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ADVANCING OPEN OMBROPHILOUS FOREST KNOWLEDGE IN THE SOUTHWEST BRAZILIAN AMAZON: STRUCTURE, FUNCTIONAL TRAITS, VEGETATION TYPES, AND THREAT ASSESSMENT IN A PROTECTED AREA

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Abstract. Biodiversity inventories present excellent opportunities for ecological investigations and the classification of different threats to the community, nonetheless these applications are not frequently employed. Our main objective was to analyse the structure of the tree and palm community in a one-hectare plot within a protected area in the deforestation arc. Additionally, we performed a comprehensive ecological characterization—encompassing functional traits, vegetation typology, and conservation threats—based on a review of the available literature and existing databases. We established a rectangular plot (10x1000m) to assess the community structure. Information on seed and fruit size attributes was obtained from the literature, along with data on the projected threat category. Overall, two taxa (Rubiaceae sp. and Rhizophoraceae sp.) were characterized only at the family level, 106 at the genus level (morpho-species), and 124 at the binomial name. We found information about seed size for 55 genera. Medium-sized seeds were the most frequent, occurring in 22 genera, followed by large seeds (16), small seeds (6), and very small seeds (5). For the projected threat status for 2050, we found that 28 species were classified as vulnerable and 16 species as endangered. In our plot, we found a few species with many individuals. Our research, though small in scale, provides a significant contribution to the region's biodiversity knowledge. Such studies are urgently needed, given the continuing loss of native vegetation due to development pressures. We conclude that it is important to improve regional floristic knowledge to address existing shortfalls in understanding species distributions and ecological interactions, such as dispersal characteristics and threat status.

Keywords: plant inventories; biodiversity; Brazilian Amazon; seed size; threat status

INTRODUCTION

The Amazon region is renowned for its extraordinary biodiversity, making it one of the most ecologically diverse regions in the world. Moreover, the acknowledgment of its essential contribution to critical ecosystem services has propelled the Amazon to attain global conservation eminence, commanding the attention of national and international scholars alike (Malhado et al. 2014; Santos et al. 2015). Regardless of this premise, substantial portions of this biome remain unexplored. The vastness and isolation of the Amazon present formidable challenges for conducting systematic and regular investigations within the region, even when employing appropriate technological advancements (Ladle & Whittaker 2014; Gardner et al. 2018; Carvalho et al. 2023). It is estimated that 40% of the Amazonian domain remains untouched by scientific inquiry (Schulman et al. 2007), indicating a significant research shortfall. Accessibility, primarily limited by poor riverine and terrestrial transportation routes, as well as the scarcity of scientific and technological facilities and infrastructure projects (e.g., hydroelectric installations) restrict research efforts in the Amazon basin (Santos et al. 2015; Correia et al. 2016). Consequently, this situation engenders uncertainties regarding the spatial distribution of numerous species owing to prevalent sampling biases (Hortal et al. 2015).

Nevertheless, the Amazon faces formidable obstacles characterized by alarming rates of habitat degradation and species extinctions (Assis et al. 2019). In the southern and southeastern regions, the presence of gaps is attributed to a long history of deforestation for pastureland, commonly referred to as the "Deforestation Arc", which has hindered specimen collections in this area (Stropp et al. 2020). This region has experienced cumulative higher taxa of deforestation over the years, resulting in the loss of numerous species, some of which may have become extinct even before being scientifically documented, rendering previously collected records obsolete (Stropp et al. 2020). Long-term floristic inventories play a crucial role in advancing our understanding of diversity patterns, the distribution of flora in the Amazon region and their dynamics. Some studies of tree species in the Amazonian region, currently estimated to range from approximately 7000 to 10 000 species (Cardoso et al. 2017; ter Steege et al. 2020), remain far from complete, with the potential for as many as 5000 new species of trees yet to be discovered (ter Steege et al. 2016).

The literature extensively addresses the knowledge gaps surrounding species occurrences, commonly referred to as the Wallacean shortfall (Brown & Lomolino 2006; Ladle & Whittaker 2014; Hortal et al. 2015). This term refers to the insufficiency of existing knowledge about species distribution and geographical dynamics. From the standpoint of conservation and policy, it becomes imperative to prioritize extensive data collection efforts in regions characterized by high conservation value or facing imminent risks of habitat destruction, particularly where sampling completeness remains low. The Raunkiaer shortfall refers to the lack of knowledge regarding ecologically relevant species traits, encompassing both intra-specific and inter-specific trait variations (Hortal et al. 2015). Furthermore, this shortfall extends to comprehending the ecological functions associated with each trait, as well as elucidating how these functions are affected by such interactions. In addition, it aims to identify the specific combination of traits that collectively contribute to the performance of distinct ecosystem functions, thus emphasizing the significance of trait bundling (Díaz et al. 2013).

Seed size is a fundamental functional trait that can provide valuable insights into various ecological dynamics (Bello et al., 2025; Malhado et al., 2015). Despite the challenges associated with directly measuring certain traits, including seed size, these data are crucial for understanding key aspects of plant life history strategies and their interactions within ecosystems (Bello et al., 2025), such as (a) smaller seeds are generally dispersed by a wider array of vectors (e.g., water, wind, animals), facilitating colonization of new areas, particularly in disturbed environments, thereby contributing to ecological succession processes; and (b) larger seed sizes may enhance seed resistance to extreme environmental conditions, such as drought or temperature extremes, influencing community composition and species resilience within the community. In other words, assessing seed size serves as an indicator of ecological strategies that impact not only the individual success of plants

but also population and community dynamics, contributing to an integrative understanding of ecological processes. However, analyzing these traits at the macroecological scale is frequently hampered by a persistent challenge: the limitation and heterogeneity of standardized quantitative data. Indeed, the majority of seed-size information for the Amazon is categorized qualitatively (e.g., very small, small, medium, large), with few records containing exact quantitative measurements of volume or mass (Malhado et al. 2015). Standardizing seed size into quantitative categories, such as centimeters, is therefore a critical step and contributes to understanding the ecological dynamics of trees in the Amazon region in several ways (Malhado et al. 2015): (a) allows for the identification of spatial and correlational patterns between seed size and environmental or ecological factors; (b) facilitates understanding how dispersal strategies contribute to functional diversity and structural adaptation in the Amazon rainforest.

Significant progress has been made in establishing a shared repertoires of valuable traits applicable to various taxa, particularly in plants, alongside the implementation of standardized sampling protocols (Hortal et al. 2015)taxonomic, and temporal scales. However, despite recent efforts to gather two centuries of biodiversity inventories into comprehensive databases, many crucial research questions remain unanswered. Here, we update the concept of knowledge shortfalls and review the tradeoffs between generality and uncertainty. We present seven key shortfalls of current biodiversity data. Four previously proposed shortfalls pinpoint knowledge gaps for species taxonomy (Linnean. Nevertheless, it is important to acknowledge the existence of substantial shortfalls in both taxonomic coverage and geographic representation, highlighting the need for further research and exploration. Our study aims to (i) characterize the structure and composition of a one-hectare open ombrophile forest area within the Jamari National Forest, located in the southwestern Brazilian Amazon, within the Deforestation Arc; (ii) assess the literature regarding the seed size of the genera recorded in our sampling units (Malhado et al. 2015); (iii) investigate the biogeographical distribution of vegetation types associated with the species present in our plot; and (iv) assess the literature regarding the future projected threat status of the species for the year 2050.

MATERIAL AND METHODS

Study area

This study was conducted in the National Forest (Flona) of Jamari, located in the state of Rondônia, in the southwestern Brazilian Amazon (Figure 1). The research was carried out within the PPBio (Biodiversity Research Program) research module 'Potosi', a permanent plot infrastructure designed for long-term ecological monitoring. This conservation unit is characterized by a unique combination of protected status and active resource use, encompassing both sustainable timber harvesting concessions and cassiterite (tin ore) mining operations. Its location within the deforestation arc, a region under intense anthropogenic pressure, makes it a critical area for biodiversity research. The choice of this site provides valuable baseline data on forest structure and composition in a complex and strategically important Amazonian landscape.

Plant inventory plot and botanical identification

We set up a one-hectare plot for plant inventory in September 2014. We established one hundred consecutive sample units measuring 10x1000m transect within the Jamari National Forest (Floresta Nacional do Jamari – Flona do Jamari). In each sample unit, we measured the diameter of all trees and palms ≥ 10cm at breast height (approximately at 1.3m high). The trees were identified in the field with the aid of parataxonomists, and material was sent to specialists for identification for confirmation. Herbarium voucher numbers of all species sampled were collected and incorporated into the Herbarium Rondoniense João Geraldo Kuhlmann of the Universidade Federal de Rondônia. The dataset is available in the open database SpeciesLink (https://specieslink.net/search/) and can be accessed using the following search query [(coll_groups:(botanical)) AND (coll_ids:(((764) OR (765) OR (257)))) AND (county:((Itapuã

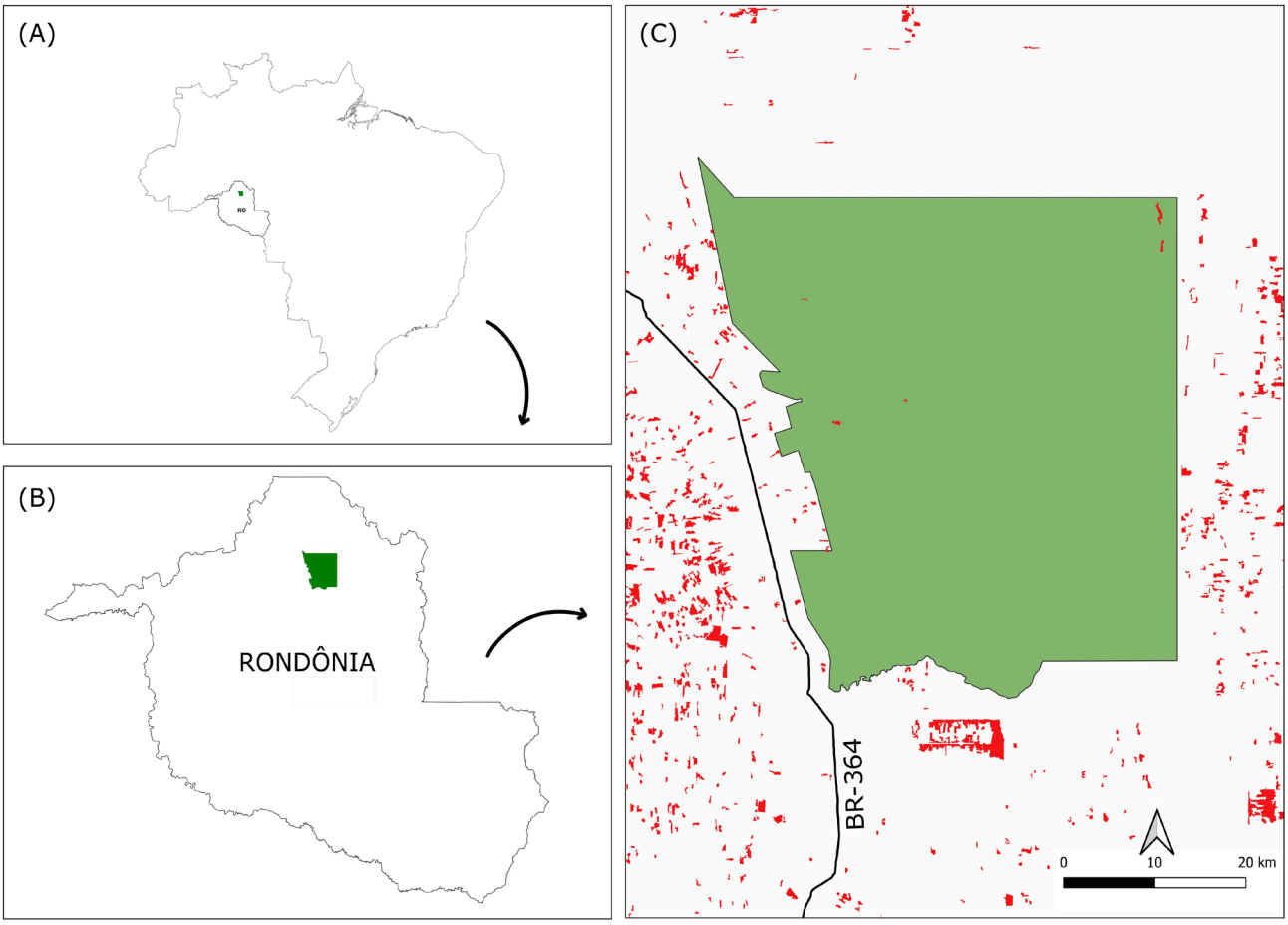

Figure 1. Maps showing the location of the Jamari National Forest (Flona do Jamari) in the state of Rondônia, Brazilian Amazon. (A) Brazil, (B) the state of Rondônia, and (C) the Jamari National Forest. The red areas in panel C represent deforested areas, based on data from PRODES (2008–2015) (Assis et al. 2019).

do Oeste))) AND (locality.normal:((Módulo Potosí)))]. We tagged trees of all morpho-species (fertile and/or sterile) and collected at least one sample per morpho-species. Species names follow the standard nomenclature provided by the Brazilian Flora Checklist (BFG, 2021).

Analysis of forest structure and plant species diversity

We characterized forest structure by estimating the following parameters for families and species of plot: absolute density (AD), relative density (RD), absolute frequency (AF), relative frequency (RF), absolute dominance (ADo), relative dominance (RDo) and importance value (VI). The Payandeh index was used to investigate patterns of tree spatial aggregation, which measures deviations from a random spatial distribution (Payandeh 1970; Carvalho 1983; Caldato 1998). To complement this structural analysis, we also calculated the Shannon-Weaver (H') index as a measure of species diversity and Pielou's evenness (J') to determine the equitability of species abundances within the community. All analyses concerned with forest structure were carried out on Fitopac 2.1 software by Shepherd (2010). The Payandeh, Shannon Weaver and Pielou equability indices were calculated with Microsoft Excel 2019. Sampling completeness and species richness were assessed using individual-based rarefaction (interpolation) and extrapolation curves (Chao & Jost 2012). Analyses were performed in R using the iNEXT package (Hsieh et al. 2016). Diversity was quantified using Hill numbers of order q=0, corresponding to species richness. To assess statistical uncertainty, 95% confidence intervals were calculated based on 1,000 bootstrap replications.

Seed size

We classified seed sizes for all genera in our plot using the categorical framework from Malhado et al. (2015). According to this framework, seeds are classified into four size levels: large (≥2.0 cm), medium (1.0–1.99 cm), small (0.5–0.99 cm), and very small (<0.5 cm). It is important to clarify that while those authors provide the classification system, we applied it to the genera in our dataset. This methodology was necessary due to the lack of published seed size data for most of the individual species we encountered. Using the genus as a functional unit is a reliable approach in such cases, as it leverages trait conservatism.

Distribution

For all taxa identified to the species level, we collected data on their distribution across Brazilian phytogeographic domains and vegetation types according to the Flora do Brasil (BFG, 2021). Furthermore, we compiled a list of all Brazilian states where each taxon has been documented using both the Flora do Brasil (BFG, 2021) and the SpeciesLink platform (CRIA, 2016). Additionally, we verified the presence of these taxa in the checklist of Brazilian Amazon tree taxa (ter Steege et al. 2016).

Threat status

We retrieved for all taxa identified at the species level the current threat status according to IUCN using the Flora do Brasil (BFG, 2021) and the list provided by Ministério do Meio Ambiente (MMA) (PORTARIA MMA Nº 148, DE 7 DE JUNHO DE 2022). Additionally, we incorporated the projected threat status for 2050 based on ter Steege et al. (2015). We used the R package 'flora' (Carvalho 2017) to retrieve information from the Brazilian Flora Checklist.

RESULTS

Forest structure and plants species diversity

We sampled 465 trees and palms belonging to 39 families, 100 genera and 220 species (Figure 2). One hundred thirty-three species (60.7%) presented an absolute density equal to one (Sup. Mat. 1). The Shannon (H') index for species was 5.11 nats.ind-1, and the Pielou equability index was 0.94. All species studied exhibited a Payandeh index value below 1, indicating a random spatial distribution. Overall, two taxa (Rubiaceae sp.and Rhizophoraceae sp.) were characterized only at the family level, 106 at the genus level (morpho-species) and 124 until binomial name. The richest genera were *Protium* (13), *Eschweilera* (11), *Licania* (10), *Pouteria* (8) and *Ocotea* (7) (Figure 3a). Fabaceae represented approximately 18,58% of the importance value, whereas another 24 families accounted for slightly more than 10% (Figure 3b). We found that 13 families were monospecific, and no species presented high relative values for any of the phytosociological parameter.

Seed size

We found information about seed size for 54 genera. Medium-sized seeds were the most frequent, occurring in 21 genera, followed by large seeds (16), small seeds (6), and very small seeds (5). Additionally, six genera had seeds that varied between small/medium (3) and medium/large (3) (Figure 4).

Distribution by vegetation type

The five predominant vegetation types that these species occur across the biomes are Floresta de Terra Firme (106), Floresta Ombrófila (53), Campinarana (36), Floresta Ciliar (20) and Floresta de Várzea (17) (Sup. Mat. 2). *Protium panamense* has not been reported to occur in the Amazonian region according to Flora do Brasil (BFG, 2021), but there are occurrences reported in Amazonas state according to the SpeciesLink database and ter Steege et al. (2016).

Threat status

Regarding the current threat status, we identified just two species from the Fabaceae family as threatened: *Peltogyne excelsa* Ducke, classified as Vulnerable (VU), and *Vouacapoua americana* Aubl classified as Endangered (EN), among the 124 species recorded in our plot. *Vouacapoua americana* was listed as threatened in both 2014 and 2022 by MMA. For the projected threat status in 2050,

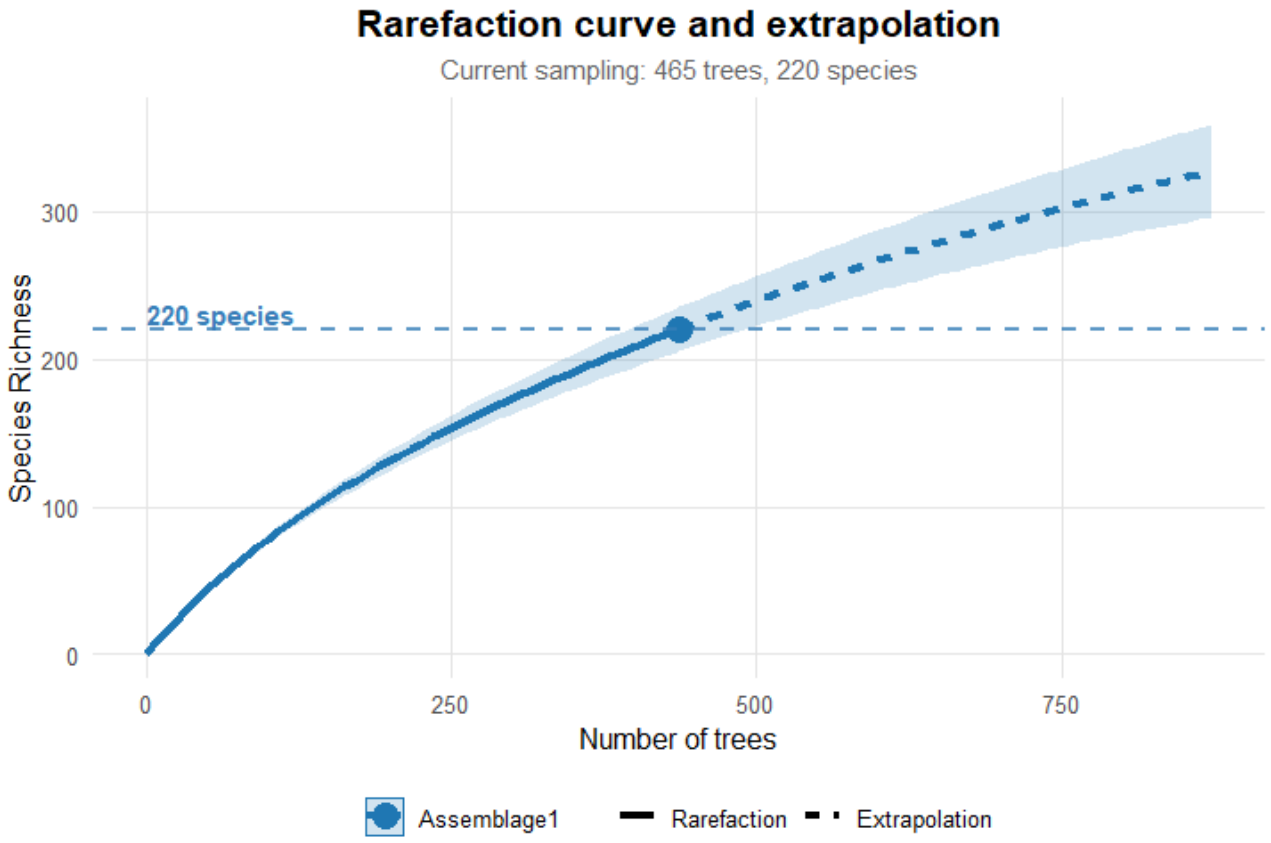

Figure 2. Individual-based rarefaction (interpolation) and extrapolation sampling curves for species richness of the studied community. The solid line represents the observed data (rarefaction), while the dashed line represents the extrapolated richness beyond the current sampling effort. The shaded area indicates the 95% confidence intervals (bootstrap).

based on ter Steege et al. (2015), we found 28 species classified as Vulnerable and 16 as Endangered by 2050 (Sup. Mat. 2).

DISCUSSION

In the entire Brazilian Amazon region, knowledge partners are spatially clustered, predominantly situated near major roads or large rivers (Stropp et al. 2020). The historical speaks in botanical sampling align with prominent research initiatives, particularly the 'Flora projects', which emphasize comprehensive field surveys and precise species documentation (Stropp et al. 2020). This approach is of great significance in regions marked by elevated deforestation rates and ecotonal vegetation, such as the southwestern Brazilian Amazon. However, one question remains: Are protected areas suitable for implementing these projects in such areas? It is likely that they are, particularly when involving international and national research centers, policymakers (e.g., municipal and state governments), indigenous leaders, and securing adequate funding. Such collaborations have the potential to reduce bureaucratic barriers and facilitate the advancement of botanical knowledge at this geographic scale.

The high number of species classified as rare, based on a single recorded individual per species, i.e. species with absolute density (AD) equal to one, underscore the importance of field data in understanding species dynamics and occurrences. Moreover, the significant number of species that have not yet been assigned a threat status by the IUCN underscores the need for accurate assessments of the conservation status of tree species, especially considering the pressures faced by forests across the region. The lack of knowledge regarding the threat status for the majority of species recorded in our plot suggests the necessity for a more comprehensive assessment to accurately evaluate the real threats to these species. Our

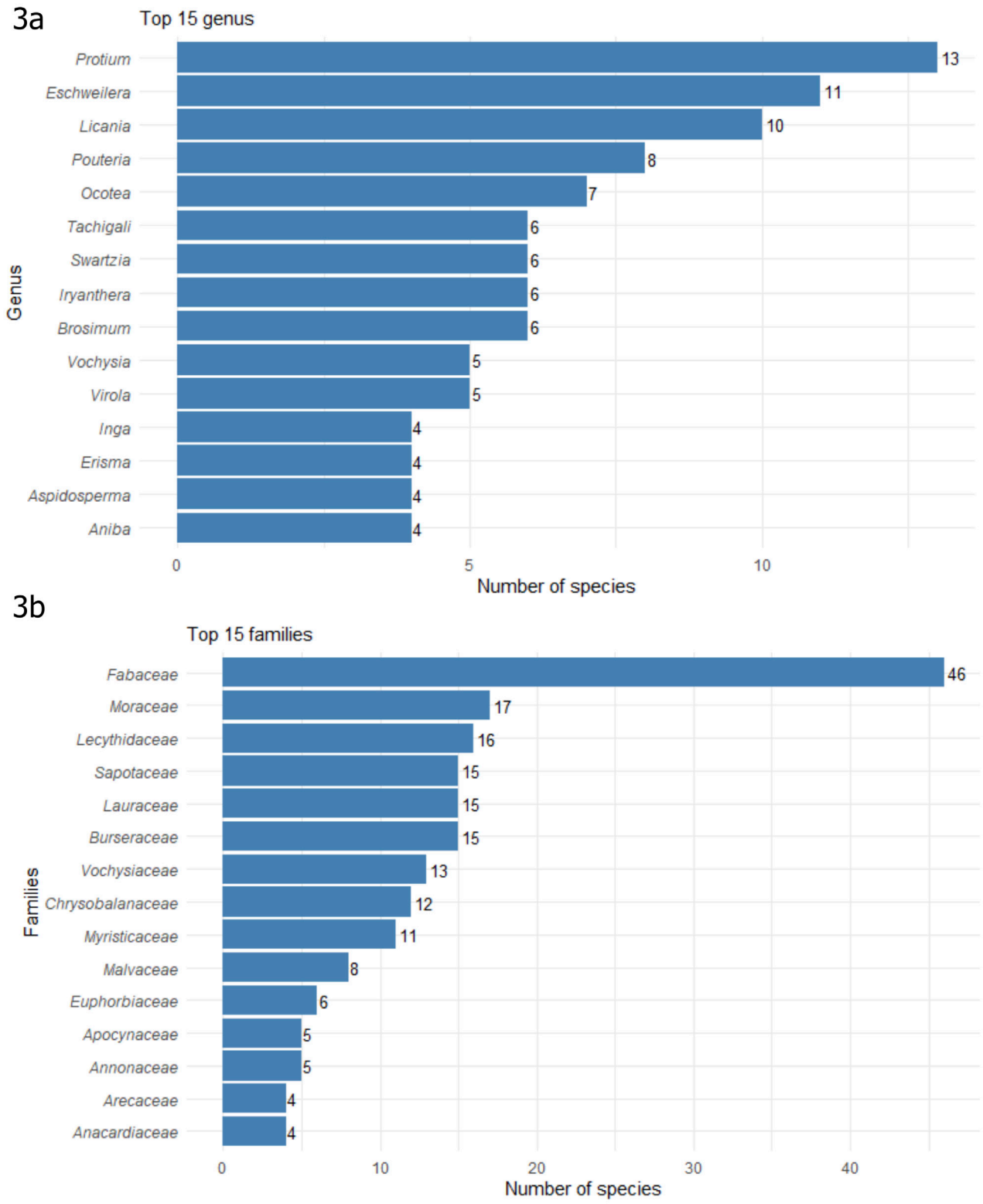

Figure 3. Species richness of the most representative botanical genus (3a) and families (3b) in the studied community. The bars represent the total number of species.

study highlights the importance of improving regional floristic knowledge to address existing shortfalls in understanding species distributions and ecological interactions, such as dispersal characteristics, and threat status. The high number of species with low density and possible new occurrences highlights the importance of gaining knowledge about ecological dynamics.

The substantial presence of species exhibiting relatively low population densities, alongside the potential identification of new occurrences, serves to underscore the paramount importance of acquiring comprehensive knowledge concerning the flora, encompassing its composition and distribution, within this conspicuously diverse yet understudied ecological region. Our investigation effectively highlights the indispensable role played by both floristic and phytosociological studies in elucidating the intricate structure and unique floristic aspects of Amazonian forests.

Structure

The number of species recorded in our inventory of the Jamari National Forest was the highest recorded so far in studies carried out in Rondônia state. Woody plant families with the highest densities also showed greater specific richness. In the present study, Fabaceae accounted for 18% of the total number of woody plants, confirming its high representativeness in tropical forests along with Burseraceae, Lecythidaceae and Arecaceae (ter Steege et al. 2016; Cardoso et al. 2017). The Equability Index was 0.94, suggesting uniformity in the relationship between the number of individuals per species within the plant community. Similar values were found by Oliveira et al. (2008) in one hectare of 'terra firme' forest in the Central Amazon, where the diversity index was H '= 5.1 *nat .individual*$^{-1}$ and the equability was e' = 0.92.

In Amazonian terra firme forests, it is common to find a large number of species with few individuals and few species with a larger number of individuals (ter Steege et al. 2013). This pattern, however, was not found in our plot. Instead, a few species, such as *Licania macrophyla* (highest IV, 2.94, with only nine individuals), *Protium* cf. *gallosum*, and *Eschweilera bracteosa* were dominant, despite the community being largely composed of a high number of singletons (133) and doubletons (54). Oliveira & Nelson (2001) counducted a study with 31 tree inventories from 12 sites in the Brazilian Amazon, one site in the Bolivian Amazon and one in the northeast Brazilian Atlantic coastal forest, and they concluded that the western Amazon regions have greater species diversity than inventories in

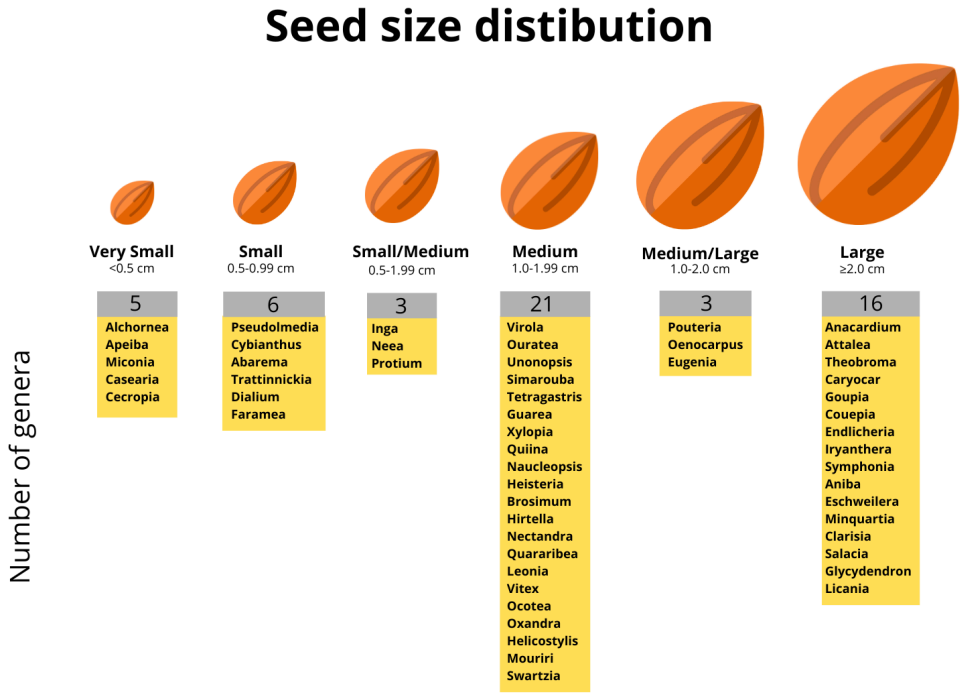

Figure 4. Seed size and size category of tree species belonging to the 54 genera recorded at one hectare of open ombrophylous forest of Flona do Jamari, Itapuã do Oeste, Rondônia. Seed size category follows Malhado et al. (2015): large (≥2.0cm), Medium (1.0–1.99cm), Small (0.5–0.99cm), Very Small (<0.5cm). There were genera with two category sizes, Small/Medium (0.5–1.99cm) a Medium/Large (1.0–2.0cm).

the east. However, inventories of terra firme forest in the central Amazon present similar tree species diversity to that found in the inventories of the western Amazon (Valencia et al 1994; Oliveira & Amaral 2004; Hubbell et al. 2008). The importance of the Fabaceae family in our study agrees with findings from terra firme forests across the Amazon (e.g., Carim et al. 2013). Similarly, Moraceae ranked among the five most important families in our study area. Both are families widely represented in the structure of Amazonian mainland forests.

Seed size

Our finding underscores a higher abundance of genera with smaller and medium-sized seeds compared to larger seeds. Amazonian tree genera with smaller seeds are prevalent in the southwestern and western margins of Amazonia (northern Bolivia and southeast Peru), while genera with larger seeds are more commonly found in central and northern Amazonia (Malhado et al. 2015). This geographic pattern aligns with the climatic correlations found by these authors, who report that larger seeds are associated with warmer and less seasonal environments. These findings are consistent with the observation that forests in the southwestern Amazonian are located in a climatological and ecological region, exhibiting lower temperatures, higher seasonality, and relatively more open canopies (Sombroek 2001; Coe et al. 2013; Saatchi et al. 2012).

The maintenance of seed size variation may reflect a balance of seed production costs, differential seedling success, and complex interactions with seed predators and dispersers, consistent with previous research on tropical trees and palms (Pizo et al., 2006). Small seeds tend to produce seedlings with lower vigour and biomass, which may compromise plant survival and success, especially under competitive conditions in the forest understory where seedling density is high (Pizo et al., 2006; Fricke et al., 2019). Furthermore, although small seeds are typically produced in greater numbers, their lack of nutritional reserves negatively affects germination success and seedling establishment, thereby influencing the population dynamics of the species (Pizo et al., 2006).

In our study area, medium was the predominant seed size, a pattern consistent with previous findings for this region of the Amazon (Malhado et al. 2015). This prevalence likely reflects an eco-evolutionary response to local edaphoclimatic conditions, particularly the constraints imposed by the predominant low-fertility latosols. In such environments, species face a fundamental reproductive trade-off: medium-sized seeds represent a strategic compromise, balancing a viable energetic cost for the parent plant with sufficient reserves for seedling establishment while facilitating broader dispersal by generalist animals. This strategy appears advantageous over producing either large seeds, which incur a high metabolic cost, or small seeds, which often struggle to establish successfully (Venable, 1992; Leishman, 2001). Notably, however, the community also included large-seeded genera such as *Licania*, *Eschweilera*, *Pouteria*, and *Aspidosperma*. Their persistence suggests a reliance on specific niches — potentially microsites with higher soil moisture — or on mutualistic interactions with large-bodied dispersers that may still be present in the area.

Distributions and threat status

According to the Brazilian Flora Checklist (BFG, 2021), seven species occurring in our plot are common across the Amazon, Atlantic Forest, Cerrado and Caatinga biomes. However, this number increases to fifteen according to information from the SpeciesLink system (CRIA, 2016). This pattern supports the findings of Carvalho & Almeida (2016) who suggest that most species have a restricted geographic distribution with a large number of individuals occurring in small areas and few occurring in many regions. Alternatively, a study highlighted the presence of species shared between biomes, focusing on trees and shrubs (Méio et al. 2003).

It is important to note that our research was limited to consulting the IUCN list evaluation criteria due to the absence of a local threat list. Nineteen percent of the inventoried species represent new occurrences in Rondônia state, indicating that the local flora may still be poorly known. Even species with a wide geographical distribution in the region are not exempt from threats. In this context, the role of protected areas such as the Flona do Jamari becomes paramount.

Located in the deforestation arc, this forest unit acts as a refuge for biodiversity, including the many newly recorded species. Our research provides essential baseline information that reinforces the conservation value of this unit and supports its long-term management against ongoing regional threats. In a heavily fragmented landscape such as the deforestation arc, the ecological traits we documented are critical for informing species-specific conservation strategies. The seed size assessment serves as a key diagnostic for understanding regeneration niches and dispersal capabilities, which are often disrupted in degraded areas. Furthermore, by mapping the other Brazilian biomes and vegetation types where these species are found, we can identify which taxa are more resilient or vulnerable to regional changes.

Wallacean and Raunkiaerian shortfalls

The Wallacean shortfall is exacerbated by the history of botanical sampling in the Amazon, which has been disproportionately concentrated near large rivers and roads (Stropp et al. 2020). This sampling bias hampers the understanding of actual distribution patterns and skews regional richness estimates. Historically linked to "Flora projects," this bias leaves vast areas — particularly ecotones and regions subjected to intense anthropogenic pressure, such as the southwestern Amazon — true black holes of biodiversity information. Moreover, the discrepancy between the number of widely distributed species recorded in the Brazilian Flora Checklist and those in SpeciesLink highlights the inconsistency of available data. The fact that seven species recorded in terra firme at Jamari National Forest are also listed for biomes as distinct as the Caatinga and Cerrado likely reflects this sparse and discontinuous sampling rather than genuine broad ecological distribution. Without robust data across different vegetation types (e.g., campinaranas, seasonal forests, ecotones) within the same region, it becomes challenging to determine species occurrence limits or areas of habitat connectivity.

Overcoming the Raunkiaerian shortfall is a crucial step toward transforming floristic data into restoration strategies. Our study advances this goal by characterizing seed size within the community, combining primary data with literature sources, revealing a predominance of species bearing medium-sized seeds—an evolutionary adaptation to the region's nutrient-poor soils. This information is highly relevant to reforestation projects within the Deforestation Arc, as it informs soil seed bank potential and best management practices, including dispersal capacity and seedling establishment. Obtaining such data within a Conservation Unit, such as the Jamari National Forest, provides a concrete ecological reference. It enables the selection of species with traits suitable for the environment, ensuring that restoration efforts aim to replicate not only the original forest's composition but also its functional attributes in regions facing anthropogenic pressures.

We must emphasize that our study underscores the necessity for meticulous investigations, where the accurate taxonomic identification of species occupies a central position in research methodologies. The discovery of 220 distinct species within a single hectare suggests that diversity and richness estimates for this portion of the Amazon may be underestimated. The impact of unknown species and taxonomic inaccuracies on these estimates requires urgent consideration. To achieve a true understanding of Amazonian flora biodiversity, the scientific community must move beyond the convenience of easily accessible sites and extend research efforts into regions more susceptible to climate change and deforestation. Our research, although small in scale, provides a significant contribution to the region's biodiversity knowledge. Such studies are urgently needed, given the continuing loss of native vegetation due to development pressures. We emphasize the importance for scientists to conduct studies addressing the new species (Linnean shortfall), spatial under sampling (Wallacean shortfall) and ecological interactions (Raunkiaer shortfall) in relations to plant structure investigations.

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AUTHOR CONTRIBUTIONS STATEMENT

Bruno Umbelino - Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing; Juliana Stropp – Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing; Ingrid Mendes-Silva - Visualization, Writing – original draft, Writing – review & editing; Ricardo Aleixo Correia – Writing – review & editing; Antônio L. P. Silveira – Writing – review & editing; Ana C. M. Malhado - Conceptualization, Supervision, Writing – review & editing.

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