases in botanical sampling. The concentration of records in Amazonas and Pará coincides with the presence of major research institutions, such as the Instituto Nacional de Pesquisas da Amazônia (INPA) and the Museu Paraense Emílio Goeldi (MPEG). Conversely, documented "collection gaps" in states such as Rondônia and Amapá suggest that actual species richness in these areas may be underestimated, emphasizing the need for targeted botanical surveys in remote regions (Hopkins, 2007; Brazil Flora Group [BFG], 2021).

From a biogeographic perspective, these results support the "center of diversity" hypothesis for Central and Western Amazonia. The decline in richness toward the southern and eastern margins—particularly within the Arc of Deforestation—represents not only a natural gradient but also a zone of heightened vulnerability, as these regions experience the highest rates of land-use change and habitat loss (Gomes et al., 2019).

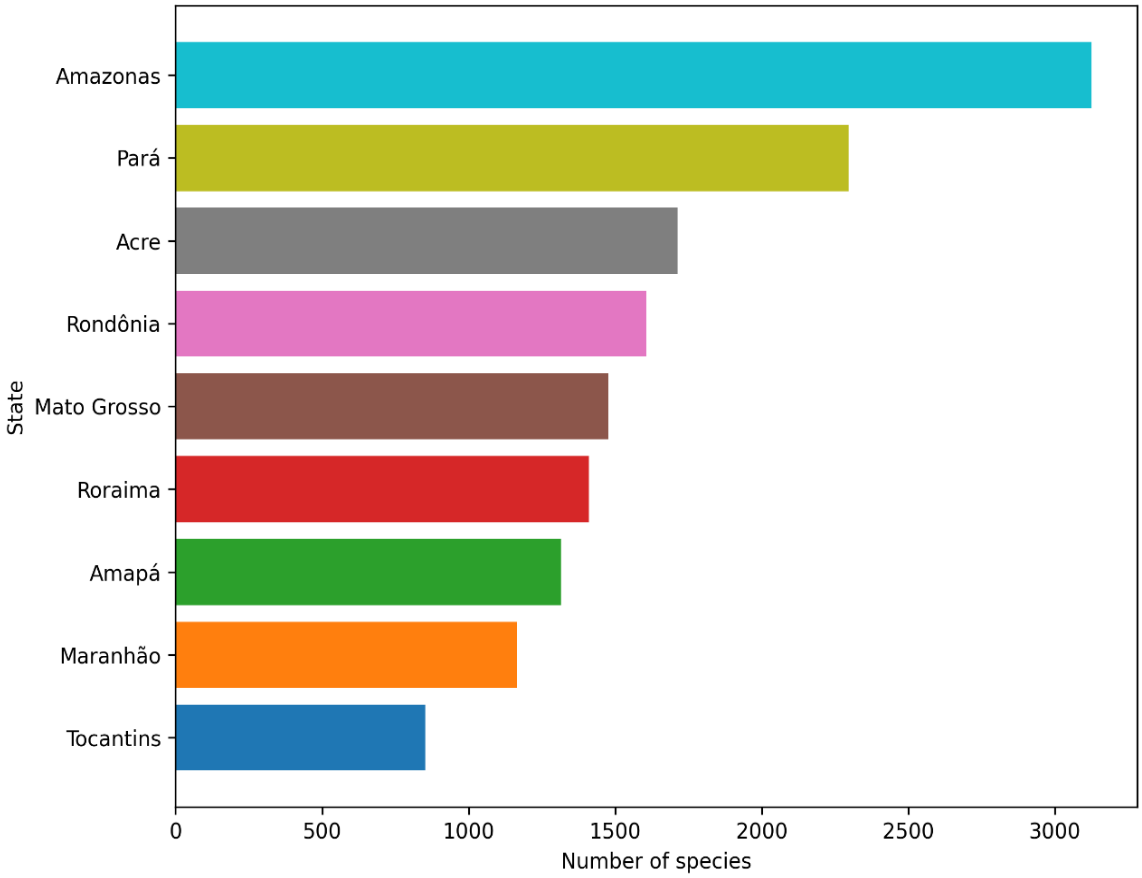

Figure 4. Number of arboreal species recorded in botanical databases by state in the Brazilian Legal Amazon.

3.3. Threat Categories of Arboreal Species

Assessment of conservation status revealed a concerning scenario marked by extensive information gaps. The most frequent category was “Not Evaluated” (NE), with the state of Amazonas alone accounting for 2496 species lacking an official extinction risk assessment. This finding highlights the mismatch between the pace of taxonomic knowledge generation and the institutional capacity to conduct formal extinction risk assessments following IUCN criteria, which require detailed demographic and population data (Martinelli & Moraes, 2013).

Species classified as “Least Concern” (LC) constituted a substantial portion of the flora in Amazonas (323 species) and Pará (242 species), generally representing taxa with broad distributions or populations occurring within protected areas. However, the high proportion of “Data Deficient” (DD) species indicates that for a significant share of the arboreal flora, current information is insufficient to reliably assess extinction risk, resulting in substantial conservation uncertainty (International Union for Conservation of Nature [IUCN], 2024).

Although less numerous, species categorized as “Critically Endangered” (CR), “Endangered” (EN), and “Vulnerable” (VU) demand immediate conservation action. Amazonas registered 12 CR and 82 EN species, while Pará recorded 8 CR and 46 EN species. Many of these taxa include timber-producing trees or species with economically valuable fruits, whose populations have declined due to historical overexploitation and ongoing habitat conversion linked to agricultural expansion (Martinelli & Moraes, 2013; Gomes et al., 2019).

Spatial analysis indicates that extinction risk drivers vary regionally. In Mato Grosso, Pará, Rondônia, threats are primarily associated with habitat fragmentation and deforestation, whereas in Amazonas, vulnerability is often linked to the geographic isolation of narrow endemic species. The intrinsic rarity of many Amazonian trees implies that even limited habitat loss can rapidly elevate species from EN to CR categories (ter Steege et al., 2015).

Overall, the results indicate that effective protection of Amazonian arboreal flora requires a dual strategy: targeted conservation actions for species already recognized as threatened, and large-scale research efforts aimed at reducing the extensive NE and DD knowledge gaps (Figure 5). Without sustained investment in taxonomy, floristic inventories, and population ecology, Brazil risks losing tree species before their conservation status is formally assessed, compromising the genetic heritage and functional resilience of the world's largest tropical forest (Stevens et al., 2020; Brazil Flora Group [BFG], 2021).

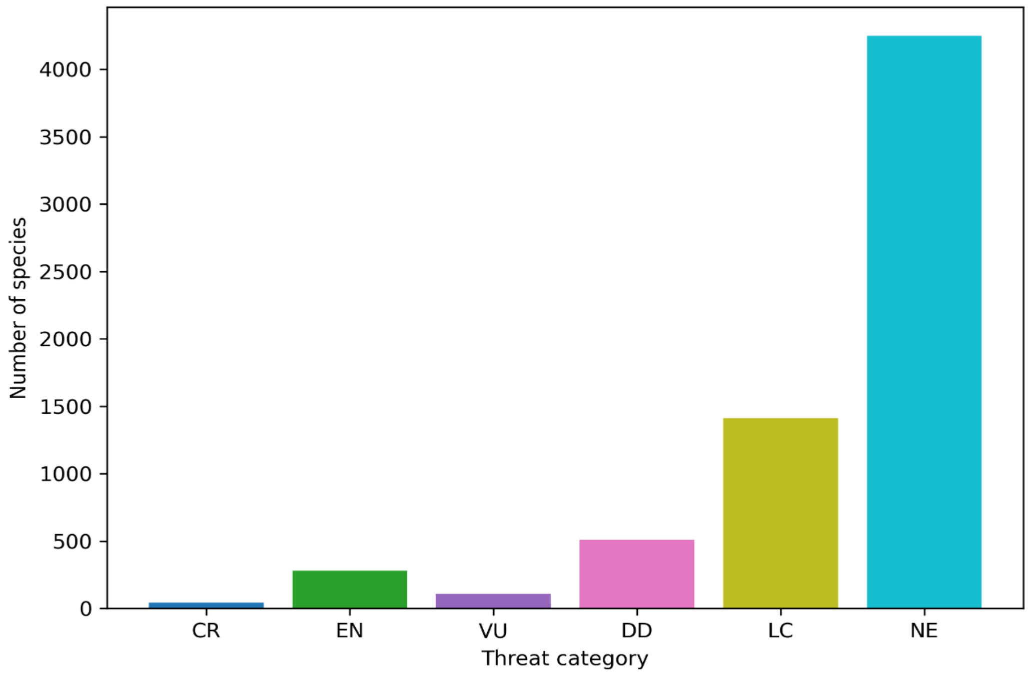

Figure 5. Distribution of arboreal species across threat categories in the Brazilian Legal Amazon

4. Discussion

Overall, the results confirm that arboreal diversity in the Brazilian Amazon is characterized by pronounced taxonomic inequality, with a small number of botanical families accounting for a disproportionately large share of species richness. The prominence of Fabaceae, Melastomataceae, and Apocynaceae supports the "hyperdominance" model proposed by ter Steege et al. (2013), indicating that the evolutionary success of these lineages is closely linked to functional traits that enable persistence in nutrient-poor soils and under intense competition for light. Fabaceae, in particular, plays a critical role in ecosystem resilience through biological nitrogen fixation, reinforcing its importance as a focal group for forest restoration and climate mitigation strategies (Cardoso et al., 2017).

However, patterns of diversity cannot be interpreted solely through species richness. The concept of "taxonomic rarity" is central to understanding Amazonian biodiversity, as most botanical families contribute only a small number of species, many of which have restricted geographic ranges and low population densities. This "long-tail" distribution pattern implies that the loss of relatively small forest fragments may result in the extinction of entire lineages lacking functional redundancy within the ecosystem (ter Steege et al., 2020).

The high Amazonian affinity observed in families such as Lecythidaceae and Myristicaceae—exceeding 80%—positions these groups as effective "sentinels of biome identity." Unlike cosmopolitan families or Neotropical generalists, these lineages diversified in close association with the geological and climatic history of the Amazonian sedimentary basin (Antonelli et al., 2018). This strong biogeographic specialization increases their vulnerability to large-scale disturbances, particularly those associated with climate change, such as prolonged droughts, given their limited phenotypic plasticity outside closed-canopy forest environments.

Many species within these families depend on biotic seed dispersal by large vertebrates, whose populations are themselves declining due to hunting pressure and habitat fragmentation. The loss of dispersers disrupts regeneration dynamics and further compromises population persistence, emphasizing that conservation of Amazonian trees requires maintaining ecological interactions rather than focusing solely on species-level protection (Gomes et al., 2019).

The concentration of recorded diversity in the states of Amazonas and Pará reflects a genuine biological gradient but must also be interpreted through the lens of the "Linnaean shortfall" and infrastructure-related sampling biases. While Amazonas undeniably represents a core area of diversity, disparities relative to states such as Amapá and Rondônia are amplified by the historical distribution of herbaria, universities, and research funding (Hopkins, 2007). Large portions of the Amazonian interior remain poorly sampled, indicating that current richness maps partially reflect logistical accessibility rather than true biological patterns.

In peripheral and transitional regions such as Tocantins and Maranhão, lower recorded species richness may result from ecological filtering imposed by greater hydrological seasonality. Nevertheless, these areas harbor species adapted to stressful environmental conditions, potentially containing genetic traits related to drought and thermal tolerance that may prove crucial for the future resilience of the biome under climate change scenarios (Esquivel-Muelbert et al., 2019). Under-sampling in these margins thus represents not only a knowledge gap but also a strategic loss of information relevant to climate adaptation.

Among all findings, the dominance of species classified as "Not Evaluated" (NE) represents the most alarming result. This pattern indicates a structural disconnect between taxonomic knowledge production and the mechanisms responsible for granting legal protection. Species lacking formal extinction risk assessments are excluded from environmental licensing frameworks, allowing populations to be legally removed by infrastructure and development projects without consideration of their conservation status (Brazil Flora Group [BFG], 2015). This form of "taxonomic blindness" constitutes one of the most silent yet pervasive threats to Amazonian arboreal flora.

Similarly, the high number of species categorized as "Data Deficient" (DD) highlights a critical bottleneck in field-based research. The DD category should not be interpreted as an absence of risk but rather as an indicator of biological rarity and insufficient data availability (International Union for Conservation of Nature [IUCN], 2024). DD species are frequently narrow endemics with few georeferenced records, limiting the calculation of Area of Occupancy (AOO). Transitioning species from DD and NE to assessed categories requires coordinated national efforts focused on collection digitization and targeted expeditions addressing neglected taxa (Martinelli & Moraes, 2013).

The occurrence of "Critically Endangered" (CR), "Endangered" (EN), and "Vulnerable" (VU) species across all states demonstrates that Amazonian degradation is spatially pervasive. In Amazonas, the relatively high number of threatened species may be associated with concentrations of endemism near Manaus, where urban expansion and infrastructure development are intense. In Mato Grosso and Pará, extinction risk is primarily driven by forest conversion to pastures and monocultures, which disproportionately affects species that are already naturally rare (ter Steege et al., 2015).

Threats are further exacerbated by the life-history traits of many endangered trees, which are often slow-growing species with dense and economically valuable timber. Selective logging preferentially removes the largest and most reproductively active individuals, leading to genetic erosion and reduced reproductive capacity in remaining populations. Without species-specific National Action Plans (PANs), many populations risk becoming "living dead" populations—persisting as isolated individuals incapable of sustaining viable reproduction (Gomes et al., 2019; Stevens et al., 2020).

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Addressing these challenges requires integrating classical taxonomy with emerging tools such as remote sensing, ecological niche modeling, and artificial intelligence. These approaches can guide targeted field surveys by predicting the potential distribution of rare and poorly known species, optimizing limited financial and logistical resources. Conservation genetics further complements this framework by enabling estimation of effective population sizes and genetic connectivity, even when occurrence data are sparse (Antonelli et al., 2018; Brazil Flora Group [BFG], 2021).

From a policy perspective, strengthening environmental governance demands mandatory consultation of official botanical databases, such as Reflora and *Flora e Funga do Brasi*l, during environmental licensing procedures. Scientific evidence of biodiversity presence already exists; the critical challenge now lies in translating botanical data into effective legal safeguards. The future of the Brazilian Amazon depends on the ability to catalog, assess, and protect its arboreal diversity before ecosystem tipping points, such as large-scale savannization, render forest protection and restoration efforts unviable.

It is essential to interpret the observed spatial patterns as reflections of documented knowledge rather than exhaustive representations of arboreal diversity. Because the dataset is derived from the Flora e Funga do Brasil platform, the results express the current state of herbarium records and taxonomic validation, rather than direct ecological sampling. Consequently, differences among states reflect a combination of forest area extent, historical sampling effort, and institutional research capacity, rather than inferred differences in ecosystem quality or productivity.

5. Conclusions

This study demonstrates the exceptionally high arboreal diversity of the Brazilian Amazon and highlights the uneven distribution of this diversity across botanical families, states, and threat categories. The concentration of species within a limited number of families, combined with strong spatial disparities in records, reflects both intrinsic biogeographic patterns of the Amazon "biome" and historical inequalities in sampling effort and floristic research.

The analysis of taxonomic richness and conservation status reveals a biologically significant heritage supported by an uneven knowledge base. While the dominance of families such as Fabaceae and Malvaceae follows well-established evolutionary patterns, the strong Amazonian affinity of lineages such as Lecythidaceae and Myristicaceae indicates that the botanical identity of the Amazon "biome" is closely tied to highly specialized and potentially vulnerable groups. Amazonian biodiversity therefore represents not merely a compilation of species, but a complex mosaic of evolutionary histories shaped by extensive environmental gradients.

Spatial patterns of diversity show that current knowledge remains concentrated around traditional research centers, generating information gaps that distort perceptions of regional richness. Although diversity gradients partly reflect ecological factors, they are also strongly influenced by logistical accessibility and historical research infrastructure. Peripheral states and ecological transition zones, despite lower absolute richness, emerge as strategic areas for identifying lineages adapted to hydrological and thermal stress, traits that are increasingly relevant under climate change scenarios.

The most critical finding is the high prevalence of species classified as "Not Evaluated" (NE) and "Data Deficient" (DD). This diagnostic gap creates a form of conservation invisibility, whereby deforestation and habitat conversion advance faster than formal risk assessments. As a result, many species remain excluded from conservation priorities and legal protection, weakening public policies aimed at safeguarding plant diversity in the Amazon.

The presence of "Critically Endangered" (CR), "Endangered" (EN), and "Vulnerable" (VU) species across all states indicates that threats are widespread and driven by both selective exploitation and habitat loss. Effective conservation strategies must therefore incorporate official databases, such as *Flora e Funga do Brasil*, into environmental licensing and land-use planning. Particular attention should be given to large, slow-growing species, whose demographic traits increase their vulnerability and justify targeted protection and connectivity measures.

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By integrating taxonomic, spatial, and conservation data from official sources, this study provides an updated synthesis of arboreal diversity in the Brazilian Amazon. The results emphasize the need to strengthen long-term taxonomic and ecological research, expand extinction risk assessments, and prioritize under-sampled regions and taxa. Ultimately, advancing Amazonian botany depends on the integration of classical taxonomy, field ecology, and emerging technologies, ensuring that scientific knowledge effectively supports conservation and environmental governance grounded in evidence.

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