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Forest dynamics and invasion of *Ligustrum Lucidum* in an urban alluvial Atlantic Forest fragment

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ABSTRACT

Alluvial forest environments are vulnerable, representing one of the most degraded ecosystems globally. This study evaluated the dynamics of an urban Alluvial Mixed Ombrophilous Forest and the invasion of *Ligustrum lucidum* W.T.Aiton (Oleaceae) in Guarapuava-PR, Brazil. Diameter at Breast Height (DBH ≥ 5 cm) and height measurements of tree individuals were carried out in 72 study plots of 100 m² each, between 2011 and 2022, and phytosociological descriptors and Relative Growth Rates and Mortality Rates were calculated. Analysis of Variance compared the abundance of the invader over the years, and Pearson correlation investigated its relationship with native species' richness. Other comparisons used Generalized Linear Models, with *Bonferroni* correction at 5% significance level. *L. lucidum* showed similar mean diameter to the native tree community, but its mean height was significantly higher. *Gymnanthes klotzschiana*, *Matayba elaeagnoides*, and *L. lucidum* had higher phytosociological descriptors and sociological position values. The growth rate of *L. lucidum* was higher along with *Casearia decandra*, and the alien species had a low mortality rate compared to *Zanthoxylum rhoifolium* and *Ocotea puberula*. However, there was no significant increase in the abundance of *L. lucidum*, although a weak negative correlation between native species richness and invader abundance was observed. The invasion degree indicated a 5% increase in the alien population during the study period. This study provides a basis for investigations into the dynamics of alluvial forests and the biological invasion process.

Keywords: araucaria mixed forest, invasive alien species, phytosociology.

Dinâmica florestal e invasão de *Ligustrum Lucidum* em fragmento aluvial urbano de Mata Atlântica

RESUMO

Os ambientes de floresta aluvial são vulneráveis, representando um dos ecossistemas mais degradados globalmente. Este estudo investigou a dinâmica de uma Floresta Ombrófila Mista Aluvial urbana e a invasão de *Ligustrum lucidum* W.T.Aiton (Oleaceae) em Guarapuava-PR. Foram realizadas medições de diâmetro à altura do peito (DAP ≥ 5 cm) e altura de indivíduos arbóreos em 72 unidades de estudo de 100 m² cada, entre 2011 e 2022 e calculados os descritores fitossociológicos e Taxas de Crescimento Relativo e Mortalidade. A Análise de Variância comparou a abundância do invasor ao longo dos anos e a correlação de Pearson investigou sua relação com a riqueza de espécies nativas. Outras comparações usaram Modelos Lineares Generalizados, com correção de *Bonferroni* com 5% de significância. *L. lucidum* apresentou diâmetro médio semelhante à comunidade arbórea nativa, já, a sua altura média foi significativamente maior. *Gymnanthes klotzschiana*, *Matayba elaeagnoides* e *L. lucidum* apresentaram descritores fitossociológicos e valores de posição sociológica mais elevados. A taxa de crescimento de *L. lucidum* foi superior juntamente com *Casearia decandra*, e a exótica obteve baixa taxa de mortalidade em comparação com *Zanthoxylum rhoifolium* e *Ocotea puberula*. Apesar disso, não houve aumento significativo na abundância de *L. lucidum* e foi observada uma correlação negativa fraca entre a riqueza de espécies nativas e a abundância da invasora. O grau de invasão indicou um aumento de 5% na população exótica durante o período estudado. Este estudo oferece base para investigações sobre a dinâmica das florestas aluviais e o processo de invasão biológica.

Palavras-chave: espécie exótica invasora, fitossociologia, floresta ombrófila mista.

1. INTRODUCTION

The alluvial environments of the urban forest are essential components of terrestrial and aquatic ecosystem diversity and functioning. They have an important role in cities, in the preservation of watercourses and their banks, supply multiple provisioning, regulatory and cultural ecosystem services (Castro-Díez *et al.*, 2021). Urban habitats are hotspots for the establishment and spread of invasive alien species (IAS) due to the high colonization and propagule pressures resulting from commerce, traffic, ornamentation and disturbances (Kühn *et al.*, 2017). And it has already been proven that the coverage of invasive species increases in cities, and likewise in specific habitats such as riverbanks, roads, and highways (Brummer *et al.*, 2016; Štajerová *et al.*, 2017).

In turn, IAS drive changes in these environments, caused by human-caused alterations, such as habitat degradation (Pyšek *et al.*, 2020), which associated with the removal of natural individuals and species are determinants in the process of colonization and invasion (Nunes *et al.*, 2018). Thus, it is necessary to monitor and mitigate these impacts in this environment. Studies evaluating the structure and dynamics of forests, which are based on the growth and mortality of trees over a given period of time, associated with environmental characteristics, are necessary for understanding the processes of biological invasion (Lázaro-Lobo *et al.*, 2022).

The presence of IAS, such as *Ligustrum lucidum* W.T.Aiton (Oleaceae), has been the subject of global concern in natural forests, as its invasion alters the ecological balance, bringing changes in the natural patterns of interactions between organisms and the environment (Duboscq-Carra *et al.*, 2021). Originally from Asia, specifically in China, *L. lucidum* was introduced outside its natural range as an ornamental plant and has been used in urban tree planting (Resende Araújo *et al.*, 2022). It is currently considered a global invasive species at risk to natural species, as it has high phenotypic plasticity, structurally dominating several phytophysiognomies (Fernandez *et al.*, 2020; Nogueira *et al.*, 2020), including in the Mixed Ombrophilous Forest (MOF), an offshoot of the Atlantic Forest in Brazil (Nogueira *et al.*, 2020; Nunes *et al.*, 2018; Resende Araújo *et al.*, 2022).

Changes in ecosystem properties in areas invaded by *L. lucidum* have already been described: changes in the specific composition of the community (Diaz Villa *et al.*, 2016), impoverishment in the richness of the arboreal component (Cadotte, 2017), increased mortality of native species and reduced growth rates at different life stages (Fernandez *et al.*, 2020), changes in the structures of the invaded community (Fernandez *et al.*, 2021), generating loss of biodiversity (Rico-Sánchez *et al.*, 2021). Substantially altering the ecosystem and landscape processes, as the structural characteristics of invasive species populations influence invasion dynamics in the properties of invaded ecosystems (Vicente *et al.*, 2019).

Therefore, the aim of this study was to evaluate the floristic composition, forest structure, and dynamic aspects of the arboreal component in an alluvial urban fragment of Mixed Ombrophilous Forest (MOF) from 2011 to 2022 and to observe the changes of *L. lucidum* within the forest fragment. To answer: Was there an increase in the abundance of invasive alien species between 2011 and 2022 in this fragment of urban alluvial forest? Would the increase in the abundance of IAS be associated with a decrease in the richness of native species?

2. METHODOLOGY

This study was conducted in the municipality of Guarapuava, located in the state of Paraná, Brazil, and was carried out at the Midwestern State University of Paraná (UNICENTRO), at CEDETEG Campus (Educational and Technological Development Center of Guarapuava). The study area covers an 11.5 hectares urban fragment of Alluvial Mixed Ombrophilous Forest (MOF), which is part of the Cascavelzinho River Hydrographic Basin (CRHB) (Watzlawick *et al.*, 2021). This forest fragment includes 72 permanently installed study plots, each measuring 10 x 10 meters (100 m²). The permanent forest inventory study plots are divided into 6 plots, each with 5 subunits, randomly installed in 2007. Additionally, 3 transects with 13, 14, and 15 subunits, installed to encompass the soil moisture gradient in the forest, from the forest edge towards a river, were allocated in 2015.

The average altitude of the place varies between 1000 and 1020 meters above sea level, providing a mild climate for most of the year. The climate is classified as Humid Subtropical Mesothermal (*Cfb*), characterized by mild summers and moderate winters. The climate is consistently humid with well-distributed rainfall, with an average annual precipitation in the region of 1968 mm year^{-1}, the average temperature during the coldest months ranges from -3°C to 18°C, while the average temperature during the warmest months is below 22°C (Rodrigues *et al.*, 2015; Watzlawick *et al.*, 2021).

The types of soil present range from the deeper, well-structured *Bruno* Latosols to hydromorphic soils with alluvial influence, which suffer flood pulses (Rodrigues *et al.*, 2016). The flooding occurring in the study area favors the invasion of *L. lucidum*, through the dispersion of its seeds through rainwater, aided by individuals of the species that were introduced abundantly and inappropriately into the city's urban trees. During periods of high rainfall in rivers adjacent to the study area, seeds are transported by floods and spread throughout the study area.

All trees (1776 total individuals) with a Diameter at Breast Height (DBH ≥ 5 cm) were measured to comprise the forest inventory, along with their height, using a graduated telescopic pole. The nomenclature of botanical families and genera followed the standards of Angiosperm Philogeneny Group IV (Chase *et al.*, 2016).

The diametric distribution was carried out following an amplitude of class intervals of 10 cm and the distribution of heights, amplitudes of 3 m (Silva and Souza, 2016). The species were classified according to ecological groups as Pioneers (Pi); early successional (ES), late successional (LS) and climax (C), in accordance with the available literature. The phytosociological descriptors used to calculate the horizontal structure were Density (RD), Frequency (RF), Dominance (RDo and ADo) in absolute and relative values, Coverage Value (CV), and Importance (IV) of the species for the years 2011 and 2022, according to Freitas and Magalhães (2012) recommendations.

The Analysis of Variance (ANOVA - one-way) was conducted to compare the abundance of *L. lucidum* between two different years, 2011 and 2022, considering the following hypotheses: Null Hypothesis (H_0): There is no significant difference in the abundance of *L.*

lucidum between the years 2011 and 2022, and Alternative Hypothesis (H_1): There is a significant difference in the abundance of *L. lucidum* between the years 2011 and 2022. And the correlation between the abundance of the IAS and the richness of native species was measured according to the *Pearson* correlation. These analyses were conducted using the R programming language.

The relative sociological position (RSP) of the species was determined according to Lima *et al.* (2022). The vertical structure was assessed by classifying the forest into three height classes: lower (Equation 1), medium (Equation 2), and upper (Equation 3), based on the mean and standard deviation of tree heights.

$$H_{lower} < (H_m - 1\sigma) \quad (1)$$

$$(H_m - 1\sigma) \leq H_{medium} < (H_m + 1\sigma) \quad (2)$$

$$H_{upper} \geq (H_m + 1\sigma) \quad (3)$$

Where: H: three height classes; Hm: Average tree height; σ: Standard deviation.

The rates of relative growth and forest mortality were carried out between 2011 and 2022, according to Forgiarini *et al.* (2015), according to the trees included in the first measurement (2011) and those that remained alive until the second assessment (2022). The impact of *L. lucidum* on native species was estimated using the Index of Alien Impact (IAI) (Equation 4), calculated based on the coefficients of environmental impact (Reaser *et al.*, 2007), derived from the Importance Value (IV) of the species (Santana and Encinas, 2008). The values of this index range from -1 to 1, where closer to the negative extreme indicates a higher level of invasion (Mielke *et al.*, 2015).

$$IAI = \frac{-(P_{alien} - P_{native})}{P_{total}} \quad (4)$$

Where: P_{alien}: IV value of alien tree; P_{native}: IV value of native tree; P_{total}: total IV value (IV = 300). IV: Importance Value.

The means of diameters, height, Relative Growth Rate (RGR) and Species Mortality Rate (M) of tree species and *L. lucidum* were compared using Generalized Linear Models (GLM), following a *Kolmogorov-Smirnov* normality test to determine the choice of link function (linear or *gamma* with a *log link*). Pairwise multiple comparisons were conducted with *Bonferroni* correction at a significance level of 5% to assess differences between native and alien species. These analyses were performed using *IBM SPSS* Statistics Subscription Trial software.

3. RESULTS

The diameter distribution for the Forest followed the negative exponential trend common in native forests. The trees are found in greater numbers in the first two class centers (5 and 15 cm), decreasing as the classes increase. *L. lucidum*, on the other hand, had a higher proportion of individuals in the second-class center (Figure 1 a). The distribution by the height of trees in the forest showed a greater number of individuals between 1.5 and 4.5 m. The population of the IAS showed higher frequency of distribution in the 4.5 m and 7.5 m class. Figure 1 (c) shows the distribution of mean diameter values for the general forest (11.61 ± 6.37 cm) and for *L. lucidum* (11.37 ± 5.94 cm), median values for the general forest (9.79 cm) and for *L. lucidum* (9.55 cm), and respective coefficients of variation of 54.44% and 53.97%. Figure 1 (d) shows the distribution of average height values for the general forest (7.92 ± 3.02 m) and for *L. lucidum*

(9.88 ± 2.25 m), with respective medians of 7.55 m and 10.00 m and coefficients of variation of 30.86% and 23.40%.

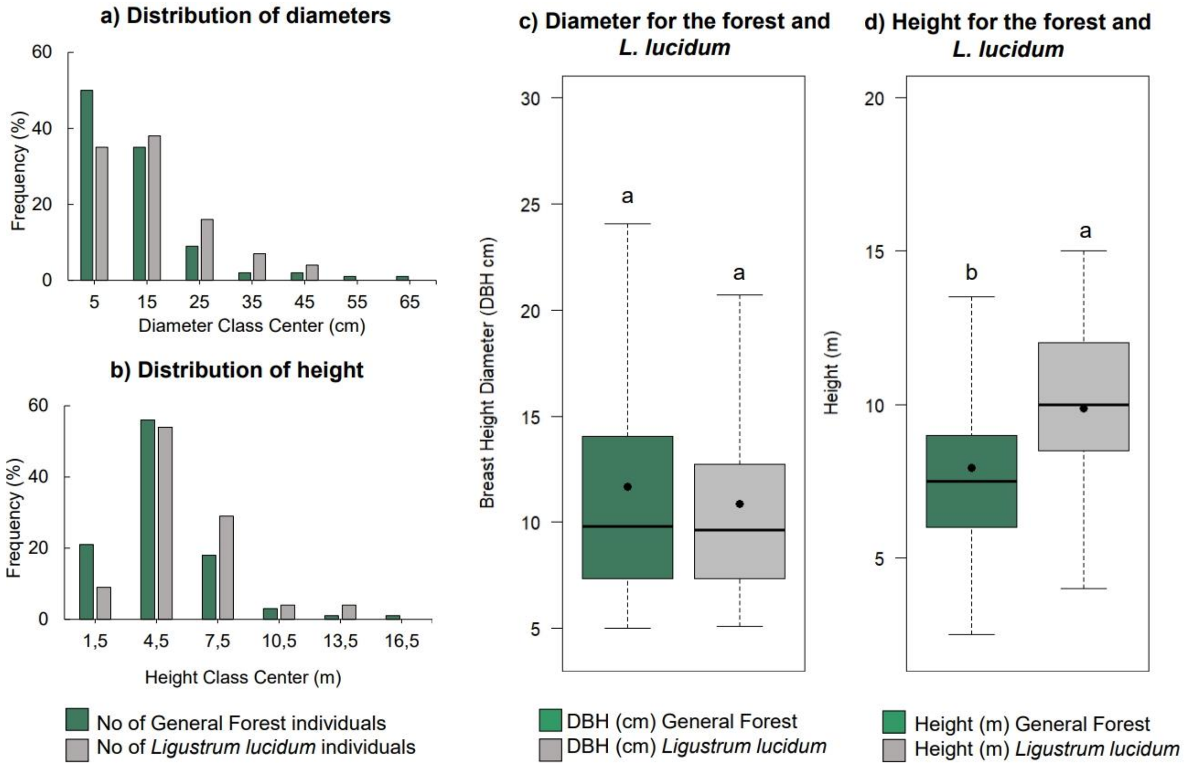

Figure 1. Distribution of diameters and height for the fragment of Mixed Alluvial Ombrophilous Forest and *Ligustrum lucidum* in the municipality of Guarapuava, Paraná, Brazil. Different letters indicate significant differences according to the *Bonferroni* Correction (α = 0.05).
Source: The authors (2024).

The forest diameter values and *L. lucidum* do not show significant differences by the generalized linear models, employing the *Bonferroni* test at a significance level of 5% (α: 0.05). However, the forest height values and *L. lucidum* showed significant differences by the same test with a significance of 5% (α: 0.05).

The floristic composition (Table 1) of the Alluvial Forest changed between 2011 and 2022. In 2011, 1,727.78 ind ha^{-1} were sampled; in 2022, 2,465.28 ind ha^{-1} were recorded. Distributed in 29 families in 2011 and 30 in 2022, the families with the highest specific richness were Myrtaceae (16%) and Lauraceae (10%) and the most representative in terms of individuals abundance were Euphorbiaceae (48%) and Sapindaceae (16%). In 2011, 43 genera and 53 species were described, with an increase of 3 genera and 4 species in 2022: *Dolichandra unguis-cati* (Bignoniaceae), *Ilex paraguariensis* (Aquifoliaceae), *Myrciantes gigantea* (Myrtaceae) and *Roupala montana* (Proteaceae). No species were excluded from the two surveys. As for the ecological group classification, most of the species evaluated are described as: early successional (36%), pioneer (33%), and late species (25%).

Table 1. List of families, species, phytosociological descriptors, sociological position and ecological groups of species between 2011 and 2022 in a fragment of Mixed Alluvial Ombrophilous Forest in the municipality of Guarapuava, Paraná, Brazil.

FAMILY	**SPECIES**	**RD**		**RF**		**RDo**		**CV**		**IV**		**RSP**	**EG**
		2011	**2022**	**2011**	**2022**	**2011**	**2022**	**2011**	**2022**	**2011**	**2022**		
Bignoniaceae	*Adenocalymma album* (Aubl.) L.G. Lohmann	0.16	0.34	0.88	1.57	0.05	0.10	0.10	0.22	0.36	0.67	0.10	Pi[9]
Bignoniaceae	*Adenocalymma marginatum* (Cham.) DC.	0.56	0.23	2.63	1.57	0.16	0.11	0.36	0.17	1.12	0.63	0.30	Ind.
Lauraceae	*Aiouea amoena* (Nees & Mart.) R. Rohde	0.08	0.11	0.44	0.78	0.13	0.11	0.10	0.11	0.22	0.34	0.09	ES[1]
Sapindaceae	*Allophylus edulis* (A.St.-Hil. *et al.*) Hieron. ex Niederl.	2.81	4.06	4.82	4.71	0.87	1.19	1.84	2.62	2.83	3.32	3.66	LS[5]
Annonaceae	*Annona sylvatica* A.St.-Hil.	0.08	0.11	0.44	0.39	0.01	0.04	0.05	0.07	0.18	0.18	0.15	LS[4]
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze	0.48	0.34	2.18	1.96	3.31	3.19	1.90	1.76	2.00	1.83	0.22	Pi[8]
Myrtaceae	*Campomanesia guazumifolia* (Cambess.) O.Berg.	0.08	0.06	0.44	0.39	0.04	0.04	0.06	0.05	0.19	0.16	0.07	LS[4]
Myrtaceae	*Campomanesia xanthocarpa* (Mart.) O.Berg	0.16	0.11	0.88	0.78	0.15	0.11	0.16	0.11	0.44	0.34	0.09	LS[4]
Salicaceae	*Casearia decandra* Jacq.	2.81	3.49	4,39	5.10	1.80	1.96	2.31	2.73	3.00	3.52	3.64	Pi[4]
Canellaceae	*Cinnamodendron dinisii* Schwacke	1.37	2.14	3.07	4.31	1.33	1.66	1.35	1.90	1.92	2.71	2.34	LS[3]
Clethraceae	*Clethra scabra* Pers.	1.13	0.79	2.63	2.35	1.39	1.17	1.26	0.98	1.72	1.44	0.88	Pi[5]
Rubiaceae	*Cordiera concolor* (Cham.) Kuntze	0.08	0.17	0.44	0.39	0.02	0.05	0.05	0.11	0.18	0.20	0.11	Ind.
Lauraceae	*Cryptocarya aschersoniana* Mez	0.08	0.06	0.44	0.39	0.03	0.03	0.05	0.04	0.18	0.16	0.07	C[1]
Sapindaceae	*Cupania vernalis* Cambess.	0.16	0.28	0.44	0.39	0.05	0.09	0.10	0.19	0.21	0.25	0.32	ES and LS[8]
Cyatheaceae	*Cyathea corcovadensis* (Raddi) Domin	0.08	0.06	0.44	0.39	0.09	0.06	0.08	0.06	0.20	0.17	0.07	Ind.
Dicksoniaceae	*Dicksonia sellowiana* Hook.	2.17	1.80	4.39	3.92	7.47	5.95	4.82	3.88	4.67	3.89	0.73	C[1]
Ebenaceae	*Diospyros kaki* L.f.	0.08	0.06	0.44	0.39	0.09	0.13	0.08	0.09	0.20	0.19	0.07	Ind.
Bignoniaceae	*Dolichandra unguis-cati* (L.) L.G.Lohmann	-	0.11	-	0.78	-	0.02	-	0.07	-	0.31	0.09	Ind.
Erythroxylaceae	*Erythroxylum deciduum* A.St.-Hil.	0.64	0.45	2.63	2.35	1.87	1.39	1.26	0.92	1.71	1.40	0.43	LA[4]
Myrtaceae	*Eugenia involucrata* DC.	0.08	0.06	0.44	0.39	0.02	0.02	0.05	0.04	0.18	0.16	0.07	C[1]
Myrtaceae	*Eugenia pyriformis* Cambess.	0.08	0.06	0.44	0.39	0.11	0.08	0.09	0.07	0.21	0.18	0.02	ES[5]
Myrtaceae	*Eugenia uniflora* L.	0.08	0.06	0.44	0.39	0.02	0.02	0.05	0.04	0.18	0.16	0.07	ES[5]
Euphorbiaceae	*Gymnanthes klotzschiana* Müll.Arg.	47.27	48.28	5.70	5.88	31.63	36.43	39.45	42.36	28.20	30.20	49.75	ES[1]
Bignoniaceae	*Handroanthus albus* (Cham.) Mattos	0.56	0.34	1.32	1.18	1.02	0.77	0.79	0.55	0.97	0.76	0.22	Pi[5]
Aquifoliaceae	*Ilex brevicuspis* Reissek	0.40	0.28	1.75	1.57	0.10	0.08	0.25	0.18	0.75	0.64	0.21	ES[1]
Aquifoliaceae	*Ilex dumosa* Reissek	0.56	0.45	1.75	1.18	0.32	0.24	0.44	0.35	0.88	0.62	0.54	ES[1]
Aquifoliaceae	*Ilex paraguariensis* A.St.-Hil.	-	0.11	-	0.78	-	0.02	-	0.06	-	0.30	0.09	LA[8]
Aquifoliaceae	*Ilex theezans* Mart. ex Reissek	3.22	3.49	4.39	5.49	1.04	1.38	2.13	2.43	2.88	3.45	3.80	ES[5]
Bignoniaceae	*Jacaranda micrantha* Cham.	0.48	0.34	0.88	0.78	1.61	1.58	1.05	0.96	0.99	0.90	0.10	ES[8]
Oleaceae	*Ligustrum lucidum* W.T.Aiton	4.82	7.89	3.07	3.14	7.54	11.08	6.18	9.48	5.14	7.37	7.27	ES[9]
Anacardiaceae	*Lithraea brasiliensis* Marchand	0.16	0.11	0.88	0.78	0.12	0.13	0.14	0.12	0.39	0.34	0.15	Pi[6]

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Anacardiaceae	*Lithraea molleoides* (Vell.) Engl.	0.48	0.28	2.19	1.57	0.33	0.26	0.41	0.27	1.00	0.70	0.32	Pi[8]
Malvaceae	*Luehea divaricata* Mart.	0.24	0.17	1.32	1.18	0.09	0.06	0.16	0.12	0.55	0.47	0.17	ES and LS[8]
Sapindaceae	*Matayba elaeagnoides* Radlk.	12.62	11.61	6.14	5.49	16.63	16.11	14.63	13.86	11.80	11.07	12.08	LS[5]
Fabaceae	*Mimosa scabrella* Benth.	0.24	0.17	0.88	0.78	0.18	0.13	0.21	0.15	0.43	0.36	0.17	Pi[8]
Celastraceae	*Monteverdia ilicifolia* (Mart. ex Reissek) Biral	0.24	0.23	0.44	0.78	0.07	0.07	0.15	0.15	0.25	0.36	0.08	ES and LS[2]
Asteraceae	*Moquiniastrum polymorphum* (Less.) G. Sancho	0.08	0.17	0.44	0.78	0.13	0.12	0.11	0.15	0.22	0.36	0.11	Pi[8]
Myrtaceae	*Myrcia palustris* DC.	0.48	0.34	0.88	1.18	0.11	0.13	0.29	0.24	0.49	0.55	0.23	Pi[5]
Myrtaceae	*Myrcia retorta* Cambess.	0.16	0.28	0.88	1.57	0.16	0.23	0.16	0.25	0.40	0.69	0.32	Pi[7]
Myrtaceae	*Myrciantes gigantea* (D. Legrand) D. Legrand	-	0.06	-	0.39	-	0.02	-	0.04	-	0.16	0.07	LS[1]
Primulaceae	*Myrsine coriacea* (Sw.) R.Br. Ex Roem. & Schult.	0.16	0.17	0.88	1.18	0.04	0.08	0.10	0.13	0.36	0.48	0.17	ES[5]
Primulaceae	*Myrsine umbellata* Mart.	0.16	0.11	0.88	0.78	0.27	0.20	0.21	0.15	0.44	0.36	0.15	Pi[5]
Lauraceae	*Nectandra megapotamica* (Spreng.) Mez	0.08	0.06	0.44	0.39	0.26	0.18	0.17	0.12	0.26	0.21	0.07	LS[5]
Lauraceae	*Ocotea diospyrifolia* (Meisn.) Mez	0.24	0.23	0.88	0.78	1.51	1.15	0.88	0.69	0.88	0.72	0.13	ES[4]
Lauraceae	*Ocotea puberula* (Rich.) Nees	1.85	0.96	4.39	3.14	5.53	3.26	3.69	2.11	3.92	2.45	0.81	ES[5]
Lauraceae	*Ocotea pulchella* (Nees & Mart.) Mez	0.56	0.68	1.32	1.96	0.84	0.83	0.70	0.75	0.91	1.15	0.84	ES[5]
Rosaceae	*Prunus myrtifolia* (L.) Urb.	5.47	3.89	5.70	4.71	4.75	3.56	5.11	3.72	5.30	4.05	4.21	ES[5]
Proteaceae	*Roupala montana* Aubl.	-	0.06	-	0.39	-	0.01	-	0.03	-	0.15	0.07	LS[5]
Euphorbiaceae	*Sapium glandulosum* (L.) Morong	0.24	0.23	1.32	1.18	0.24	0.25	0.24	0.24	0.60	0.55	0.18	Pi[5]
Anacardiaceae	*Schinus terebinthifolia* Raddi	0.80	0.28	2.63	1.18	0.31	0.17	0.56	0.23	1.25	0.54	0.26	Pi[8]
Solanaceae	*Solanum mauritianum* Scop.	0.24	0.23	1.32	1.57	1.15	0.95	0.70	0.59	0.90	0.92	0.13	Pi[8]
Loganiaceae	*Strychnos brasiliensis* (Spreng.) Mart.	0.08	0.11	0.44	0.78	0.05	0.08	0.07	0.10	0.19	0.33	0.15	LS[4]
Styracaceae	*Styrax leprosus* Hook. & Arn.	0.08	0.11	0.44	0.78	0.02	0.04	0.05	0.08	0.18	0.31	0.15	ES[5]
Asteraceae	*Vernonanthura discolor* (Spreng.) H.Rob.	0.16	0.17	0.88	1.18	0.49	0.38	0.33	0.27	0.51	0.58	0.22	Pi[8]
Lamiaceae	*Vitex megapotamica* (Spreng.) Moldenke	0.96	0.96	3.51	3.14	0.46	0.48	0.71	0.72	1.64	1.53	0.94	LS[8]
Salicaceae	*Xylosma ciliatifolia* (Clos) Eichler	0.64	0.56	3.07	3.14	0.35	0.27	0.50	0.42	1.35	1.33	0.52	ES[5]
Rutaceae	*Zanthoxylum rhoifolium* Lam.	2.97	1.69	5.70	5.10	3.68	1.72	3.33	1.71	4.12	2.84	1.67	Pi e ES[2]

Where: DR: Density (%); RF: Frequency (%); RDo: Dominance (%); CV: Coverage Value (%); IV: Importance Value (%) of the species; RSP: Sociological Position (%). EG: Ecological group (Pi: Pioneer; ES: Early successional; LS: Late successional; C: Climax). References: 1: (Araujo *et al.*, 2010); 2 and 3: (Carvalho, 2010); 4: (Costa *et al.*, 2022); 5: (Ferreira *et al.*, 2013); 6: (Lorenzi, 2002). 7: (Meira Junior *et al.*, 2015); 8: (Saueressig, 2017); 9: (Silva *et al.*, 2022).

Source: The authors (2024).

Analyzing the community structure, *G. klotzschiana* is the most important species in the study area (Table 1). This species has high phytosociological descriptors compared to the others, with high density (RD) (47.27% in 2011 and 48.28% in 2022) and dominance (RDo) (31.63% in 2011 and 36.43% in 2022). Its frequency (RF) went from 5.70% in 2011 to 5.88% in 2022 and its importance value (IV) increased (28.20% in 2011 and 30.20% in 2022), corresponding to the species with the highest value.

In 2022, *G. klotzschiana*, *M. elaeagnoides*, *L. lucidum* and *P. myrtifolia* account for 69.42% of the coverage value and 52.69% of the importance value among the species, which in 2011 corresponded to 65.36% and 50.45% respectively. *M. elaeagnoides* and *P. myrtifolia* suffered a reduction in their phytosociological descriptors, as did a large number of representative MOF species (*O. puberula*, *Z. rhoifolium*, *M. elaegnoides* and *P. myrtifolia*).

Absolute dominance (ADo) in the forest increased from 20.59 m^2 ha^{-1} to 33.89 m^2 ha^{-1}. As a result, the forest grew by approximately 13.30 m^2 ha^{-1} and *L. lucidum* grew by 2.20 m^2 ha^{-1} in the basal area over the 11 years. As for the dominant species, there were changes over the period analyzed: *G. klotzschiana* (6.51 m^2 ha^{-1}), *M. elaeagnoides* (3.42 m^2 ha^{-1}), *Prunus myrtifolia* (0.97 m^2 ha^{-1}), *Ocotea puberula* (1.13 m^2 ha^{-1}) and *L. lucidum* (1.55 m^2 ha^{-1}), with data observed in 2011. In 2022, *L. lucidum* moved up to third place in terms of basal area (3.75 m^2 ha^{-1}), behind *G. klotzschiana* (12.34 m^2 ha^{-1}) and *M. elaeagnoides* (5.46 m^2 ha^{-1}). *L. lucidum* increased concerning phytosociological descriptors, such as a relative density (RD) increase of 3.07%, coverage values (CV) by 3.3%, and importance values (IV) by 2.22%. *L. lucidum* increased its presence in relation to the number of plots that occurred in 2011, with its RF rising from 3.07% to 3.14%. And it showed a 3.54% increase in its dominance (RDo) in 2022.

However, according to the Analysis of Variance (ANOVA) used to investigate potential differences in the abundance of *L. lucidum* between the years 2011 and 2022, it was found that there was no statistically significant effect on the abundance of the invasive species ($F(1, 142) = 3.678$, $p = 0.0571$). This suggests that there is not enough evidence to reject the null hypothesis that there are no significant differences in abundance between the years considered. Additionally, Figure 2 shows a weak negative correlation ($r = 0.1$) between the abundance of the IAS, *L. lucidum*, and the richness of native species, as only about 10% of the variation in species richness can be explained by the variation in the abundance of the invader. In other words, there is a slight tendency for a decrease in native species richness as the abundance of the invader increases.

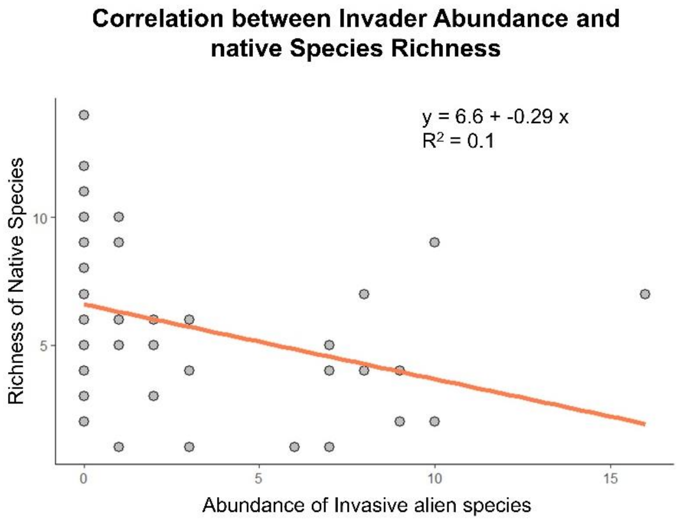

Figure 2. Pearson correlation illustrating a weak negative correlation between the abundance of invasive alien species and the richness of native species.
Source: The authors (2024).

G. klotzschiana, *M. elaeagnoides* and *L. lucidum* accounted for 69.11% of the RSP values (Table 1). *P. myrtifolia* (RSP: 4.21%), *I. theezans* (RSP: 3.80%), *A. edulis* (RSP: 3.66%), *C. decandra* (RSP: 3.64%), *C. dinisii* (RSP: 2.34%), *Z. rhoifolium* (RSP: 1.67%), and *V. megapototica* (RSP: 0.94%) have individuals in all three height classes (Table 2). This characteristic ensures the permanence of the species in the forest, showing that there are trees in different life stages.

As for the vertical structure (Table 2), the first (lower class) includes individuals with a height of less than 5.52 m. This class corresponds to the regeneration of the forest's tree and shrub species and is represented by 17% of the individuals (307) and 23 species sampled. *Dicksonia sellowiana*, *Myrcia palustres*, and *Monteverdia ilicifolia* correspond to a greater number of individuals in this class. This also applies to sciophytic species such as *I. paraguariensis* and the other representatives of the Aquifoliaceae, which grow under diffuse light and are found in the lower class of the forest.

The second vertical structure (intermediate class) corresponds to trees between 5.53 m and 10.46 m. In this class, most of the species were occupied, corresponding to 67% of the individuals (1193), including 53 species and the greatest occupation in terms of basal area of the individuals (18.64 m^2 ha^{-1}). It is occupied by heliophytes which also prefer diffuse light, such as *C. xanthocarpa*, *G. klotzschiana* and *Lithraea brasiliensis*.

Table 2. Characteristics of height classes in a fragment of Mixed Alluvial Ombrophilous Forest in the municipality of Guarapuava, Paraná, Brazil.

Height Class			Percentage of individuals	Basal area (m^2 ha^{-1})	Average BHD (cm)	Average Height (m)
Bottom	H < 5.52 m	Forest	17%	3.99	9.40 ± 5.56	4.82 ± 0.81
		L. lucidum	4%	0.07	9.12 ± 5.77	4.83 ± 0.88
Intermediate	H > 5.53 m and < 10.46 m	Forest	67%	18.64	10.97 ± 4.80	7.81 ± 1.18
		L. lucidum	60%	1.50	11.55 ± 5.43	8.72 ± 1.20
Superior	H > 10.47 m	Forest	16%	11.25	16.93 ± 9.43	12.31 ± 1.58
		L. lucidum	36%	2.20	18.16 ± 8.58	12.27 ± 1.11

Where: H: tree height (m); BHD: diameter at breast height.
Source: The authors (2024).

Individuals taller than 10.47 m correspond to the upper class, representing 16% of the individuals (275) and 30 species sampled. Strictly heliophytic species such as *M. elaeagnoides*, *O. puberula*, *A. angutifolia*, *H. albus*, and *J. micranta* represent this height class of forest, characteristic for having the highest BHD and height values.

L. lucidum has 60% of its individuals in the intermediate height class, 36% of them in the upper class and 4% in the lower class (Table 2), as do the other species with the highest density in the forest, such as *G. klotzschiana* (70% in the intermediate class) and *Prunus myrtifolia* (75% in the intermediate class). However, *L. lucidum* is the tallest in the intermediate and upper classes, with an average height lower than the forest in the upper class.

L. lucidum has the highest growth rate in the fragment (Figure 2 a), but it does not differ statistically from the other species according to the Bonferroni test at 5% probability. Next, species with the highest growth rate were *C. decandra*, the forest as a whole, *G. klotzchiana*, *P. myrtifolia*, and *M. elaeagnoides*.

L. lucidum has the highest growth rate in the fragment, with an average of 0.013 cm^{-1} $year^{-1}$ (Figure 3a), but does not differ statistically from *C. decandra*, with an average of 0.009 cm^{-1} $year^{-1}$, however, differing from the other species by the *Bonferroni* test at 5% probability. Meanwhile, species with lower growth rates, such as *A. edulis* (0.007 cm^{-1} $year^{-1}$), *C. dinisii* (0.007 cm^{-1} $year^{-1}$), *G. klotzchiana* (0.008 cm^{-1} $year^{-1}$), *I. theezans* (0.007 cm^{-1} $year^{-1}$), *M.*

elaeagnoides (0.007 cm^{-1} $year^{-1}$), *P. myrtifolia* (0.007 cm^{-1} $year^{-1}$), *O. puberula* (0.005 cm-1 year-1), and *Z. rhoifolium* (0.008 cm^{-1} $year^{-1}$did not differ from each other by the same test.

Native species experienced a higher mortality rate than the invasive population according to the *Bonferroni* test at 5%. *Z. rhoifolium* and *O. puberula* exhibited the highest mortality rates. This could be understood as a natural event of forest succession or as competition for resources associated with the population of *L. lucidum*. On the other hand, *C. dinisii*, *L. lucidum*, and *G. klotzchiana* showed low mortality rates, while *A. edulis* did not exhibit mortality during the analyzed time period (Figure 3b).

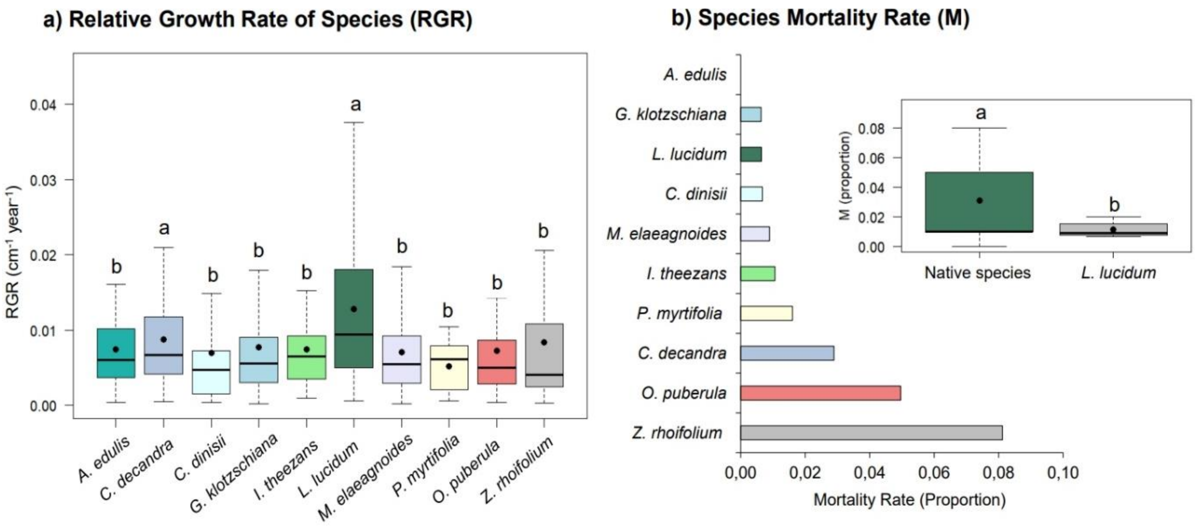

Figure 3. Growth (a) and mortality (b) rates of species in a fragment of Mixed Alluvial Ombrophilous Forest in the municipality of Guarapuava, Paraná, Brazil. Different letters indicate significant differences according to the *Bonferroni* Correction (α = 0.05).
Source: The authors (2024).

The index of alien impact (IAI) complements the data presented to estimate the potential impacts. In 2011, the IAI of the fragment studied was 0.90, and in 2022 this value rose to 0.85. This variation suggests an increase in the *L. lucidum* population, with its invasion rate increasing from 10% to 15% of the total number of individuals in the forest. These numbers indicate a slight increase in the abundance of the invasive species, resulting in a slight increase in the IAI in both years.

4. DISCUSSION

In the context of biological invasion into new communities, alien species benefit from the absence of adverse biological interactions (Prior *et al.*, 2015), such as predation and herbivory. This can result in greater propagule pressure and provide the invasive species with pre-adaptation to environmental conditions (Pearman *et al.*, 2008). Similarly, *L. lucidum* exhibits remarkable phenotypic plasticity that gives it the ability to thrive in similar climatic environments and distinct contexts from its natural habitat (Dreyer *et al.*, 2019).

In the alluvial forest fragment studied, *L. lucidum* has diameter values (DBH cm) equal to the forest average. Differently, Trautenmüller *et al.* (2018) report that the diameters of the alien species were larger when compared to the forest. However, they have a height (m) higher than the forest average, occupying all three height classes of the fragment and most of the intermediate classes and higher height classes in relation to the general forest.

The diameter distribution pattern for the forest demonstrates the balance between mortality and entry of individuals (Turmina *et al.*, 2020), suggesting a regeneration process (Bambolim and Wojciechowski, 2017). On the other hand, *L. lucidum* showed a higher frequency in the second diameter class, indicating more trees with diameters between 10 and 20 cm. Kanieski *et al.* (2012) stated that *L. lucidum* showed different growth according to the sociological position of the species, with those occupying higher classes showing significant growth compared to species in lower classes. The height distribution of *L. lucidum* also shows a higher frequency in higher height classes than the forest, occupying different height classes, with an assured presence in the structure and dynamics of the forest, ensuring success in reaching the canopy and the absence of natural enemies makes this situation possible (Nunes *et al.*, 2020).

Fernandez *et al.* (2020) state that *L. lucidum* can regenerate successfully even in polluted environments, and those seedlings show greater survival than other tree species, both in clearings and under shade. However, the lower height class, corresponding to forest regeneration, does not include most of the *L. lucidum* individuals. In the study fragment there are considerable reproductive trees that are reservoirs of propagules, for the invasion sequence using the subsequent river banks as dispersers, to occupy other spaces.

Nunes *et al.* (2018) describe the increased representation of *L. lucidum* in the forest, highlighting its opportunistic behavior, occurring in places with low interspecific competition. As demonstrated in this study, this growth is reflected in the importance of this species, which increased slightly in VI by 2.23% between 2011 and 2022, with an increase in phytosociological descriptors, which indicates its expected participation and persistence in the community.

It is a fact that the invasive species has rapid growth and a long life cycle, reaching the forest canopy and casting shadows on native species (Fernandez *et al.*, 2020). However, in this research there is not enough evidence to reject the null hypothesis that there are no significant differences in the abundance of *L. lucidum* between the years considered. Therefore, it cannot be stated that there was a significant change in abundance throughout the study period, although these results contribute to the understanding of the temporal dynamics of the variable in question. Other authors show that the vertical structure of vegetation and the species composition and abundance of individuals <2.5 cm DBH in stands dominated by *L. lucidum* and in adjacent stands dominated by native forest were also significantly different, where the coverage of herbaceous and shrub strata was substantially lower in stands dominated by invasive than in adjacent native forests (Hoyos *et al.*, 2010).

Other studies show that IAS richness is often negatively correlated with native species richness at the small spatial scale of sampling plots (Capers *et al.*, 2007). In this study, a weak negative correlation occurred, so only about 10% of the variation in species richness can be explained by variation in invader abundance. There is a small tendency for the richness of native species to decrease as the abundance of the invader increases. In turn, richness and coverage, both alien and native, are weakly positively correlated by Brummer *et al.* (2016). However, Bradley *et al.* (2019) shows that regardless of trophic level, taxon or recipient habitat, the increase in the abundance of IAS has pronounced negative impacts on populations and communities of native species. And at the community level, increasing invader abundance has significantly greater effects on species evenness and diversity than on species richness. Furthermore, native responses to invasion critically depend on the abundance and trophic position of the invasive species.

Species with great economic potential, such as *Araucaria angustifolia* (Castrillon *et al.*, 2023), occur with low phytosociological descriptors, a consequence of the exploitation that took place in the past and the imposition of the alluvial environment. In short, the dynamics of the forest fragment studied are evolving in terms of structure. In a general analysis of the forest, this tree community showed an increase in the number of individuals and in basal area and constancy in specific richness, with an increase of only 3 genera and 4 species.

G. klotzschiana and *M. elaeagnoides* are the most important species (IV) of the fragment. *G. klotzschiana* occupies areas of greater hydromorphy, closer to the river, together with *L. lucidum*, a consequence of the phenotypic plasticity of these species (Fernandez *et al.*, 2020;

Kolb *et al.*, 1998). *M. elaeagnoides* develops in more drained areas of the fragment, being common in studies in the MOF (Forgiarini *et al.*, 2015; Souza *et al.*, 2014). Nunes *et al.* (2018) showed that *G. klotzschiana* presented higher mortality in invaded areas, unlike what occurred in the study fragment: this species presented a low mortality rate due to its adaptation to hydromorphic environments (Kolb *et al.*, 1998).

Z. rhoifolium and *O. puberula* had higher mortality rates, which is a natural event in forest succession, in which the displacement of species or the persistence of others is evident (Turmina *et al.*, 2020). It could also be evidence of competition for resources associated with the introduction of *L. lucidum*, either because of light, where the IAS provides shade for the aforementioned species. These changes can disturb the ecological balance necessary for the survival of these native species, even those with some degree of adaptation to this environment, leading to their decline and death. Although most non-native species infiltrate ecosystems without causing major disturbances, invasive species cause significant negative ecological and economic impacts on the native population (Loehle *et al.*, 2023). Several studies have already shown that invaded environments have their biomass patterns in the forest altered, natural tree species displaced, with the dominance of the non-native population (Castro-Díez *et al.*, 2019) and even higher mortality rates of native species (Franco *et al.*, 2018; Malizia *et al.*, 2017).

A significant portion of IAS possess physiological and morphological characteristics that afford them competitive advantages over native species, thereby facilitating their stability and dispersion across diverse environments (Kumar and Garkoti, 2021; Liu and Kleunen, 2017). *L. lucidum* exhibited the highest mean relative growth rates, as similarly reported in other studies (Arias *et al.*, 2023; Fernandez *et al.*, 2021). However, it did not significantly differ from the native species *C. decandra*. Most native species, except *C. decandra*, did not show significant differences in growth rates in this study and others (Kanieski *et al.*, 2012).

As for the IAI, which shows the degree of invasion and conceptualizes the current circumstances of biological invasion, although, does not predict the invasive potential of the plant community, but indicates a 5% increase in the *L. lucidum* population in the studied microenvironment. In 2011, the alien population represented 10% of individuals, while the current invasion situation has increased to 15% of all individuals. Reaser *et al.* (2007) state that values below 0.8 are a concern for local biodiversity, as around 20% of the area is occupied by alien vegetation.

Larsen *et al.* (2020) indicate that IAS and native species share the same functional gradient; however, the position of non-native species in the functional space is characteristic of each one and their functional traits. The same authors suggest that non-native species become invasive through different strategies, such as occupying marginal functional niches, thus avoiding competition in the community or even competing for space in the environment, displacing natural species. Nogueira *et al.* (2020) explain that the advantage of *L. lucidum* can be attributed to its ability to maintain a specific climatic niche, making it occupy a marginal functional niche in the MOF, which results in a differentiated reproductive phenology compared to native species. This allows the invader to take advantage of resources not used by native species, even if only temporarily, reducing competition for dispersers (Pyšek *et al.*, 2020).

In this context, Bennett (2019) and Larsen *et al.* (2020) suggest that when a community is invaded, non-native species can become dominant, replacing the native ones through the process of limiting similarity, with an overlap of niche between natural and invasive species with a continuous coexistence. In these situations, competition is greater between species with similar characteristics, so the invader needs to be similar to the native species in some respects, but different in others (Bennett, 2019). This tends to result in lower richness, diversity, and evenness in invaded natural forests (Fernandez *et al.*, 2020).

5. FINAL CONSIDERATIONS

The Alluvial Forest areas are environments susceptible to invasions and, therefore, the persistence of *L. lucidium* may play a role in their degradation, since there is no clear tendency for invasion to spread. This study shows an increase in the phytosociological descriptors of the IAS, shows that *L. lucidum* is among the tallest trees in the forest, but at the same time, there was no significant increase in abundance between 2011 and 2022, and there is a weak negative correlation between richness of native species and abundance of invasive species. Studies related to the assessment of the regeneration potential of species, including seedlings, samplings and other small classes not evaluated in this work, can indicate the invasion potential with greater precision. In short, awareness raising and the aggregation of science, management and policy are necessary to promote conservation and ensure a healthy and balanced environment in alluvial MOF areas.

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