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Phytosociological characterization of urban forest fragments with the occurrence of invasive exotic species

Caracterização fitossociológica de fragmentos florestais urbanos com ocorrência de espécies exóticas invasoras

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ABSTRACT

This study analyzed the composition and floristic structure of two Urban Forest Fragments (UFFs) in Curitiba, Paraná, to evaluate the impact of biological invasion on ecological stability. We tested the hypothesis that the Papa João Paulo II forest exhibits higher degradation than the Gutierrez forest due to its central urban location. Ten plots (20 x 30 m) were sampled, including all tree individuals with a Diameter at Breast Height (DBH) > 4.78 cm. Floristic characterization distinguished native Mixed Ombrophilous Forest (MOF) species from exotic and invasive ones. Phytosociological indices (AD, RD, AF, RF, ADo, RDo, and IV) and Non-Metric

Multidimensional Scaling (nMDS) were calculated using R version 4.2.0. A total of 546 arboreal individuals were recorded: 336 in Papa João Paulo II and 210 in Gutierrez. Native individuals accounted for 83.51% of the sample, while invasive exotics represented 15.01%. *Ligustrum lucidum*, *Hovenia dulcis*, and *Persea americana* exhibited the highest phytosociological expression among exotics. The nMDS analysis indicated significant floristic-structural differences between the forests, confirming H1, as the Papa João Paulo II forest showed a substantially higher density of invasive individuals (21.43%) than the Gutierrez forest (4.76%). Invasion by *L. lucidum* is already actively compromising the ecological stability and successional trajectory of these UFFs, necessitating urgent management and control measures.

Keywords: Ecological sustainability, Floristics, Invasive species, Urban forest.

RESUMO

Esta pesquisa analisou a composição e a estrutura florística de dois Fragmentos Florestais Urbanos (UFFs) em Curitiba, Paraná, para avaliar o impacto da invasão biológica na estabilidade ecológica. Testou-se a hipótese de que o Bosque Papa João Paulo II apresenta maior degradação do que o Bosque Gutierrez, devido à sua localização urbana central. Dez parcelas (20 x 30 m) foram amostradas, incluindo todos os indivíduos arbóreos com Diâmetro à Altura do Peito (DAP) > 4,78 cm. A caracterização florística distinguiu espécies nativas da Floresta Ombrófila Mista (FOM) de espécies exóticas e invasoras. Índices fitossociológicos (DA, DR, FA, FR, DoA, DoR e VI) e o Escalonamento Multidimensional Não Métrico (nMDS) foram calculados utilizando o R versão 4.2.0. Um total de 546 indivíduos arbóreos foi registrado: 336 no Bosque Papa João Paulo II e 210 no Gutierrez. Os indivíduos nativos representaram 83,51% da amostra, enquanto os exóticos invasores representaram 15,01%. *Ligustrum lucidum*, *Hovenia dulcis* e *Persea americana* apresentaram a maior expressão fitossociológica entre as exóticas. A análise nMDS indicou diferenças florístico-estruturais significativas entre os bosques, confirmando a H1, uma vez que o Bosque Papa João Paulo II apresentou uma densidade de indivíduos invasores substancialmente maior (21,43%) do que o Bosque Gutierrez (4,76%). A invasão por *L. lucidum* já está comprometendo ativamente a estabilidade ecológica e a trajetória sucessional destes UFFs, demandando medidas urgentes de manejo e controle.

Palavras-chave: Espécies invasoras, Floresta urbana, Florística, Sustentabilidade ecológica.

1 **Introduction**

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Forest ecosystems are increasingly susceptible to human actions, especially changes in land use, notably urbanization and the invasion of exotic species. These factors impact biodiversity and ecological processes in these environments and reduce their ability to maintain ecological sustainability and provide Ecosystem Services (ES). Therefore, biological invasion is considered an Ecosystem Disservice (ED), as it negatively impacts natural environments and human well-being (Potgieter et al., 2019).

Urban Forest Fragments (UFFs) in the urban environment suffer different degrees of impacts from human actions, but even so, can provide various ecosystem services, such as climate and noise mitigation, soil and water protection, opportunities for leisure, and biodiversity conservation, among others. However, due to pressures caused by urbanization, its natural characteristics can be modified at different levels, such as floristic composition and structure, and the abiotic environment.

The presence of invasive species in these remnants is not merely a change in species list, but a factor that directly interferes with the successional trajectory of the forest. In many cases, these invaders outcompete native individuals for space and resources, leading to a simplification of the forest structure and a reduction in taxonomic diversity. Consequently, a single Urban Forest Fragment (UFF) may harbor varied successional stages and dynamic trajectories that diverge from the classical patterns observed in non-urban forests (Adler & Tanner, 2015; Johnson et al., 2020).

Therefore, it is necessary to investigate the phytosociological patterns of UFFs and analyze the possible implications of invasive flora in these areas. This information enables specific management measures to be implemented, focusing on the control of invasive species and improving ecosystem sustainability within the urban landscape. Therefore, this study addresses the following research question: How do invasive exotic species influence the floristic structure and successional dynamics of UFFs in Curitiba?

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To answer this, the main objective of this study was to analyze the composition and floristic structure of two urban forest fragments in Curitiba, Brazil, evaluating the influence of invasive exotic species on their ecological resilience.

Based on the preliminary context of urban degradation in Curitiba, this study tests the following hypothesis: The Papa João Paulo II forest exhibits a higher density and basal area of invasive exotic individuals compared to the Gutierrez forest due to its longer history of anthropogenic disturbance.

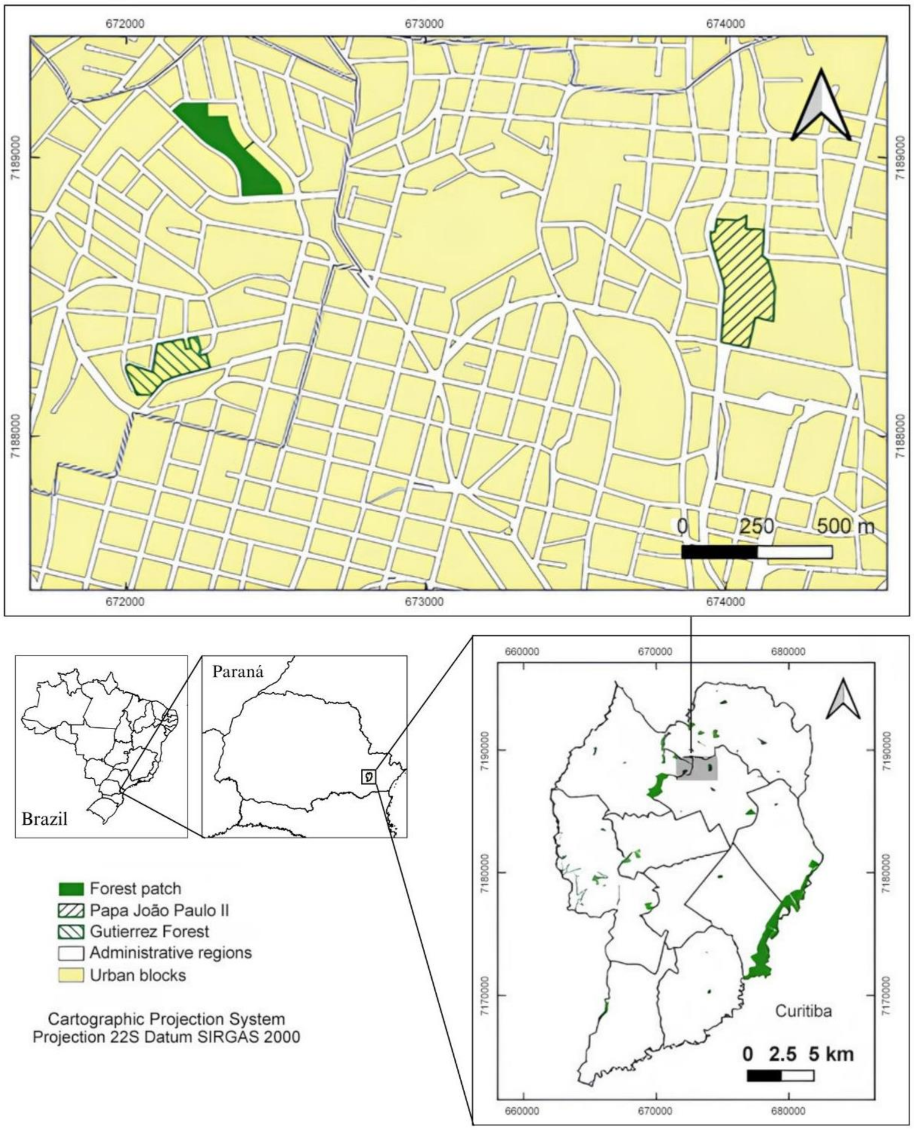
The main objective of this study was to analyze the composition and floristic structure of two urban forest fragments in Curitiba, Brazil, to evaluate the influence of invasive exotic species on their ecological resilience. Specifically, the study sought to: (1) identify and quantify native, non-invasive exotic, and invasive exotic tree species in both forests; (2) compare the species composition and phytosociological indices between the two forests; (3) evaluate the structural impact of invasive species on the community dynamics; and (4) assess the differences in the floristic-structural organization.

2 **Material and Methods**

2.1 Study area

The study was conducted in the city of Curitiba, capital of the state of Paraná, located in the southern region of Brazil (FIGURE 1). Tiradentes Square, in the city center, is the municipality's ground zero (25º25'40" South and 49º16'23" West), at an altitude of 934 m (Instituto de Pesquisa e Planejamento Urbano de Curitiba (IPPUC), 2021).

Figure 1. Location of the Papa João Paulo II and Gutierrez forests, in the municipality of Curitiba, Paraná, Brazil.



Source: Authors (2025).

Curitiba has a Cfb climate according to the Köppen-Geiger classification, characterized as humid mesothermal with cool summers (IAPAR, 2019). The average annual temperature is 22.31 °C, ranging from 18.22 °C in winter to 25.68 °C in summer (Wrege & Fritzsons, 2015). Annual precipitation in Curitiba varies from 1400.1 to 1600 mm, with an average of 1587.52 mm (Wrege & Fritzsons, 2015; IAPAR, 2019).

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The Papa João Paulo II and Gutierrez forests were selected to conduct this study because, according to Mielke (2012), they have the highest densities of invasive exotic tree vegetation in Curitiba. This suggests that the aforementioned UFFs present relevant environmental changes from their original phytosociological characteristics.

Papa João Paulo II forest is located in the Centro Cívico neighborhood. It was opened in 1980 and has a total area of 46,337 m² (4.63 ha) (Macedo & Sakata, 2010). The remaining forest of this UFF is classified as Montana Mixed Ombrophylous Forest (Montana MOF), in an intermediate to advanced stage of ecological succession and with a medium degree of environmental change (Borgo & Silva, 2003). The forest has three distinct forest strata: the discontinuous canopy, in which specimens of *Araucaria angustifolia* (Bertol.) Kuntze (araucaria) stands out; the lower stratum, and the herbaceous-shrub (Sociedade de Pesquisa em Vida Selvagem e Educação Ambiental (SPVS), 2009).

Gutierrez forest was created in 1986 with the aim of preserving water sources, and its remaining forest has a total area of 26,280 m² (2.63 ha). The forest is located in an Alluvial MOF region, with an intermediate to advanced stage of regeneration and a medium degree of environmental change (Borgo & Silva, 2003). The forest canopy presents discontinuities and is composed of two main arboreal strata (SPVS, 2009).

Data collection and field sampling in the public forest fragments were conducted under formal authorization granted by the Municipal Secretariat of the Environment of Curitiba (SMMA). The research followed all administrative procedures established by Municipal Ordinance Nº 012/2004, which standardizes the protocols for authorizing scientific research and educational activities within the Conservation Units of the Municipality of Curitiba.

3 **Procedures**

3.1 Installation of sample plots

The areas composed of remnants of arboreal vegetation were delimited in each forest, totaling 3.60 ha in the Papa João Paulo II forest and 2.28 ha in the Gutierrez forest. To define the sampling units, a grid of potential rectangular plots measuring 20x30 m (600 m²) was initially demarcated over the arboreal cover, resulting in 41 potential plots in Papa João Paulo II and 18 in Gutierrez.

To ensure an unbiased selection, a Simple Random Sampling (SRS) design was implemented. All potential plots were assigned a unique identification number, and the final selection was performed using the RANDBETWEEN function in Microsoft Excel 2016. Following the sampling intensity suggested by Kauai et al. (2019), six plots were randomly selected in the Papa João Paulo II forest and four in the Gutierrez forest. Consequently, the sampling effort covered a total area of 0.36 ha (10.71%) and 0.24 ha (10.56%), respectively, ensuring that at least 10% of the tree cover in each UFF was represented.

The selection of areas for installing the sample plots was performed using the Google Earth® and QGIS 3.16® programs based on satellite images dated September 2019. The plots were drawn using Microsoft Excel 2016®.

3.2 Characterization of the floristic composition

A floristic characterization was performed to distinguish native species of the Mixed Ombrophilous Forest (MOF) from exotic species, including invasive ones. The inventory included all tree and palm individuals with a Diameter at Breast Height (DBH) greater than 4.78 cm (equivalent to a circumference at breast height > 15 cm). This data collection stage took place between November 2021 and March 2022.

To identify the species, the currently accepted scientific names in the Flora do Brasil (floradobrasil.jbrj.gov.br) and World Flora Online (worldfloraonline.org) databases were adopted. Invasive exotic species were categorized according to the official lists of the municipality of Curitiba (Decree No. 473/2008) and the state of Paraná (IAP Ordinance No. 59/2015), specifically considering those with recorded occurrence in MOF regions.

Statistical analyses were conducted in the R environment, version 4.2.0 (R Core Team, 2022). The iNext package was used to calculate sample sufficiency, while phytoR and vegan were utilized for phytosociological calculations. The indices calculated to characterize the structure of the evaluated UFFs were: Absolute Density (AD), Relative Density (RD), Absolute Frequency (AF), Relative Frequency (RF), Absolute Dominance (ADo), Relative Dominance (RDo), and Importance Value (IV).

Non-Metric Multidimensional Scaling (nMDS) was selected as the ordination method to define floristic groups based on the composition and diversity of each plot. nMDS was chosen because it is highly robust for ecological community data, which often exhibit non-linear relationships and a high frequency of zero values. Unlike linear methods such as Principal Component Analysis (PCA), which rely on Euclidean distances and assume multivariate normality, nMDS utilizes rank-based dissimilarity (Bray-Curtis distance), which is more effective at preserving ecological distances between plots in complex forest fragments.

4 **Results**

Sampling sufficiency was confirmed as adequate, as a 10% increase in sampling would result in less than a 5% increase in the number of species, equivalent to 14 species (FIGURE 2).

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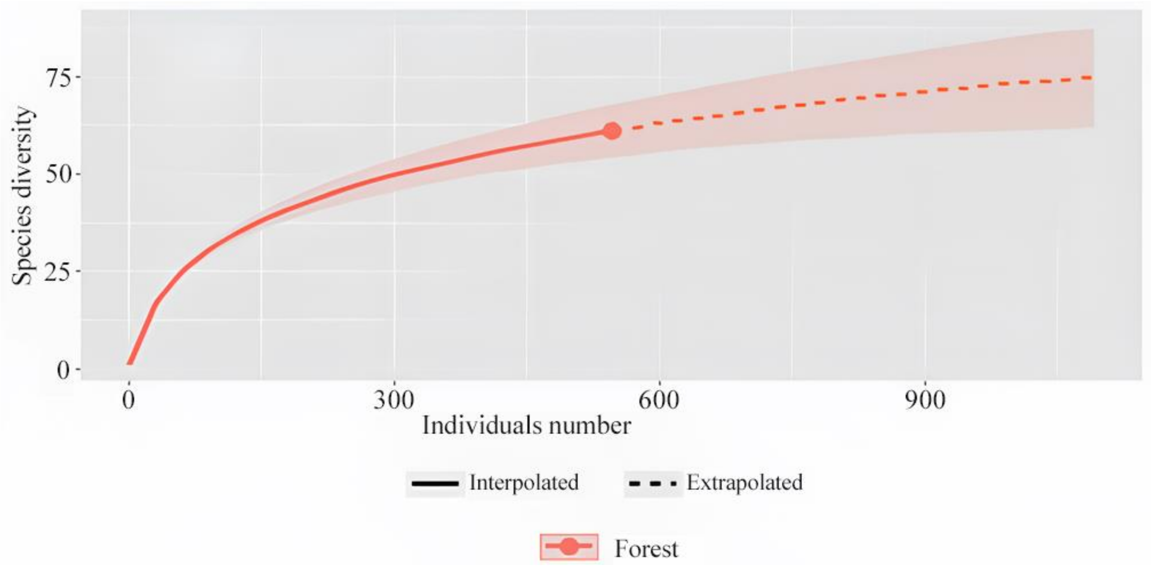
Figure 2: Sampling intensity curve for sample plots.



Source: Authors (2025).

A total of 546 arboreal individuals were recorded. Of these, 456 individuals belonged to native species (83.51%), eight to non-invasive exotic species, and 82 to invasive exotic individuals (15.01%). Specifically, in the Papa João Paulo II forest, 257 individuals were native MOF species, while 72 were invasive individuals. In the Gutierrez forest, 199 individuals of native MOF species (94.76%), one non-invasive exotic (0.48%), and 10 invasive individuals (4.76%) were sampled.

A total of 61 species were identified among the tree individuals sampled, with 41 species recorded in Papa João Paulo II forest and 38 in Gutierrez forest. Of this total, 18 species were found simultaneously in both forests, including individuals of the exotic species: *Ligustrum lucidum* W.T.Aiton (alfeneiro), *Persea americana* Mill. (abacateiro) and *Eriobotrya japonica* (Thunb.) Lindl. (nespereira).

These species belong to 31 botanical families, the most representative of which are Myrtaceae (14.76%), followed by Salicaceae (11.48%), Lauraceae (9.83%), and Fabaceae (6.56%), together constituting 42.63% of the total species sampled.

Of the total, 86.89% of the species found are native to the MOF, while 4.91% are non-invasive exotics in MOF regions, including *Euterpe edulis* Mart. (palmito-juçara), which is native to the dense rainforest; *Ceiba speciosa* (A.St.-Hil.) Ravenna (floss silk tree) and *Platanus occidentalis* L. (American sycamore or planetree); and 8.2% are invasive exotics: *L. lucidum*, *Hovenia dulcis* Thunb., *P. americana*, *E. japonica,* and *P. undulatum* Vent. Only one species, *A. angustifolia*, is threatened with extinction, being classified as "EN" (Endangered) according to MMA (2022).

4.1 Phytosociological indices

The analysis of phytosociological indices demonstrated that the species with the highest number of individuals, absolute density, and relative density were *Casearia sylvestris* Sw. (cafezeiro-do-mato), *Matayba elaeagnoides* Radlk. (miguel-pintado) and *L. lucidum*, respectively (Supplementary Material).

The species with the highest absolute and relative dominance values were *A. angustifolia*, followed by *Ocotea puberula* (Rich.) Nees (canela-guaicá) and *Cabralea canjerana* (Vell.) Mart. (canjerana). Next, *L. lucidum* appears again.

The most frequent species were *C. sylvestris*, with 70 individuals, and found in all plots; *Eugenia uniflora* L. (pitangueira) was not present in plot 9; *M. elaeagnoides*, not found in plots 1, 3, and 7; *Casearia decandra* Jacq. (guaçatunga-branca), not found in plots 7 and 9; and *O. puberula*, present in all plots of the Papa João Paulo II forest and plot 9.

The importance value (IV) was higher with values above 7.0 for the species *A. angustifolia*, *C. sylvestris,* and *M. elaeagnoides*, all native to the MOF. Among these, *L. lucidum* exhibited the most significant expression, appearing in 60% of the plots with a Relative Density (RD) of 9.34% and an

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Importance Value (IV) of 7.04. In the Papa João Paulo II forest, this species was particularly prominent, contributing significantly to the total basal area of plot 4 (22.55 m^2 ha^{-1}).

The exotic species with the highest phytosociological values were *L. lucidum*, *H. dulcis,* and *P. americana*. Considering the total floristic composition of the sample plots, and since the participation of invasive species in the floristics of the UFFs was lower than that of native species, plot 9 had the lowest number of tree individuals, with 26 (433.33 ind. ha^{-1}), and plot 4 had the most trees, 80 in total (1,333.33 ind. ha^{-1}). The largest quantity for the number of species was found in plot 7 (29). Plots 2 and 4 had the smallest quantities of 12 species.

The basal area varied from 10.22 m^2 ha^{-1} in plot 9 to 67.56 m^2 ha^{-1} in plot 3, with a total average of 34.37 m^2 ha^{-1}. Plot 4 had the highest number of individuals per hectare regarding tree density of 1,333.33 ind. ha^{-1}, while plot 9 had the lowest amount (433.33 ind. ha^{-1}).

The mean DBH varied from 13.91 cm in plot 8 to 22.55 cm in plot 3 due to the presence of *A. angustifolia* individuals. Thus, the general DBH mean was 16.52 cm. The mean height of trees in plots 1 to 6 was higher, reaching up to 12.17 m in plot 3, while the mean height in plot 10 was 8.53 m. The total mean height was 10.07 m. Thus, the mean height of trees in the plots in Papa João Paulo II forest was generally higher than in Gutierrez forest, with 10.68 m in the first and 9.16 m in the second.

Table 1 presents the values of the parameters related to the total floristic composition of the sample plots.

Table 1. Total floristic composition of the sample plots.

Plot	Num. individuals	Num. species	G (m^2 ha^{-1})	Density (ind. ha^{-1})	Mean DBH (cm)	Mean height (m)

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1	43	17	32.00	716.67	18.41	11.12
2	53	12	37.02	883.33	17.49	10.55
3	47	14	67.56	783.33	22.55	12.17
4	80	12	43.66	1,333.33	16.82	10.66
5	44	15	24.44	733.33	15.68	9.91
6	69	23	58.41	1,150.00	17.89	9.69
7	64	29	22.06	1,066.67	14.04	9.95
8	67	17	26.78	1,116.67	13.91	9.00
9	26	17	10.22	433.33	14.27	9.15
10	53	18	21.57	883.33	14.18	8.53

Source: Authors (2025).

The smallest number of arboreal individuals in relation to exotic species (Table 2) was found in plots 8 and 10, where there were no records, with two individuals in plots 2 and 5 (33.33 ind. ha^{-1}), with plot 4 having the most trees in this group, 34 in total (566.67 ind. ha^{-1}).

Table 2**.** Floristic composition of exotic species in sample plots.

Plot	**Num. individuals**	**Num. species**	**G (m^2 ha^{-1})**	**Density (ind. ha^{-1})**	**Mean DBH (cm)**	**Mean height (m)**
1	3	2	2.14	50.00	21.29	13.00
2	28	4	16.58	466.67	18.23	11.96
3	5	3	4.18	83.33	20.81	11.50
4	34	2	22.55	566.67	18.79	10.87
5	2	2	0.54	33.33	13.34	9.00
6	7	4	3.37	116.67	12.85	7.50
7	8	2	1.05	133.33	9.04	6.38
8	0	0	0.00	0.00	0.00	0.00

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9	2	2	0.86	33.33	15.36	8.00
10	0	0	0.00	0.00	0.00	0.00

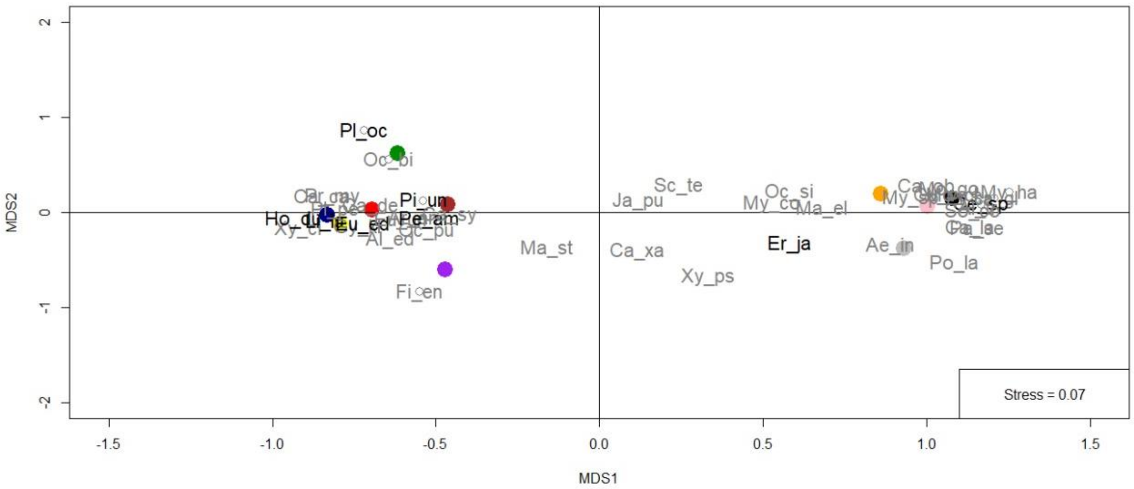
Source: Authors (2025).

Plots 2 and 6 contained the highest number of exotic species (four each), while plots 1, 4, 7, and 9 had two species each. The basal area of exotic species was nonexistent in plots 8 and 10, whereas plot 4 reached the highest value at 22.55 $m^2\ ha^{-1}$.

The mean DBH of the exotic species ranged from 9.04 cm in plot 7 to 21.29 cm in plot 1. The mean height of this group of trees was also greater in plot 1, with 13.00 m, while plot 7 had the lowest mean height (6.38 m).

The nMDS analysis ordination effectively segregated into two dimensions according to the density of each species (FIGURE 3). The stress of the nMDS analysis (which compares the dissimilarity of the original data with the dissimilarity of the current solution) reached 0.07, and since it was lower than 0.2, this indicates that the organization of the data in the nMDS was satisfactory.

Figure 3. nMDS analysis for sampled species.



Source: Authors (2025).

5 **Discussion**

Given the complexity of these urban ecosystems, this study provides a comprehensive analysis of the floristic composition and structure of two forest fragments in Curitiba, Paraná, to understand how the presence of invasive exotic species influences their long-term ecological resilience.

The research begins by identifying and quantifying the distribution of native and exotic tree species within the fragments, establishing a baseline to compare their phytosociological profiles. Furthermore, the analysis examines the specific structural impacts of dominant invaders, such as L. lucidum, H. dulcis, and P. americana, on the overall community dynamics. By applying Non-Metric Multidimensional Scaling (nMDS), the study explores the underlying differences in the floristic-structural organization between the two forests, offering insights to support management strategies and the conservation of biodiversity in urban green areas.

5.1 Phytosociological indices

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The phytosociological indices for M. elaeagnoides in the UFFs were high, as was found in an UFF in the Alluvial MOF region in Guarapuava, PR (Biz, 2017). For the author, this result indicates a prominent participation of the species in ecological succession in an anthropized environment (Biz, 2017).

Table 2 shows that there is an important presence of L. lucidum in the plots, whose ecological dynamics may already have been significantly affected by the invasion of the species. The presence of at least one adult L. lucidum individual in almost all plots indicates the need to manage of the species in order to mitigate biotic homogenization in both forests.

The highest frequency of C. sylvestris, E. uniflora, M. elaeagnoides, C. decandra, and O. puberula species in the evaluated forests is due to their ecological characteristics, ranging from pioneer to initial secondary and undemanding about edaphoclimatic conditions, as well as their adaptation to altered locations.

The species with the highest importance value (IV), namely A. angustifolia, C. sylvestris, and M. elaeagnoides, were also those with the highest IV in other UFFs of Curitiba, as verified by Santos et al. (2023).

One factor that explains the greater occurrence of invasive species in UFFs, especially on the edges, is the proximity to more anthropogenic places, such as streets and residential gardens, in addition to the use and occupation of the land before the area was designated as a park or forest. This is also due to easier access for homeless people who shelter in these places and can carry propagations of invasive species. The invasive species found are commonly used for ornamental and/or food purposes, which facilitates the dispersion of their seeds by people and fauna.

Therefore, replacing these species with native ones helps to reduce their spread into other nearby urban green areas. In conjunction with this, UFF visitors must be made aware of the risks of discarding seeds from these species in places with native vegetation, in addition to using these species in their backyards.

In other UFFs in Curitiba, Santos et al. (2023) found mean basal areas larger than those observed in this study, between 47.43 and 69.39 m2 ha-1, indicating greater conservation of those environments. When compared to well-preserved remnants of Mixed Ombrophilous Forest (MOF), the urban fragments in this study exhibit significant structural degradation. In more conserved primary or late-successional MOF areas, the basal area typically ranges between 40 and 60 m2 ha-1, whereas the average found in the Papa João Paulo II and Gutierrez forests was notably lower at 34.37 m2 ha-1. Furthermore, while undisturbed forests maintain high tree densities (often exceeding 1,500 m2 ha-1) and complex vertical stratification, the lower densities observed here, reaching as low as 433.33 in Plot 9, indicate a simplified forest structure.

Unlike conserved forests, where canopy gaps are naturally filled by native pioneers in a structured successional sequence, these urban fragments face 'arrested succession' due to the dominance of invasive exotics. The high importance value of L. lucidum and H. dulcis demonstrates that these species are not merely occupying empty niches but are actively displacing native MOF components. This shift from a diverse, Araucaria-dominated canopy to a simplified, invader-dominated understory marks a clear divergence from the ecological trajectory of protected forest remnants in the southern Brazilian plateau.

The structural and floristic patterns observed in Curitiba's fragments align with global trends in urban forest ecology, characterized by a transition from specialized native communities to generalized, invasive-dominated stands. This process, often termed 'biotic homogenization,' is a hallmark of urban ecosystems where anthropogenic disturbances and high propagule pressure favor opportunistic species over late-successional natives (Potgieter et al., 2019; Johnson et al., 2020).

Furthermore, the significant reduction in basal area and tree density compared to well-preserved MOF remnants suggests that these urban forests may be losing their capacity to function as effective carbon sinks and climate regulators. In a broader context, the 'arrested succession' identified in the Papa João Paulo II and Gutierrez forests reflects a common challenge in subtropical urban forestry: the displacement of long-lived, high-biomass species (like Araucaria angustifolia) by fast-growing, short-lived invaders (like L. lucidum). This shift not only alters the vertical stratification of the forest but also compromises the long-term provision of ecosystem services, such as local temperature mitigation and hydrological protection, which are critical for urban climate resilience in the face of global environmental change.

The tree densities found in this study are also lower than those found by Santos et al. (2023) in other UFFs in Curitiba, where the lowest observed tree density was 1,670 m2 ha-1 in the General Iberê de Mattos Municipal Natural Park (Parque Bacacheri). Thus, it is evident that the evaluated UFFs are more severely impacted by urbanization and biological invasion than other forest remnants in Curitiba.

The mean DBH of the individuals evaluated was slightly higher than that found in the UFF evaluated by Santos et al. (2023) in Curitiba, whose means varied between 13.50 and 16.40 cm. This shows that there is a distinction in forest succession in the UFFs sampled in both surveys, which may be due to the presence of invasive species with more expressive development. On the other hand, the total heights of the individuals are consistent with what was found by Santos et al. (2023), as the heights of tree individuals in UFFs of Curitiba were between 9.3 and 10.8 m. However, this result shows that there is greater heterogeneity in the UFF canopy evaluated in this study compared to that in the aforementioned study.

The fact that the mean height of the plots in Papa João Paulo II forest is higher than that in Gutierrez forest can be explained by the greater frequency of individuals of the A. angustifolia species in Papa João Paulo II forest, especially in plots 3 and 6.

The largest basal area in plot 4 is explained by the presence of L. lucidum individuals, whose structural dominance, especially in the Papa João Paulo II forest, highlights an opportunistic nature in disturbed urban remnants. As noted by Nunes et al. (2018), this species capitalizes on fragile interspecific relationships to establish itself in environments subject to anthropogenic disturbances. Its widespread occurrence across the study plots suggests a process of biotic homogenization, facilitated by efficient seed dispersal by avifauna and high shade tolerance (Hoyos et al., 2010; Bellis et al., 2020). Such invasion patterns directly compromise ecological stability by inhibiting native succession, as further evidenced by the smaller tree sizes observed in plots with higher invasive pressure, such as plot 7.

The MDS 1 (x axis) better explains the data and separates the plots in each forest, with the plots in the Papa João Paulo II forest on the left and the plots in the Gutierrez forest on the right. Thus, it is clear that there is a floristic-structural difference between the forests, with the Pope John Paul II forest having the greatest presence of invasive species.

The greatest influence of H. dulcis can be seen in plot 2 and L. lucidum in plot 4, both in the Papa João Paulo II forest. On the other hand, only E. japonica is related to the Gutierrez forest, possibly exerting the greatest influence on its floristic composition.

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Invasion by L. lucidum has negative ecological impacts at local and landscape scales, maximized by the dispersal of its seeds by avifauna, which facilitates invasion into new locations (Bellis et al., 2020). In a study conducted by Powell and Aráoz (2017), it was found that defecation by birds involves longer digestive times than regurgitation, helping defecated L. lucidum seeds reach greater distances. Furthermore, L. lucidum individuals have high shade tolerance and can occupy native forests that are not highly disturbed (Hoyos et al., 2010).

The fact that plot 7 has the smallest tree sizes may indicate that it is in the initial process of biological invasion, since eight adult individuals of the invasive species were found there.

In addition, the occurrence of E. japonica individuals in the evaluated plots indicates the need for its control in order to protect native species. This is because this species has allelopathic properties that inhibit seed germination in other species, thereby favoring the biotic homogenization of the community (Costalonga & Batitucci, 2020).

The results of this study are specific because they are restricted to the two forests studied (Papa João Paulo II and Gutierrez). Still, it is already known that this situation of contamination by invasive exotic species is repeated in most cities with forest remnants in urban environments. Therefore, it is recommended to monitor the dynamics of ecological succession in these UFFs to obtain more in-depth information regarding the influence of invasive exotic species on the ecological processes of these environments.

Despite the relevance of the phytosociological findings, it is important to acknowledge that the sampling threshold adopted (DBH > 4.78 cm) represents a specific limitation of this study, as it omits the regeneration strata. Given that invasive species often exhibit prolific recruitment and high shade tolerance in their early stages, this exclusion may lead to an underestimation of the actual invasion dynamics within these fragments. Consequently, the observed structural patterns reflect the established community, but the potential for future shifts in species composition remains high. Future research focusing on the regenerative component (DBH < 4.78 cm) is recommended to complement these findings and provide a comprehensive overview of the long-term invasion trajectory and successional dynamics in these urban forests.

The findings of this study allow for the prioritization of management actions based on the specific invasion stage of each forest fragment. In areas with established dominance, such as Plot 4 in the Papa João Paulo II forest, the priority should be the gradual removal of reproductive adults of L. lucidum. This must be coupled with the enrichment planting of late-successional native MOF species (e.g., Araucaria angustifolia and Ocotea puberula) to maintain the canopy structure and prevent new light gaps that could trigger secondary invasions.

In contrast, fragments in the initial stages of invasion, such as Plot 7 in the Gutierrez forest, require intensive monitoring and mechanical control of the regenerative bank. Eradicating invasive individuals before they reach reproductive age (DBH < 4.78 cm) is more cost-effective and preserves the existing ecological resilience. Additionally, management strategies by the SMMA should include the replacement of invasive ornamentals in the immediate urban matrix (surrounding streets and residential gardens) with native zoochorous species. This targeted replacement directly addresses the primary dispersal vector identified, like avifauna, thereby reducing the pressure of propagules entering the urban forest fragments.

6 **Conclusions**

The phytosociological analysis of the Papa João Paulo II and Gutierrez forests confirms that urban forest remnants in Curitiba are undergoing a critical process of structural simplification and biotic homogenization. Although native species still predominate in absolute numbers, the high Importance Value (IV) of L. lucidum and H. dulcis demonstrates that biological invasion is already actively displacing native Mixed Ombrophilous Forest (MOF) components. This ongoing process confirms the initial expectation of significant ecological degradation and structural simplification within these fragments.

To mitigate these impacts and restore ecosystem resilience, management actions must be prioritized according to the specific invasion stage of each fragment. In areas with established dominance, such as the Papa João Paulo II forest, the priority should be the gradual removal of reproductive invasive adults combined with enrichment planting of late-successional, high-biomass native species (e.g., Araucaria angustifolia and Ocotea puberula) to maintain canopy cover. Conversely, in fragments at earlier invasion stages, such as the Gutierrez forest, efforts should focus on the mechanical control of the regenerative bank and intensive monitoring to prevent new establishments.

On a broader scale, these results contribute to urban ecology theory by illustrating the 'arrested succession' phenomenon in subtropical forests, where invasive species disrupt natural recovery trajectories. Furthermore, public policies coordinated by the Municipal Secretariat of the Environment (SMMA) should prioritize the replacement of invasive ornamentals in the surrounding urban matrix to effectively reduce propagule pressure. Future research incorporating regenerative strata and edge-to-interior gradients is essential to provide a longitudinal perspective on the long-term conservation of these vital urban climate regulators.

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Supplementary material: Phytosociological indices calculated for the sampled species.

Species	**N**	**AD**	**RD**	**ADo**	**RDo**	**AF**	**RF**	**IV**
Casearia sylvestris Sw.	70	116.67	12.82	1.49	4.35	100	5.75	7.64
Matayba elaeagnoides Radlk.	63	105.00	11.54	2.01	5.84	80	4.60	7.32
Ligustrum lucidum W.T.Aiton	51	85.00	9.34	2.87	8.34	60	3.45	7.04
Casearia decandra Jacq.	43	71.67	7.88	0.70	2.05	80	4.60	4.84
Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.	40	66.67	7.33	0.85	2.48	70	4.02	4.61
Eugenia uniflora L.	26	43.33	4.76	0.43	1.24	90	5.17	3.73
Ocotea puberula (Rich.) Nees	18	30.00	3.30	3.72	10.83	80	4.60	6.24

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Hovenia dulcis Thunb.	18	30.00	3.30	1.58	4.59	40	2.30	3.39
Picrasma crenata (Vell.) Engl.	17	28.33	3.11	1.14	3.31	40	2.30	2.91
Cabralea canjerana (Vell.) Mart.	14	23.33	2.56	3.69	10.73	40	2.30	5.20
Monteverdia gonoclada (Mart.) Biral	14	23.33	2.56	0.65	1.88	30	1.72	2.06
Cupania vernalis Cambess.	12	20.00	2.20	0.85	2.46	40	2.30	2.32
Schinus terebinthifolia Raddi	11	18.33	2.01	2.34	6.81	60	3.45	4.09
Myrcia splendens (Sw.) DC.	10	16.67	1.83	0.13	0.38	50	2.87	1.69
Persea americana Mill.	10	16.67	1.83	0.43	1.24	30	1.72	1.60
Aegiphila integrifolia (Jacq.) Moldenke	10	16.67	1.83	0.24	0.71	30	1.72	1.42
Araucaria angustifolia (Bertol.) Kuntze	9	15.00	1.65	6.92	20.14	40	2.30	8.03
Alchornea triplinervia (Spreng.) Müll.Arg.	8	13.33	1.47	0.28	0.82	40	2.30	1.53
Jacaranda puberula Cham.	6	10.00	1.10	0.23	0.67	40	2.30	1.36
Ocotea bicolor Vattimo-Gil	6	10.00	1.10	0.53	1.55	20	1.15	1.27
Gymnanthes klotzschiana Müll.Arg.	6	10.00	1.10	0.11	0.31	40	2.30	1.24
Solanum compressum L.B.Sm. & Downs	6	10.00	1.10	0.06	0.19	40	2.30	1.20
Euterpe edulis Mart.	6	10.00	1.10	0.04	0.12	40	2.30	1.17
Casearia lasiophylla Eichler	5	8.33	0.92	0.06	0.17	20	1.15	0.75

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Ocotea silvestris Vattimo-Gil	5	8.33	0.92	0.05	0.13	20	1.15	0.73
Campomanesia xanthocarpa (Mart.) O.Berg	4	6.67	0.73	0.50	1.47	30	1.72	1.31
Prunus myrtifolia (L.) Urb.	4	6.67	0.73	0.19	0.56	40	2.30	1.20
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.	3	5.00	0.55	0.35	1.01	20	1.15	0.90
Palicourea sessilis (Vell.) C.M.Taylor	3	5.00	0.55	0.15	0.43	30	1.72	0.90
Machaerium stipitatum Vogel	3	5.00	0.55	0.13	0.39	30	1.72	0.89
Sapium glandulosum (L.) Morong	3	5.00	0.55	0.12	0.35	20	1.15	0.68
Myrsine umbellata Mart.	3	5.00	0.55	0.05	0.15	20	1.15	0.61
Mollinedia clavigera Tul.	3	5.00	0.55	0.02	0.06	20	1.15	0.59
Annona sylvatica A.St.-Hil.	2	3.33	0.37	0.09	0.25	20	1.15	0.59
Eriobotrya japonica (Thunb.) Lindl.	2	3.33	0.37	0.09	0.25	20	1.15	0.59
Senna multijuga (Rich.) H.S.Irwin & Barneby	2	3.33	0.37	0.25	0.72	10	0.57	0.55
Xylosma pseudosalzmannii Sleumer	2	3.33	0.37	0.03	0.08	20	1.15	0.53
Pimenta pseudocaryophyllus (Gomes) Landrum	2	3.33	0.37	0.20	0.57	10	0.57	0.50
Casearia obliqua Spreng.	2	3.33	0.37	0.07	0.22	10	0.57	0.39
Vernonanthura discolor (Spreng.) H.Rob.	2	3.33	0.37	0.04	0.12	10	0.57	0.36

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Dahlstedtia floribunda (Vogel) M.J. Silva & A.M.G. Azevedo	2	3.33	0.37	0.02	0.04	10	0.57	0.33
Platanus occidentalis L.	1	1.67	0.18	0.12	0.35	10	0.57	0.37
Miconia petropolitana Cogn.	1	1.67	0.18	0.12	0.34	10	0.57	0.37
Aiouea glaziovii (Mez) R.Rohde	1	1.67	0.18	0.09	0.26	10	0.57	0.34
Annona emarginata (Schltdl.) H.Rainer	1	1.67	0.18	0.08	0.25	10	0.57	0.33
Myrcia hatschbachii D.Legrand	1	1.67	0.18	0.07	0.19	10	0.57	0.32
Ceiba speciosa (A.St.-Hil.) Ravenna	1	1.67	0.18	0.04	0.12	10	0.57	0.29
Xylosma ciliatifolia (Clos) Eichler	1	1.67	0.18	0.03	0.09	10	0.57	0.28
Podocarpus lambertii Klotzsch ex Endl.	1	1.67	0.18	0.03	0.08	10	0.57	0.28
Ficus enormis Mart. ex Miq.	1	1.67	0.18	0.02	0.06	10	0.57	0.27
Muellera campestris (Mart. ex Benth.) M.J. Silva & A.M.G. Azevedo	1	1.67	0.18	0.02	0.05	10	0.57	0.27
Nectandra lanceolata Nees	1	1.67	0.18	0.01	0.03	10	0.57	0.26
Pittosporum undulatum Vent.	1	1.67	0.18	0.01	0.03	10	0.57	0.26
Myrceugenia acutiflora (Kiaersk.) D.Legrand & Kausel	1	1.67	0.18	0.01	0.03	10	0.57	0.26
Banara parviflora (A.Gray) Benth.	1	1.67	0.18	0.01	0.02	10	0.57	0.26

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Myrrhinium atropurpureum Schott	1	1.67	0.18	0.01	0.02	10	0.57	0.26
Roupala montana var. *brasiliensis* (Klotzsch) K.S.Edwards	1	1.67	0.18	0.01	0.02	10	0.57	0.26
Solanum sanctae-catharinae Dunal	1	1.67	0.18	0.01	0.02	10	0.57	0.26
Myrcia selloi (Spreng.) N.Silveira	1	1.67	0.18	0.01	0.02	10	0.57	0.26
Citharexylum solanaceum Cham.	1	1.67	0.18	0.00	0.01	10	0.57	0.26
Plinia peruviana (Poir.) Govaerts	1	1.67	0.18	0.00	0.01	10	0.57	0.26

Source: Authors (2025).