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Alien plants from Paraíba (NE-BR): a survey based on secondary data

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Abstract
Currently, alien plants are the second largest loss of biodiversity in the world, second only to direct human exploitation. Therefore, this work aimed to identify in the literature in the literature and databases the exotic and invasive plants occurring in the state of Paraíba, in order to complement the information on these non-native species for the state. Therefore, it was necessary to prepare a general list of species, as well as autoecological information and evaluation of the degree of floristic similarity between the sampled areas. Floristic data were obtained through scientific articles from indexed academic journals and available on virtual platforms. We survey 265 species, distributed in 23 botanical families. The floristic similarity analysis indicated clusters that were not very similar to each other, revealing that these floras, even though they are in close areas, form distinct floristic compositions. The regression analysis also revealed that the similarities between the evaluated areas did not present a significant relationship with the geographic distance. In general, the exotic flora of Paraíba consists mainly of Poaceae, Asteraceae and Fabaceae, as the most representative components. This flora, in general, is composed of species with wide geographic distribution and predominance of autochoric dispersion. Through the results, one can demonstrate the importance of floristic surveys as an important mechanism for understanding the exotic flora of an ecosystem, in addition to providing essential bases for subsequent studies.

Keywords: Exotic flora; Similarity, Floristic Research.

Plantas exóticas da Paraíba (NE-BR): um levantamento a partir de dados secundários

Resumo
Atualmente as plantas exóticas são a segunda maior perda de biodiversidade no mundo, perdendo apenas para exploração humana direta. Diante disso, este trabalho visou identificar na literatura e em bases de dados, as plantas exóticas e invasoras ocorrentes no estado da Paraíba, a fim de complementar as informações sobre essas espécies não-nativas para o estado. Para tanto foi necessária a elaboração de uma lista geral de espécies, bem como informações autoecológicas e avaliação do grau de similaridade florística entre as áreas amostradas. Os dados florísticos foram obtidos por meio de artigos científicos de periódicos acadêmicos indexados e disponíveis em plataformas virtuais. Foram levantadas 265 espécies, distribuídas em 23 famílias botânicas. A análise de similaridade florística indicou agrupamentos pouco similares entre si, revelando que essas floras, por mais que estejam em áreas próximas, formam composições florísticas distintas. A análise de regressão, revelou, também, as similaridades entre as áreas avaliadas não apresentaram relação significativa com a distância geográfica. De um modo geral, a flora exótica da Paraíba é constituída principalmente de Poaceae, Asteraceae e Fabaceae, como componentes mais representativos. Essa flora, em geral, é composta de espécies de ampla distribuição geográfica e predomínio de dispersão autocórica. Mediante os resultados, pode-se demonstrar a importância dos levantamentos florísticos como um importante mecanismo de conhecimento da flora exótica de um ecossistema, além de fornecer bases essenciais para estudos subsequentes.

Palavras-chave: Flora exótica; Similaridade, Pesquisa Florística.

Introduction

Exotic plants are defined as coming from different biogeographical regions and are therefore not part of the native flora (Kleunen *et al*., 2018). Although many of these plants have been accidentally introduced throughout history, in most cases it has been done intentionally (IUCN, 2001), but

without the awareness of potential problems these plants could cause. Researchers and environmentalists only became aware of the importance of these introductions when they realized how much these exotic plants altered the characteristics of the ecosystems in which they were established, as many of these species became invasive and suppressed the occurrence of native plants.

Some of these exotic plants, when inserted into new habitats, were able to form self-sustaining populations, sometimes in a restricted way, and have been called "naturalized" (Kleunen *et al*., 2018). In other cases, when these naturalized plants became capable of colonizing other habitats, they have been considered "invasive" (IUCN, 2001). The spread or dispersal of these invasive exotic plants is recognized as one of the greatest threats to ecological balance and the well-being of the world economy, because in addition to promoting changes in the niches of native populations, they lead to a loss of biodiversity (Alexander *et al*., 2016), 2016) and promote strong competition for resources and establish deleterious ecological relationships (Ziller, 2001; Ehrenfeld, 2003; Novak *et al*., 2018), in addition to unbalancing various human production chains (Bartz & Kowarik, 2019) and even causing disruption to hydroelectric power plants (Peres *et al*., 2018).

It has therefore been widely accepted among scholars in the field that exotic plant species represent a potential threat and should be investigated, identifying new introductions or monitoring existing ones. This is mainly because it is not known when a newly introduced species can become invasive. Despite this, some scientists suggest that these species share similar biological attributes, which could categorize them as potential invaders (Hulme & Bernard-Verdier, 2017; Kleunen *et al*., 2018), such as the following: long flowering and fruiting periods, high seed production and early reproduction; efficient dispersal (mainly anemochory), with the formation of a seed bank with long viability; few pathogens or native herbivorous consumers; high efficiency in capturing water and nutrients from the environment, and exhibiting greater phenotypic plasticity and adaptability.

In view of this, researchers in Brazil have been dedicating themselves to floristic studies of these exotic plant species, and a milestone in this effort was access to information compiled by specialists in the creation of the Flora e Funga do Brasil website (2020), which contains a list of naturalized species recorded in the Brazilian territory by specialists in the field. However, this list needs systematic and continuous review, especially when comparing the data from this platform with others, such as SpeciesLink (2020), which indicates the collection of non-native species in various Brazilian states that are not yet included in Flora e Funga do Brasil (2020). It is therefore believed that information on exotic flora in Brazil is still underestimated.

Most studies on exotic plants are concentrated in the southern cone of Brazil, restricted to areas of the Atlantic Forest, while studies in the Northeast are scarcer. Although the Brazilian Northeast has some works that have compiled information on various exotic groups occurring in its geographical area (Leão *et al*., 2011) and technical sheets on species occurring in the Caatinga (Fabricante, 2013), there is still a lack of more in-depth information on exotic plants within the states of Northeast Brazil.

This knowledge about exotic flora, specifically in the state of Paraíba, is precarious and is still being obtained indirectly. Most studies have identified this exotic flora when analyzing the tree-planting practices of some cities in the state (Andrade & Jeronimo, 2015; Lucena *et al*., 2015; Barroso *et al*., 2016; Bezerra *et al*., 2016; Fabricante *et al*., 2017; Santos *et al*., 2017), noting that there is a certain predilection for exotic species in local landscaping. However, the lack of knowledge about exotic flora in Paraíba is even greater when looking for information on conservation areas, where only the work by Lopes-Silva *et al*. (2018) presents data on the exotic flora of inselbergs in the municipality of Patos.

In view of the above, this work aimed to survey the exotic and invasive plants occurring in the state of Paraíba, based on secondary data, in order to complement the information on these non-native species for the state, and also as a way of collaborating in the understanding of this floristic diversity for the Northeast of Brazil.

With this information, this study aims to assess whether areas closer to each other are more similar than areas further away. If this hypothesis is true, a regression analysis between the similarity values and geographical distance would correlate significantly. However, if this hypothesis is false, the expansion of territories by exotic plants must be governed by more random factors, such as dispersal by wind or carried by man. Based on this, a correlation analysis between urbanization and exotic species richness was also performed, to detect how much the effect of urbanization can influence the diversity of exotic plants in a locality.

Material and Methods

In order to obtain the data for this research, we consulted digital information platforms on the registration of exotic plants in the state of Paraíba (Flora e Funga do Brasil, 2020; SpeciesLink, 2020; Instituto Hórus, 2020), in an attempt to create a floristic list that was as close to reality as possible.

This floristic list was supplemented with information from scientific articles published in academic journals available on the Google Scholar online platform (2020), using the keywords "exotic species + Paraíba" in Portuguese, English and Spanish. To broaden the research effort, a search was made of the bibliographical references of the selected articles in order to identify other manuscripts cited in these references. Duplicate articles, books, etc. were discarded, with the exception of some conference publications available online, which could be considered relevant if there was a shortage of information for certain regions.

This general floristic list produced was updated according to the APG IV proposal (2016). In addition, only the currently valid names of the species found by the search were considered, checking the name of the taxonomic authority of each species, based on consultation of the Flora

e Funga do Brasil portal (2020), and comparing this with information on the Plants of the World website (2020).

From this list, an electronic spreadsheet was organized containing autecological information on the species, such as habit according to Veloso *et al*. (1992); dispersal syndrome *sensu* Pilj (1982); biological spectrum according to Raunkiaer (1934); geographical distribution consulted from the Global Biodiversity Information Facility platform (2020); and the biogeographical origin of the species by consulting articles or books in the field of plant taxonomy and the Plants of the World website (2020).

A similarity analysis was carried out to detect floristic connections among the areas analyzed in Paraíba, using the UPGMA method (1958) and the Jaccard similarity index (Mueller-Dombois & Ellenberg, 1974). In this grouping analysis, only the municipalities with at least one exotic species were considered, i.e. municipalities were excluded in which there were no reports of exotic plant species. Thus, of the 223 municipalities in Paraíba, a total of 107 localities were considered in this analysis.

A regression analysis was carried out to test the hypothesis that floristic similarity increases with proximity among areas (Mueller-Dombois & Ellenberg, 1974). For this analysis, Jaccard's similarity values were compared with the distances among the cities to check for a significant relationship (p-value < 0.05) between these variables. As for the correlation analysis (Mueller-Dombois & Ellenberg, 1974), we used the urbanization index of the municipalities analyzed in Paraíba (IBGE, 2022) to find a relationship with the species richness reported for the respective municipality.

Results and Discussion

The total number of species surveyed, considering data from SpeciesLink (2021) and the articles found, was 265 species (Appendix) distributed in the state of Paraíba (Figure 1). Few scientific articles were found to complement these SpeciesLink data, and a total of 13 publications was identified (Almeida *et al*., 2005; Agra *et al*., 2007; Nascimento, 2008; Leão, 2011; Souza *et al*., 2011; Moro *et al*., 2013; Ribeiro, 2014; Araújo & Moreira, 2015; Menezes *et al*., 2015; Souza, 2016; Alves *et al*., 2017; Silva *et al*., 2017; Pinto *et al*., 2020).

The results showed more records of exotic species in the coastal region of the state, in the municipality of João Pessoa, in Conde and along the north coast (Marcação, Baía da Traição and Mataraca). In the Agreste region, Campina Grande, Pocinhos, Massaranduba, Areia, Rio Tinto and Cuité showed the highest local frequency. In the Borborema region, Soledade and Monteiro, and in the Paraíba Sertão region, Patos, São José de Piranhas and Sousa, recorded the highest number of exotic plants.

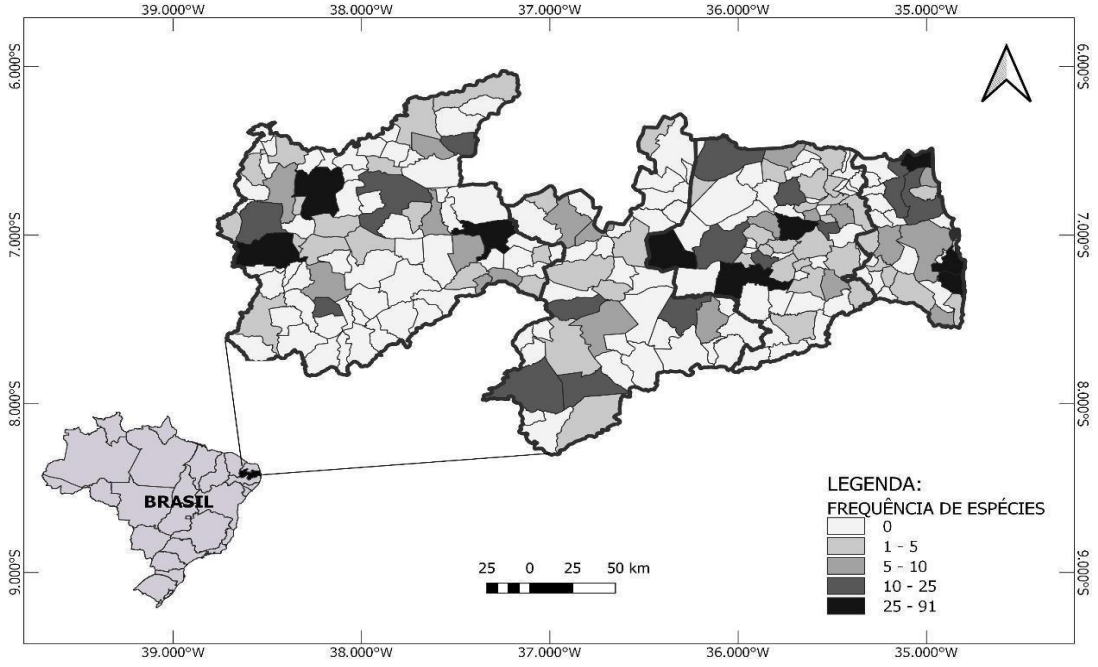

Figure 1. Frequencies of exotic species in gray scale (the darker the tone, the more species reported) for the municipalities of Paraíba (Northeast Brazil). Source: The author (2024).

With regard to botanical families, those with the highest species richness were Poaceae (39 spp.), Fabaceae (30 spp.) and Asteraceae (15 spp.) (Figure 2). The greater diversity of species from the Poaceae and Asteraceae families is related to the ease of dispersal and dissemination of these groups, which are predominantly anemochorous (Souza & Valio, 2001). As for the Fabaceae, which are largely autochorous, their representative richness is related to the fact that these plants form associations with nitrifying bacteria that help in their

colonization and maintenance, even in highly modified environments (Freitas *et al*., 2011).

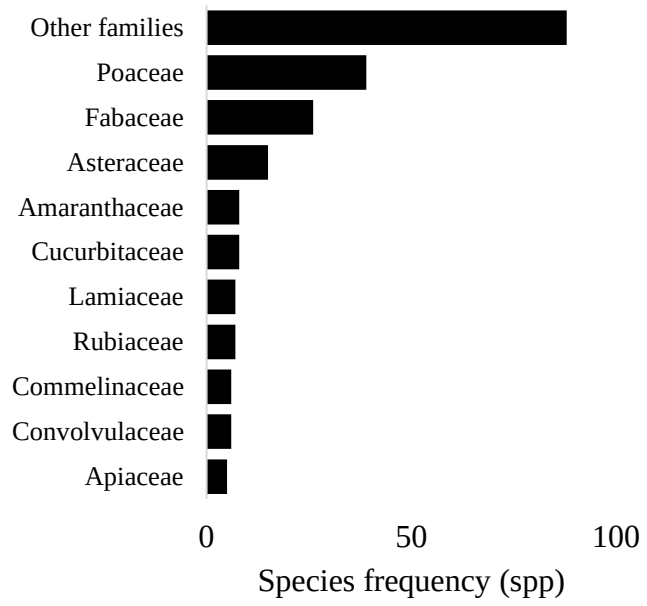

Figure 2. Main botanical families of exotic plants considered in this analysis for Paraíba (Northeast Brazil). Source: The author (2024).

With regard to the habit of the species surveyed, there was a predominance of herbaceous species, followed by trees, shrubs, lianas/climbing plants and sub-shrubs (Figure 3). Herbaceous plants, in general, are easier to disperse due to their smaller diaspore size and greater ability to settle in new habitats, especially when referring to anthropized ecosystems (Andrade et al., 2019). In addition, they have a shorter life cycle, producing several generations in a short space of time. As such, this habit has greater potential for spreading in natural ecosystems, compared to other habits.

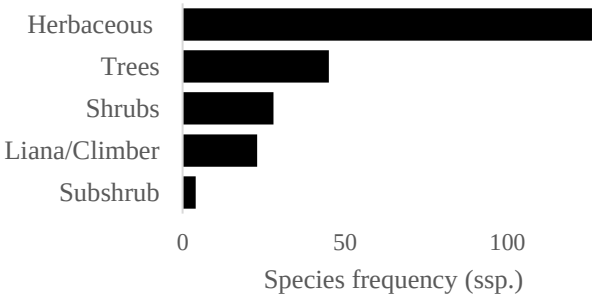

Figure 3. Predominant habit of plants considered exotic in Paraíba (Northeast Brazil). Source: The author (2024).

It is worth noting that a large part of the exotic herbaceous layer still benefits from the surrounding vegetation, which provides shade and creates a mild microclimate. For this reason, several scholars have theorized that native plants can potentially facilitate the establishment of exotic species (Lucero *et al*., 2019). In addition, these exotic plants can offer floral resources, which attract native pollinators and dispersers, and benefit from this established relationship, especially when the native plants are not in their fertile period (Staab *et al*., 2020). This alien vegetation can also be a carrier of viral or fungal diseases or host to parasitic animals of economic importance and thus promote other damage to native forests or agricultural crops, with the spread of plant diseases. These new facilitation/inhibition relationships can lead to the gradual replacement of native vegetation by exotic vegetation (Staab *et al*., 2020).

This information reinforces an alarming fact: the more conserved a habitat is, the more prone it is to invasion by exotic plants (Brummer *et al*., 2016; Hui & Richardson, 2017; Jeschke *et al*., 2018). In general, conserved areas are not prepared for competitive relationships with new, introduced species. Therefore, the monitoring of this type of flora must be treated with attention for emergent and precise decision-making when it comes to biological invasion.

Although the success of an invasive exotic plant is dependent on an environmental context, usually associated with typically anthropized areas (Zenni & Nuñez, 2013), the framework of when an exotic plant has become an invader, or pest itself, is still very subjective from a scientific point of view (Peng *et al*., 2019). However, as a precautionary measure, it is better to assume that an exotic plant, regardless of whether or not it impacts native plants, should be taken as an urgent issue in any given ecosystem (Peng *et al*., 2019).

Regarding the dispersal syndrome of the species analyzed, endozoochory was the most commonly recorded type of diaspore dispersal, followed by autochory, anemochory, ectozoochory and hydrochory (Figure 4).

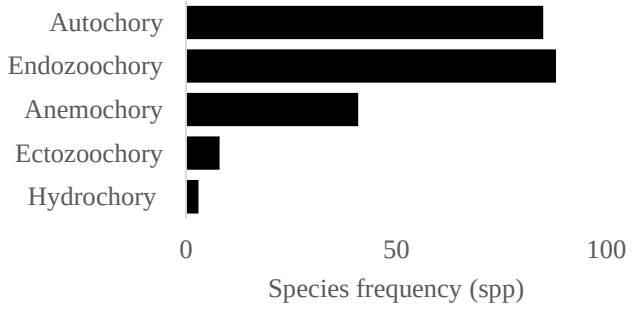

Figure 4. Types of dispersal of plants occurring in floristic surveys for Paraíba (Northeast Brazil). Source: The author (2024).

Species with endozoochorous dispersal mostly require dispersing animals attracted by a food resource, which is the fleshy fruit. In general, the endozoochoric species in this survey are not exactly related to wild natural dispersers, but

rather to man himself, as most of these plants include those used in the human diet (*Mangifera indica* L; *Annona squamosa* L; *Opuntia ficusindica* (L.) Mill) or for shading (*Terminalia catappa* L; *Pithecellobium dulce* (Roxb.) Benth. etc.) and are selected for planting predominantly because of these socio-economic benefits.

Autochorous species, on the other hand, do not need external agents (wind, water or animals) and end up perpetuating themselves in the areas, forming autochthonous patches with delimited boundaries or "draining" their collectivity through anthropized corridors, as road ecology studies have reported (Jakobsson *et al*., 2018; Lobo & Ervin, 2019). In this context, the homogenization of the anthropized landscape acts as a drain for autochorous exotic species, which end up finding no limits for their establishment. Not to mention that autochory is often accompanied by a secondary syndrome, usually mediated by ants (myrmecochory), birds (ornithochory) or ruminants (mammaliochory) (van der Pijl, 1982).

On the other hand, anemochorous species play a fundamental role in the invasion process mainly due to the stochastic or unpredictable nature of their potential colonization (Blacknurn *et al*., 2015). Their propagules can overwhelm deterministic processes, resulting in idiosyncratic patterns in their final establishment, regardless of the scale and number of introduction events and the number of individuals introduced (Lockwood *et al*., 2005). This type of vegetation is very common in agrarian and anthropized environments.

With regard to the phytogeography of these exotic species, there is a predominance of groups with a wide geographical distribution, such as cosmopolitan, Pantropical and Neotropical plants. These compositions of exotic species are facilitated by processes of biological invasion with appropriate dispersal, which would explain the predominance of more generalist species with a low degree of endemism.

On the other hand, there are the cases of exotic plants brought by man, which have a historical-cultural relationship, mainly for economic, religious and ornamental purposes. It is worth noting that most of the urbanophile flora is made up of exotic plants, as a diverse floristic component (Ward & Amatangelo, 2018) and that this flora becomes naturalized very easily in this process, forming real population stocks. In addition, research indicates that the older the anthropized area, the more diversity of exotic plants it has (Figueroa *et al*., 2018). Therefore, the rate of urbanization could be an important factor in this matter, but we'll look at this issue of urbanism later.

The most frequent biogeographical regions for the origin of the exotic species found in this survey are consistent with the literature (Plants of the World, 2020). Asia was considered the main region of origin of exotic species in the world.

In relation to the similarity analysis, a co-efficient correlation (ce=0.6953) was obtained, indicating a 69.53% chance of these observed groupings being as close as possible to reality (Figure 5). The cluster analysis revealed the formation of several groups with significant similarity (above the red line on the graph), although the heterogeneity among the mesoregions is evident, i.e. it was expected that the floras within the contexts of the mesoregions would be more similar to each other, but the result proved to be much more random than expected.

Two or more areas can be considered similar in terms of floristic composition when they have at least 25% species in common (Mueller-Dombois & Ellenberg 1974). Considering this parameter, the areas with the greatest similarity are the municipalities of Conceição and Desterro (85%); Ingá and Marizópolis (80%); Aroeiras and Itaporanga (80%). These municipalities share several species in common, even though they are in different mesoregions: *Calotropis procera* (Aiton) W.T.Aiton; *Momordica charantia* L; *Parkinsonia aculeata* L; *Pithecellobium dulce* (Roxb.) Benth; *Leonotis nepetifolia* (L.) R.Br; and *Argemone mexicana* L. The registration of these invasive exotic species may be an indicator of the potential loss of native diversity and the start of widespread biological invasion processes, as this process compromises local diversity in the medium to long term.

Another interesting factor to note is that the similarity analysis, contrary to expectations, showed that geographical proximity did not define floristic homogeneity within their respective mesoregions, i.e. areas that were close to each other still showed different floristic compositions. An example of this is the municipalities of João Pessoa and Cabedelo, which are geographically close, and despite being conurbations, the areas analyzed showed more dissimilarity than expected. This can be attributed to the low number of records of this exotic flora in the municipalities of Paraíba in general, together with the lack of collections of this type of material in all of the state's municipalities.

Comparative floristic studies using cluster analyses are extremely important for recognizing a general phytogeographic identity. Such studies make it easier to understand the distribution of species, as they make it possible to assess the similarities and differences in the composition of a given plant community with other regions, leading to the possible identification of correlations with environmental or anthropogenic variables (Meira-Neto & Martins, 2002).

The regression analysis indicated that the similarity values among the areas evaluated showed no significant relationship ($P > 0.05$) with the geographical distance among these same areas, i.e. the distribution of these exotic plants in the state of Paraíba is much more unpredictable than expected (Figure 6). This factor may be related to the scarcity of data on the actual species composition per municipality. If there were reliable inventories of each town in Paraíba, there would probably be a clearer floristic pattern.

Finally, it can also be seen that the rate of urbanization and the richness of exotic species did not indicate a significant relationship ($P > 0.05$) between them (Figure 7). Regardless of the degree of urbanization of Paraíba's municipalities, the number of exotic species is also an unpredictable variable.

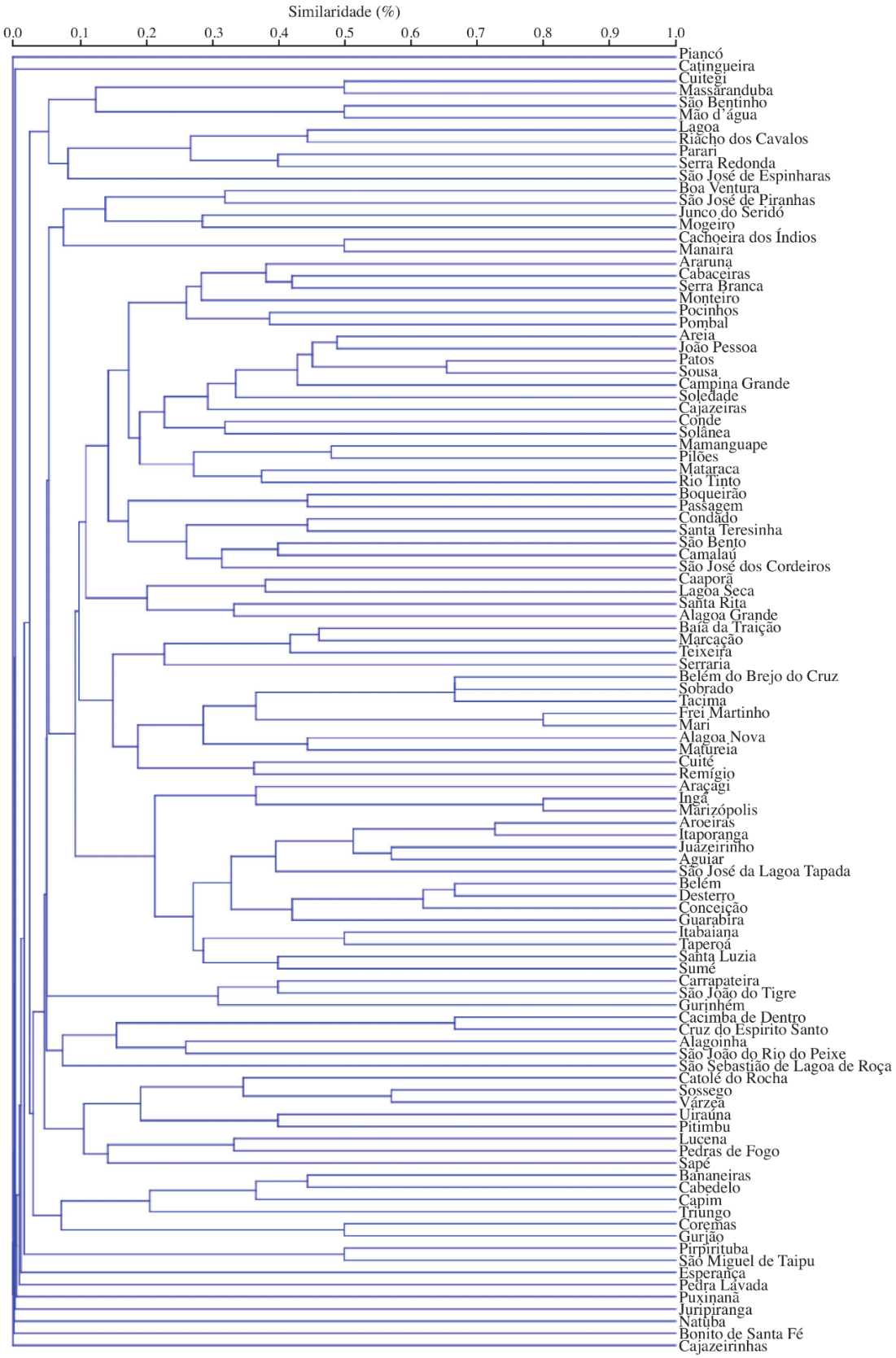

Figure 5. Cluster analysis dendrogram (UPGMA), using the Jaccard Similarity Index (JSI), for the municipalities in the state of Paraíba (Northeast Brazil). Mesoregions are indicated; in red we have the municipalities of the Sertão mesoregion, in blue those of the Agreste mesoregion, in pink those belonging to the Borborema mesoregion, and in green those of the Zona da Mata mesoregion. Source: The author (2024).

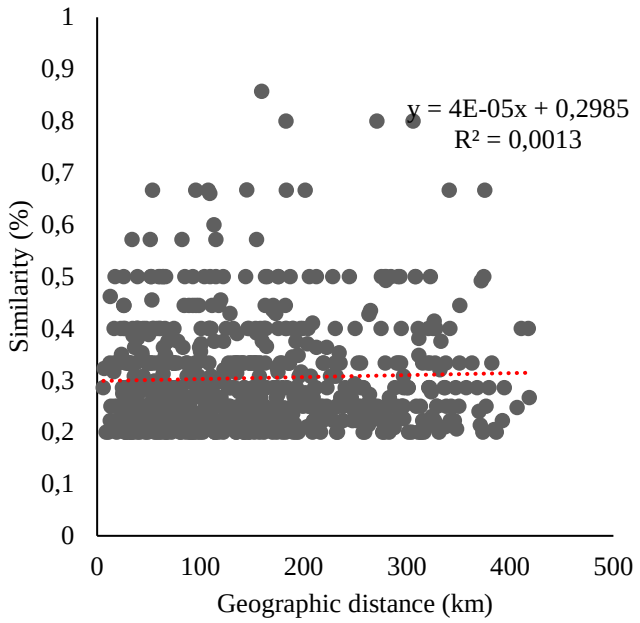

Figure 6. Regression analysis based on similarity and geographical distance among municipalities in Paraíba (Northeast Brazil). Source: The author (2024).

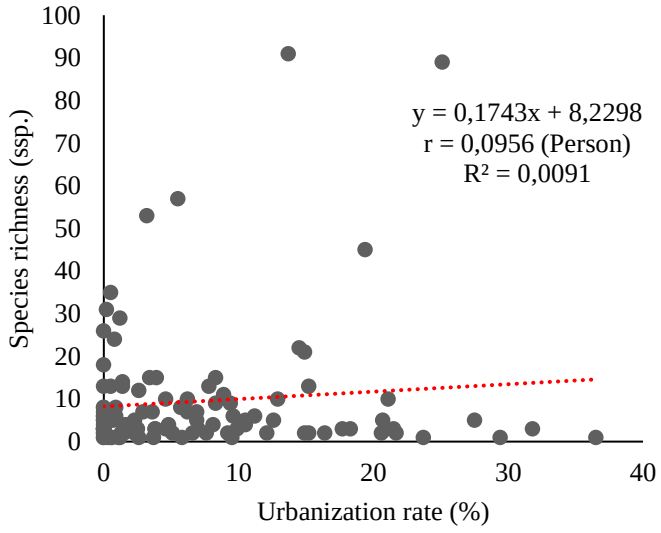

Figure 7. Correlation analysis between the urbanization rate of municipalities in Paraíba (Northeast Brazil) and the richness of exotic species in the respective municipalities. Source: The author (2024).

Most likely, the lack of a general inventory of exotic plants in the state of Paraíba has led to this result, since most studies in the area suggest that as an area becomes more urbanized, it becomes a source of invasion for new, exotic species. This usually starts in environments disturbed by humans, especially urbanized ones, and continues along their circulation routes, mainly into natural ecosystems (Zenni & Nuñez, 2013; Boscutti *et al*., 2022).

Conclusion

Given the results, it can be concluded that the anthropogenic factor interferes in an unpredictable way with the diversity of exotic plants in the state of Paraíba (Northeast Brazil). The results of this study were more random than expected, which rejects the initial hypotheses. Factors such as geographical proximity were not related to floristic similarity among areas, meaning that the areas ended up being more different from each other than expected. Even the urbanization factor did not define a different direction in terms of species richness between more urban and more rural areas, for example.

These results indicate that the number of occurrences of exotic plants recorded in official bodies or scientific publications is still small and certainly does not reflect the reality of exotic and invasive species in the federal state in question. Despite the wealth of exotic plants in Paraíba accounting for more than 200 species, the low number of records within the municipalities is an indication that little is known about the flora of these localities, and there is a need for greater research effort and description of invasions by technicians from environmental agencies and researchers in public teaching, research and extension institutions.

As a result of the few studies, it has been difficult to detect more consistent patterns. For this reason, the call for more studies on the subject is reinforced in order to fill in the gaps in this knowledge, given that it is currently necessary to protect and conserve the environment in accordance with current legislation. It is in this sense that we are looking for new models of environmental planning and management in an engaged, participatory, conscious, and interdisciplinary way, with a total vision for sustainable development of the local/regional flora.

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