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Enviroment

Environmental Variables, floristics, diversity, and species distribution in an Urban Alluvial Forest

Variáveis ambientais, florística, diversidade e distribuição de espécies em Floresta Aluvial Urbana

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ABSTRACT

The Alluvial Forest is found along the margins of watercourses and temporarily flooded areas. The correlation between tree vegetation and environmental variables was studied to understand the distribution of species in Urban Alluvial Atlantic Forest (Guarapuava, Paraná, Brazil). A floristic survey was conducted in three transects, with 42 sample subunits of 100 m² (10 m x 10 m), covering the water gradient across the riverbed. Tree species that presented a Diameter at breast height (DBH) ≥ 5 cm were measured. The measured environmental variables were: piezometric level, soil moisture, resistance to penetration, and chemical and granulometric analyses of the soil. Groupings were formed using the TWINSPAN multivariate technique, and environmental variables were correlated with abundance (ind. ha^{-1}) using Canonical Correspondence Analysis. Four groups were identified: (1) drained; (2) intermediate characteristics; (3) saturated; and (4) hydromorphic soils. Subunits with higher water influence showed the lowest diversity values and the highest dominance values. The canonical correspondence analysis showed that the distribution of *Gymnanthes klotzschiana*, *Ligustrum lucidum*, and *Allophylus edulis* is related to soil water saturation, while *Matayba elaeagnoides* and *Ocotea puberula* are correlated with drained soils. The species were separated into groups according to environmental characteristics, indicating that hydromorphism influences the establishment of the forest community.

Keywords: Atlantic Forest; Mixed Ombrophilous Forest; Water Gradient; Water Table; Flooding

RESUMO

A Floresta Aluvial é encontrada ao longo das margens de cursos d’água e áreas temporariamente inundadas. A correlação entre a vegetação arbórea e variáveis ambientais foi estabelecida para entender a distribuição de espécies na Floresta Atlântica Aluvial Urbana (Guarapuava, Paraná, Brasil). Foi realizado um levantamento florístico em três transectos, com 42 subunidades amostrais de 100 m² (10 m x 10 m), cobrindo o gradiente de água ao longo do leito do rio. As espécies arbóreas que apresentaram Diâmetro à Altura do Peito (DAP) ≥ 5 cm foram medidas. As variáveis ambientais medidas foram: nível piezométrico, umidade do solo, resistência à penetração e análises químicas e granulométricas do solo. Os agrupamentos foram formados usando a técnica multivariada TWINSPAN, e as variáveis ambientais foram correlacionadas com a abundância (ind. ha^{-1}) utilizando a Análise de Correspondência Canônica. Quatro grupos foram identificados: (1) solos drenados; (2) características intermediárias; (3) solos saturados; e (4) solos hidromórficos. As subunidades com maior influência de água mostraram os valores mais baixos de diversidade e os valores mais altos de dominância. A análise de correspondência canônica mostrou que a distribuição de *Gymnanthes klotzschiana*, *Ligustrum lucidum* e *Allophylus edulis* está relacionada à saturação do solo com água, enquanto *Matayba elaeagnoides* e *Ocotea puberula* estão correlacionadas com solos drenados. As espécies foram separadas em grupos de acordo com as características ambientais, indicando que a hidromorfia influencia o estabelecimento da comunidade florestal.

Palavras-chave: Floresta Atlântica; Floresta Ombrófila Mista; Gradiente de Água; Lençol Freático; Inundação

1 INTRODUCTION

Alluvial forests are recognized as diverse and dynamic terrestrial habitats that play a critical role in the ecological function of rivers (Canham et al., 2021). They are involved in the maintenance of watersheds, filtering sediments, and providing habitats for aquatic and terrestrial organisms (Yirigui et al., 2019). These environments, especially in urban areas, are described as heterogeneous systems (Steenberg, 2018), often subject to floods along rivers, in addition to natural and anthropogenic disturbances (Zacarias et al., 2012). Thus, the dynamics of water in the soil combined with flooding establish a vegetational mosaic, i.e., such factors define the distribution and diversity of tree species along a gradient perpendicular to the river (Pasdiora et al., 2021).

In Alluvial Mixed Ombrophilous Forest (MOF) environments, some forest species are characterized by the selectivity and adaptability in which they develop, which are conditioned to environmental variables, especially with hydromorphic soil characteristics, resulting in oxygen deficiency induced by flooding and the rise of the water table (Amendola et al., 2018). With this, species need to be evolutionarily adapted by changing their morphoanatomical and metabolic structures to obtain energy (Martins Bassaco et al., 2019). In this phytophysiognomy, *Gymnanthes klotzschiana* Müll. Arg, cited in several studies, is identified as a key species that holds an important role in the ecological balance of this vegetation (Kanieski et al., 2017; Longhi-Santos et al., 2019; Martins Bassaco et al., 2019). Furthermore, the presence and insertion of inappropriate exotic species in the urbanization of the urban MOF (such as *Ligustrum lucidum* W.T.Aiton), which are adapted to these factors, have invaded and modified the specific composition of the community (Fernandez et al., 2020), causing “self-degradation” in the forest.

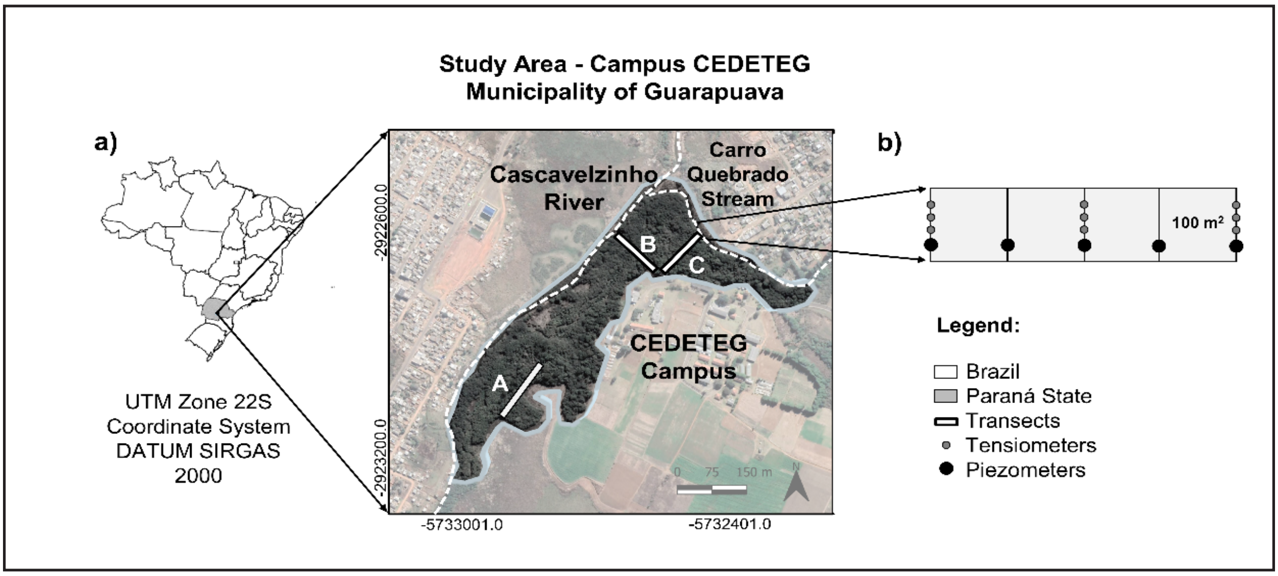
In this sense, urban Alluvial Mixed Ombrophilous Forest (MOF) environments, such as this one, are recognized as important for waterways conservation. However, they are threatened by anthropogenic activities since they are located in strategic areas of development. Thus, studies observing the structure, floristics, and phytosociology are considered relevant for understanding the biodiversity and distribution of species (Rahman et al., 2022), verifying the influence of water and edaphic factors in the establishment of arboreal vegetation.

The objectives of this study were established as follows: (1) to quantify different environmental variables, (2) to carry out a floristic and dendrometric inventory of tree vegetation, and (3) to verify the distribution pattern, i.e., the association of species in the forest fragment. Our interest is to answer the question: Is the influence of environmental variables affecting the distribution of tree species within the urban fragment of Mixed Alluvial Ombrophilous Forest?

2 MATERIAL AND METHODS

The study area is comprised of an 11.5 ha fragment of Mixed Alluvial Ombrophilous Forest, part of the Cascavelzinho River watershed (*Bacia Hidrográfica do Rio Cascavelzinho*, BHRC) and the *Carro Quebrado* Stream. It is located on the CEDETEG Campus (*Centro Educacional de Desenvolvimento Tecnológico de Guarapuava*) of the Midwestern State University (UNICENTRO) in Guarapuava, Paraná, Brazil (Figure 1a). The area corresponds to an altitude varying between 1,000 and 1,020 meters above sea level. The climate is classified as Humid Subtropical Mesothermal (Cfb). The predominant soil classes in the study area are the Latossolos Bruno, which are deeper and more structured, and hydromorphic soils of alluvial influence (A. L. Rodrigues et al., 2016).

Figure 1 –Study area (a) and Representation of the location of the piezometer and tensiometer installations (b) in an Urban Fragment of Alluvial Mixed Rain Forest in Guarapuava, Paraná, Brazil



Source: Authors (2024)

Three transects were allocated in the fragment as shown in Figure 1b (A: 15; B: 13; and C: 14 subunits); each subunit was measured as 10 m x 10 m (100 m²), starting from the riverbank towards the edge of the fragment (B and C) and from a wetland area (A). The floristic survey and the measurement of the Diameter at breast height (DBH) of trees were carried out considering individuals with DBH ≥ 5 cm.

Water and edaphic environmental variables were measured in each sample unit. The water variables identified were: variation of the water table and soil moisture. For this, during the period of one year, in each plot, the piezometric level of the soil was surveyed, monitoring the variation in the water table and the vertical oscillation of water in the soil. The water table was measured in piezometers installed on-site, and the piezometric level for each sample unit was determined by averaging the values obtained. Soil moisture was indirectly measured using tensiometers installed near each piezometer at 30, 60, and 100 cm depths.

The edaphic variables consisted of the soil penetration resistance analysis and the different variables from the physicochemical analysis data. Penetration resistance was measured at five places within each subunit using an electronic soil compaction penetrometer (PenetroLOG, model PLG 1020, Falker Automação Agrícola).

Deformed samples were collected to determine the gravimetric soil moisture. These samples were collected with a Dutch auger at depths of 0-20, 20-40, and 40-60 cm and, also, with five repetitions per sampling unit, near the collection places for penetration resistance. These samples were taken to the laboratory for weighing and then dried in an oven with mechanical air circulation at a temperature of 105 ºC for 48 hours. Also, in each sampling unit, three soil samples were collected at a depth of 0-20 cm using a Dutch auger. These samples were homogenized to compose a single sample for each sampling unit, directed to the determination of pH (in $CaCl_2$), Organic Matter (OM), base saturation percentage (V%), aluminum saturation (M%), besides the determination of the soil textural class.

The species abundance data were processed through the multivariate technique TWINSPAN (Two-way Indicator Species Analysis), verifying the occurrence of patterns in the distribution of species associated with the local environmental conditions. The analysis matrix was based on the density values (ind. ha^{-1}) of the species. For the analysis, eight variables were considered: pH, organic matter (OM), base saturation percentage (V%), aluminum saturation (M%), penetration resistance (PR), moisture taken together with penetration resistance (PR Humidity), piezometric level (PL), mean moisture measured by tensiometry (Humidity), and two vegetational variables: Shannon diversity index (H') and dominance (G). Thus, the species matrix was composed of 14 species of higher density (ind. ha^{-1}) (*G. klotzschiana*; *A. edulis*; *L. lucidum*; *S. terebenthifolius*; *I. thezzans*; *I. dumosa*; *P. myrtifolia*; *C. dinisi*; *C. decandra*; *V. megapotamica*; *Z. rhoifolium*; *M. elaeagnoides*, *O. puberula*, and dead trees) and the matrix with the environmental and vegetation characteristics was composed of ten variables. The variables that presented the highest association values in the correlation matrix and the principal axes were selected, in which the canonical correspondence analysis was performed. The canonical correspondence analysis was performed with the software Pc Ord for Windows, version 5.0 (Mccune et al., 2016).

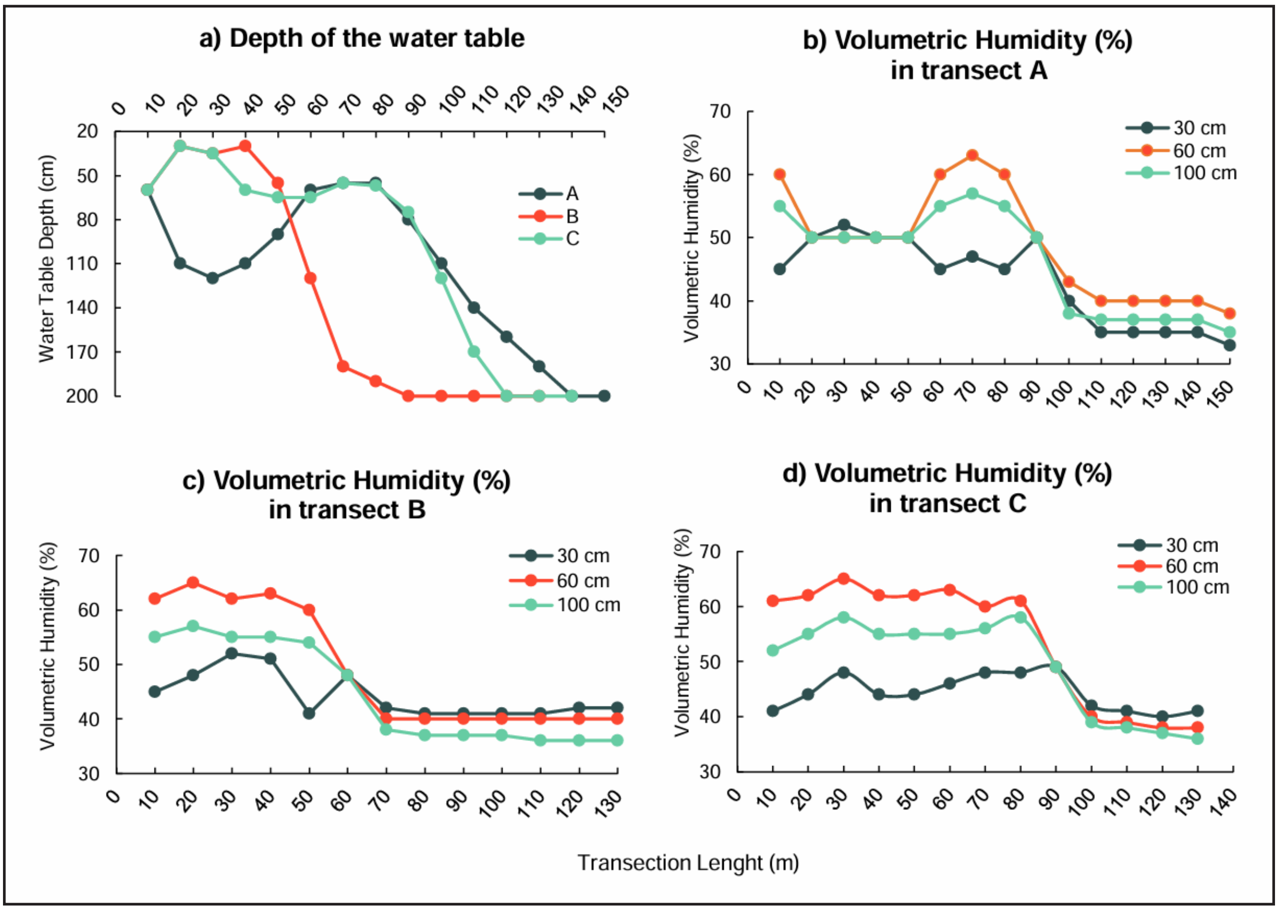
With the results of the groups formed, the calculations of the horizontal structure (phytosociology) were performed by the estimators Absolute (AD) and Relative Density (RD), Absolute (AF%) and Relative Frequency (RF%), Absolute (ADo) and Relative Dominance (RDo), Cover (CV), and Importance Value (IV). The ecological indices of Shannon-Weaver Diversity (H'), Simpson's Dominance (C), and Pielou's Equitability (J') were calculated using the R statistical programming language, with the use of the Vegan package (Oksanen et al., 2014).

3 RESULTS

3.1 Characterization of water table and soil moisture

Variations in the water table were observed among the different soil depths. On average, the greater the soil depth, the higher the soil moisture was; in transect "A" (80 m), the average annual water table was found to be 60 cm below the soil surface. Regarding transects "B" and "C", which were allocated in a water gradient perpendicular to the river, it was discovered that the sampling units located closer to the river presented a more superficial water table (Figure 2a).

Figure 2 – Average depth of the water table between 2013 and 2014 (a). Volumetric Humidity values (%) by tensiometry in transects A (b), B (c), and C (d)

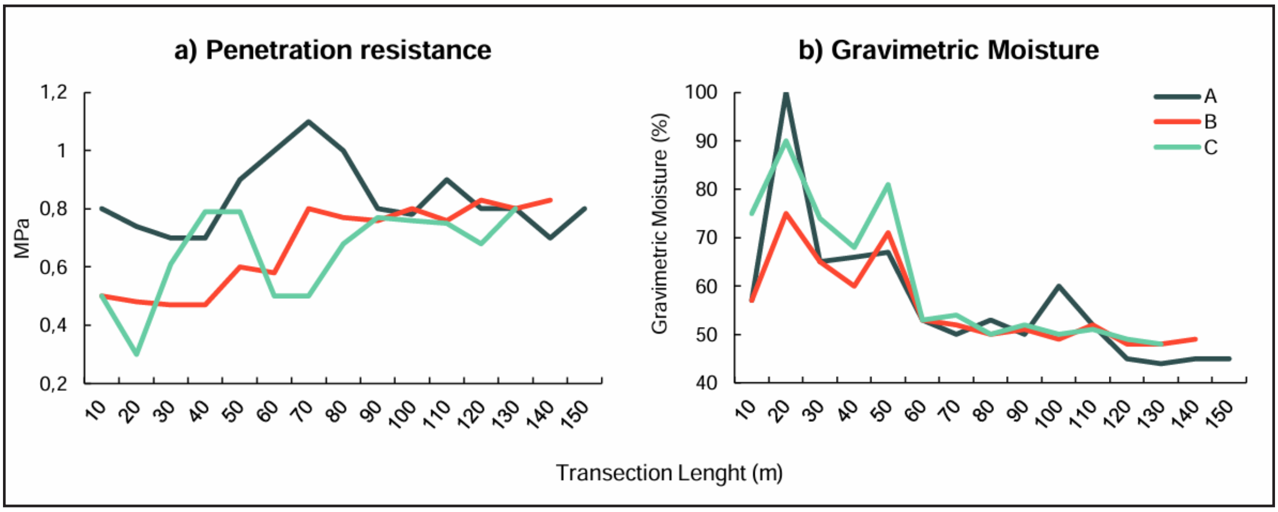


Source: Authors (2024)

The annual average soil moisture was found to present a dynamic variation very similar to the piezometer values. Some sampling units were observed to present values close to 70% moisture at 60 cm depth. This was evidenced in the sampling units between 60 and 80 m of transect “A” (Figure 2b), in the sampling units from 10 to 40 m of transect “B” (Figure 2c), and in the sampling units from 20 to 80 m of transect “C” (Figure 2d). The highest moisture values were recorded in the sampling units near the river and the lowest values in the areas of better drainage near the edges.

The analysis of soil penetration resistance showed a variation of 0.295 to 1.09 MPa in the 42 subunits. On average, the highest average value was obtained by the “A” transect, with a value of 0.826 MPa, followed by the “B” transect with an average value of 0.680, and the "C" transect with a value of 0.623 (Figure 3a). The same was observed with the gravimetric moisture (U%) in the deformed samples; higher values were obtained by transect A, reflecting higher soil water retention capacity. This was followed by transect C and then B, with greater variations in the first sub-units (50 m) of the three transects (Figure 3b).

Figure 3 – Penetration resistance values (Mpa) (a) and Gravimetric Moisture (U%) (b) in an Urban Alluvial Mixed Ombrophilous Forest fragment in Guarapuava, Paraná, Brazil



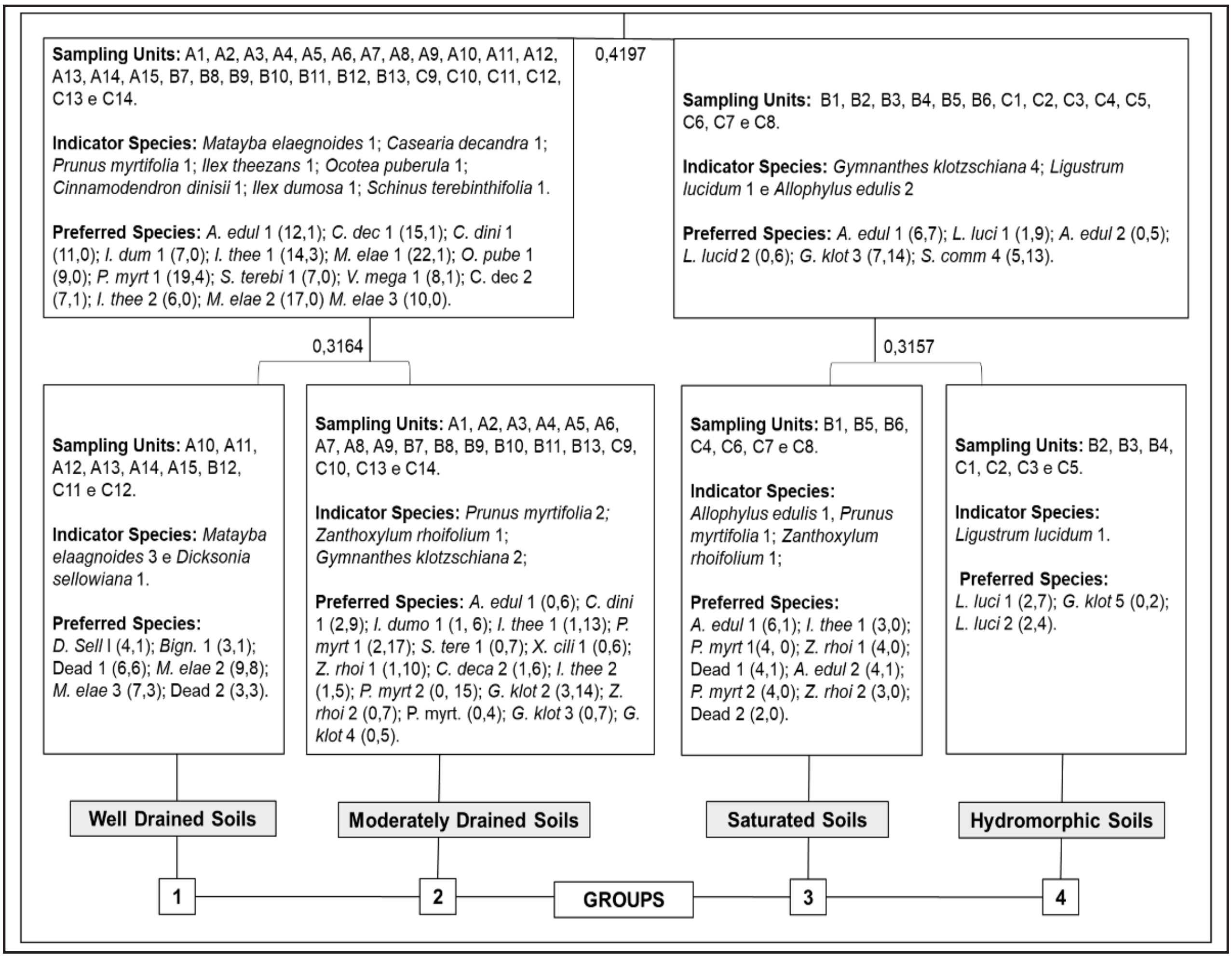
Source: Authors (2024)

3.2 Grouping Analysis

As a result, four groups were obtained: 1) well-drained soils; 2) moderately drained with intermediate characteristics between the groups; 3) soils with water saturation; and 4) soils with greater hydromorphy. The first division presented an eigenvalue of 0.4197. As this value is higher than 0.30, the two groups formed were divided, separating the sample units according to distinct characteristics (Figure 4).

The left side of the division was represented by the sampling units closer to the edge of the fragment. Presented as indicator species were *Matayba elaeagnoides*, *Casearia decandra*, *Prunus myrtifolia*, *Ilex theezans*, *Ocotea puberula*, *Cinnamodendron dinisii*, *Ilex* *dumosa*, and *Schinus terebinthifolia*, while the right side was represented by sampling units highly influenced by soil water saturation, with *Gymnanthes klotzschiana*, *Ligustrum lucidum*, and *Allophylus edulis* as indicator species, which generally occur in moist soils.

Figure 4 – Grouping analysis in the sampling units using the TWINSPAN technique in an Urban Alluvial Mixed Ombrophilous Forest fragment in Guarapuava, Paraná, Brazil



Source: Authors (2024)

The four groups were formed by the second and third divisions with eigenvalues of 0.3164 and 0.3157, respectively. The second division gave rise to the first two groups. The first group was composed of sample units located in the highest plots and with better soil drainage conditions. The sampling units of this group presented a piezometric average of 175 cm with the lowest water saturation when compared to the other groups. This group presented *Matayba elaeagnoides* and *Dicksonia sellowiana* as indicator species.

The second group was made up of plots with moderately drained soils with intermediate characteristics of the other groups, presenting a piezometric average of 140 cm with the water table closer to the soil surface. This grouping presented *Gymnanthes klotzschiana*, *Prunus myrtifolia*, and *Zanthoxylum rhoifolium* as indicator species. This hydric condition was proven to be more favorable for the development of the species since it presented a higher diversity.

The third division gave rise to groups 3 and 4, which are totally opposite to groups 1 and 2 in terms of drainage. The soils of the plots in these groups have difficulty draining, as they are located in the lower parts and have higher soil moisture indexes. The indicator species of this group were *Prunus myrtifolia*, *Zanthoxylum rhoifolium*, and *Allophylus edulis*, showing the development of these species in soils with less drainage. The fourth group, which had characteristics of soils with greater hydromorphy, presented *Ligustrum lucidum* as an invasive exotic species and *Gymnanthes klotzschiana* as a typical species representative of alluvial areas as preferred species.

3.3 Floristics, Phytosociology, and Ecological Indices

In the inventory, 904 individuals were sampled, 33 species distributed in 28 genera and 21 families. Among the botanical families with the largest number of individuals are Euphorbiaceae (44.55%), Sapindaceae (14.73%), Rosaceae (9.41%), Aquifoliaceae (6.44%). The families with the largest number of species were Myrtaceae (4), followed by Lauraceae (3) and Sapindaceae (3). The most abundant species, which occur in greater density (AD ind. ha^{-1}) among the groups, are *Gymnanthes klotzschiana*, *Matayba elaeagnoides*, *Prunus myrtifolia*, *Zanthoxylum rhoifolium*, *Casearia decandra*, *Ilex theezans*, *Ligustrum lucidum*, and *Allophylus edulis* (Table 1).

Table 1 – Relationship of families, species, and absolute density (AD ind. ha-1) among the groups in an Urban Alluvial Mixed Ombrophilous Forest fragment in Guarapuava, Paraná, Brazil

Family	Species	Absolute Density (AD ind. ha^{-1}) of the species among the groups			
		1	2	3	4
Anacardiaceae	*Lithraea molleoides* (Vell.) Engl.		10.5		
	Schinus terebinthifolia Raddi		52.6		
Aquifoliaceae	*Ilex dumosa* Reissek	11.1	110.5		
	Ilex theezans Mart. Ex Reissek	22.2	131.6	42.9	
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze		5.3		14.3
Bignoniaceae	*Adenocalymma album* (Aubl.) L.G. Lohmann		57.1		
	Jacaranda micrantha Cham.		26.3		
Canellaceae	*Cinnamodendron dinisii* Schwanke	55.6	84.2		
Celastraceae	*Monteverdia aquifolia* (Mart.) Biral		5.3		
Clethraceae	*Clethra scabra* Pers.		15.8		
Dicksoniaceae	*Dicksonia sellowiana* Hook.	55.6	5.3	28.6	
Erythroxylaceae	*Erythroxylum deciduum* A. St.-Hil.		5.3		
Euphorbiaceae	*Sapium glandulatum* (Vell.) Pax	11.1	10.5		
	Gymnanthes klotzschiana Müll.Arg	133.3	663.2	1,471.4	2,187.1
Fabaceae	*Mimosa scabrella* Benth.			28.6	
Lamiaceae	*Vitex megapotamica* (Spreng.) Moldenke	44.4	47.4	14.3	
Lauraceae	*Ocotea diospyrifolia* (Meisn.) Mez		10.5		
	Ocotea puberula (Rich.) Nees	55.6	68.4		
	Ocotea pulchella (Nees & Mart.) Mez		5.3		
Malvaceae	*Luehea divaricata* Mart. & Zucc.		15.8		
Myrtaceae	*Campomanesia guazumifolia* (Cambess. O.Berg.		5.3		
	Campomanesia xanthocarpa O.Berg		5.3		
	Eugenia pyriformis Cambess			14.3	
	Eugenia uniflora L.		5.3		
Oleaceae	*Ligustrum lucidum* W. T. Aiton	33.3	5.3	71.4	228.6
Rosaceae	*Prunus myrtifolia* (L.) Urb.	352.6	352.6	185.7	
Rutaceae	*Zanthoxylum rhoifolium* Lam.	11.1	136.8	171.4	14.3
Salicaceae	*Casearia decandra* Jacq.	55.6	126.3		42.9
	Xylosma ciliatifolia (Clos) Eichler		42.1	14.3	14.3
Sapindaceae	*Allophylus edulis* (A.St.-Hil. et al.) Hieron. ex Niederl.		31.6	200	57.1
	Cupania vernalis Cambess.		5.3		
	Matayba elaeagnoides Radlk.	644.44	215.8	28.6	
Solanaceae	*Solanum mauritianum* Scop.		10.5		
Dead species		111.1	57.9	100	57.2

*(1) drained; (2) intermediate characteristics; (3) saturated; and (4) hydromorphic soils. Shaded lines represent the species that occur in all four groups.

Source: Authors (2024)

The highest number of individuals (2,615.8 ind. ha^{-1}) and greatest dominance (42.69 m^2 ha^{-1}) are registered in group 4, while the lowest number of individuals (1,333.2 ind. ha^{-1}) and dominance (21 m^2 ha^{-1}) is registered in group 1, i.e., these estimators increase from areas of drained soils to areas of hydromorphic soils. The same happens with the average piezometric level for the sampling units, which also increases from the first to the second group.

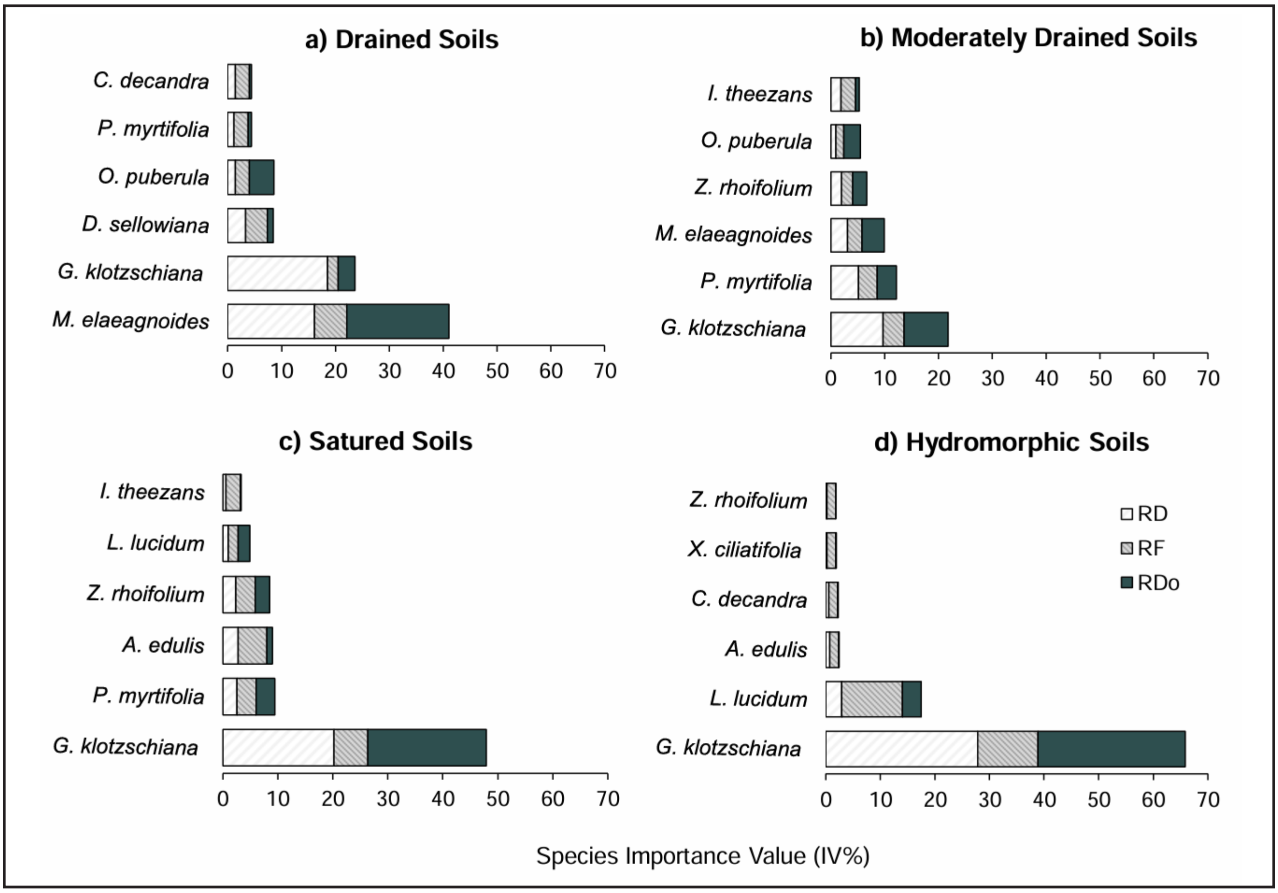
This same increasing pattern is observed regarding the phytosociological estimators in group 3 (47.88%), and it triples in group 4 (65.92%). The sampling units increase with the elevation of the piezometric level. Thus, the higher values of dominance (RDo) in sites with greater hydric influence are directly related to the greater quantity and size of individuals of *Gymnanthes klotzschiana*. This species presents the highest Importance Value (IV%) in groups 2, 3, and 4. It demonstrates a more equitable distribution in relation to other species with an importance value of 21.81% in group 2 (Figure 5).

When analyzing the annual average piezometric level of the groups, it is observed that *Gymnanthes klotzschiana* is dominant in environments with higher water saturation, although it occurs in all four groups formed. The samples also show that groups 3 and 4 suffer greater influence from the elevation of the water table, which results in selecting species specifically adapted for development.

A pattern different from *Gymnanthes klotzschiana* regarding the increase in piezometric levels is presented by *Matayba elaeagnoides*. The species estimator tends to decrease, having a preference for well-drained soils, with higher IV% and thus higher density (RD), frequency (RF), and dominance (RDo) estimators in group 1 (Figure 5).

Frequency values (FR) similar to those of *Gymnanthes klotzschiana* were presented by the exotic species *Ligustrum lucidum*, which is also found in all four groups formed. However, lower values of density (RD) and dominance (RDo) were shown in hydromorphic soil areas, and the species was recorded with the second highest IV% in group 4 (17.49%). Higher phytosociological estimators were exhibited by *Prunus* *myrtifolia* and *Allophylus edulis* in areas with characteristics intermediate between the groups. *Zanthoxylum rhoifolium*, although present in all four groups, showed higher descriptors for the saturated areas (Figure 5).

Figure 5 – Phytosociological Descriptors of species among the groups: well drained soils, moderately drained soils, saturated soils and hydromorphic soils in an Urban Alluvial Mixed Ombrophilous Forest fragment in Guarapuava, Paraná, Brazil



Source: Authors (2024)

It is noteworthy that only the highest densities (RD) were shown in well-drained soils (Group 1) by *Matayba elaeagnoides* and *Dicksonia sellowiana*, and the same occurred with the dominance (RDo) of *Ocotea puberula*. The highest density values (RD) and more uniform dominance values (RDo) were shown by almost all species in Group 2. In this case, the average annual piezometric level was 140 cm from the soil surface in group 2 (with the highest phytosociological descriptors).

The highest Shannon-Weaver diversity (H') value (2.51 nats ind^{-1}) was shown by Group 2, followed by group 1 (1.99 nats ind^{-1}), group 3 (1.54 nats ind^{-1}), and group 4 (0.70 nats ind^{-1}). The same distribution pattern was shown by Pielou equitability (J), with the equitability decreasing from the first groups (Group 1 and 2: 0.65) to the last ones (Group 3: 0.57 and 4: 0.40). Contrarily, dominance (C) increased from group 1 (0.25) and 2 (0.15) to group 3 (0.45) and 4 (0.36).

When better drainage conditions are present in soils (Group 1), higher diversity (H') and equitability (J) values are observed, and lower dominance (C) is noted. When the piezometric level increases, diversity and equitability decrease drastically; dominance, in turn, increases considerably (Groups 3 and 4). A relatively low value for the Pielou equitability index (J') (0.62) was resulted in for sampling units with higher water saturation (Groups 3 and 4).

3.4 Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis (CCA) resulted in a three-axis ordering, with eigenvalues for axis 1 of 0.444, for axis 2 of 0.208, and for axis 3 of 0.107, explaining 22.2%, 10.4%, and 5.4% of the total data variance, respectively. The analysis indicated that the ten environmental variables accounted for 38% of the variation in floristic composition and density within the forest fragment. Pearson's species-environment correlations were strong, with values of 0.912 (axis 1), 0.816 (axis 2), and 0.633 (axis 3), highlighting a significant relationship between environmental variables and vegetation parameters (Table 2).

Table 2 illustrates the coefficients of correlations between environmental variables and vegetational variables derived from CCA. Among the axis 1 variables, OM showed the lowest correlation value. The variables pH, V%, Humidity, PL, and G showed high positive correlations with axis 1, while PR Humidity also had a positive correlation but not as high. The variables M%, PR, and H' presented high negative correlations with axis 1. Regarding axis 2, the variable that correlated the most was H' negatively (Figure 6).

Table 2 – Coefficients of correlations between environmental variables and vegetational variables with the ordination axes resulting from the Canonical Correspondence Analysis (CCA) in an Urban Alluvial Mixed Ombrophilous Forest Fragment in Guarapuava, Paraná, Brazil

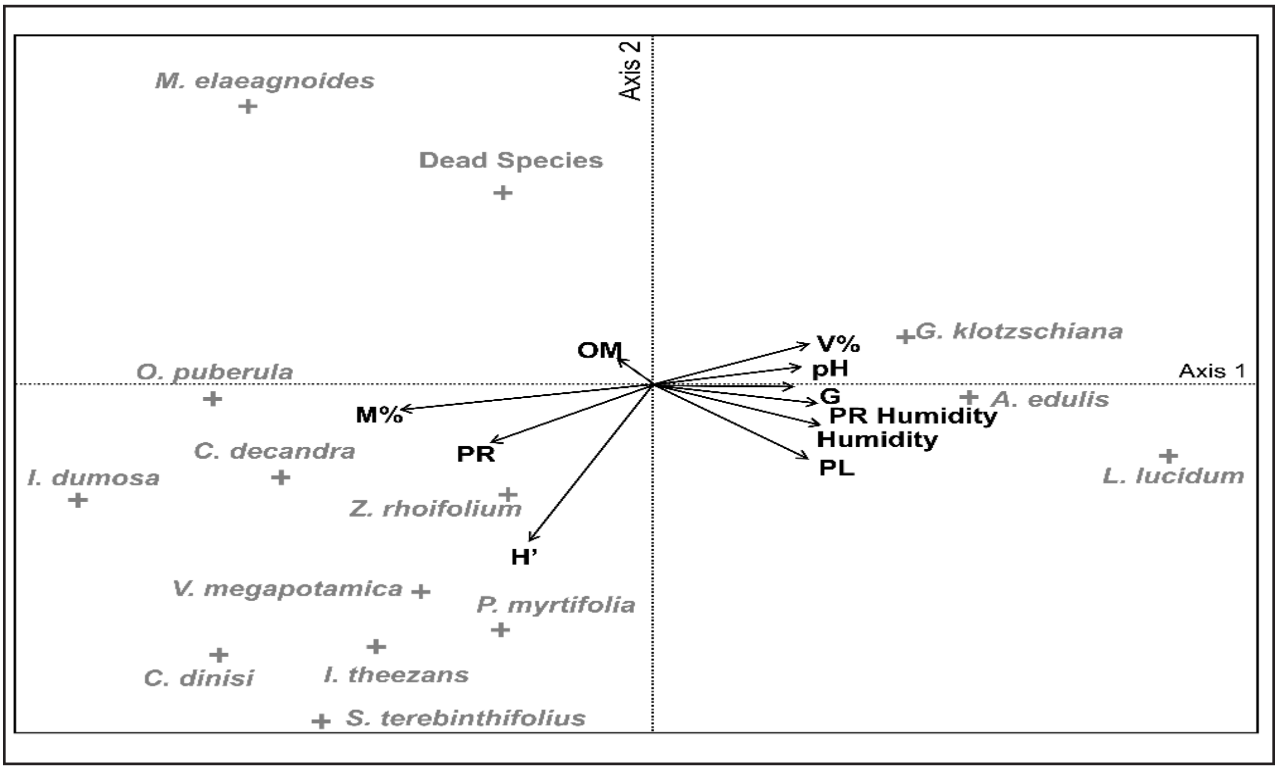
Variables	Axis 1	Axis 2	Axis 3
pH - hydrogen potential	0.731	0.036	-0.230
OM - organic matter	-0.176	-0.062	0.077
V% - base saturation	0.778	0.118	-0.236
M% - saturation by aluminum	-0.795	-0.089	0.267
PR - resistance to penetration	-0.551	-0.181	0.233
PR Humidity - Moisture taken together with the resistance to penetration	0.535	-0.058	0.068
PL - piezometric level	0.758	-0.275	0.141
Humidity - mean of moisture by tensiometry in 30, 60 and 100 cm	0.723	-0.150	-0.011
H’ - Shannon-Weaver diversity index	-0.578	-0.511	0.088
G - species dominance (ind. ha^{-1})	0.641	-0.006	-0.167

Source: Authors (2024)

It was demonstrated by the results that the species *Gymnanthes klotzschiana*, *Ligustrum lucidum*, and *Allophylus edulis*, as shown in Figure 6, present high correlations with axis 1. Moreover, the variables base saturation, pH, dominance, humidity, and piezometric level are positively associated with the occurrence of these species.

The diversity and aluminum saturation variables are highly related to the Penetration resistance (PR) variable, which is inversely represented when compared to the other variables. This factor is evident in the case of PR since the higher its values, the lower the humidity values are. The same happens with the aluminum saturation, which is inversely proportional to the base saturation and the pH. In turn, diversity (H’) is highly correlated with the greatest number of species (8).

Figure 6 – Graphical representation of the ordination resulting from the Canonical Correspondence Analysis of species and environmental variables in an Urban Alluvial Mixed Ombrophilous Forest fragment in Guarapuava, Paraná, Brazil



In which: pH = hydrogen potential; OM = organic matter; V% = base saturation; M% = saturation by aluminum; PR = resistance to penetration; PR Humidity = Moisture taken together with the resistance to penetration; PL = piezometric level; Humidity = mean of moisture by tensiometry in 30, 60 and 100 cm; H' = Shannon-Weaver diversity index; G = species dominance (ind. ha^{-1}).

Source: Authors (2024)

4 DISCUSSION

In the studied fragment of alluvial forest, the highest levels of water saturation are experienced by the sample units bordering the floodplain, with an average annual moisture content ranging from 35% to 70%. Other research has demonstrated that these wetlands are significant carbon reservoirs and that soil organic carbon stocks are enhanced by the occurrence of flooding periods (Yin et al., 2019). Flooding, in turn, causes rapid depletion of oxygen in the soil pores, leading to widespread changes in the soil's physicochemical properties and consequently, damage to plants (Thoms et al., 2005). The growth, activity, and survival of plants can be directly affected by these changes (Liu et al., 2015; Yu et al., 2015).

Consequently, selective pressure is exerted on species by humid microenvironments, influencing the composition and structure of forest formations, and causing changes in the soil, such as a decrease in O_2, accumulation of CO_2, and formation of toxic compounds (Duarte et al., 2020). As a result, the morphoanatomical and metabolic structures of species need to be "evolutionarily" changed to obtain energy (Martins Bassaco et al., 2019). The distribution of woody species in hydromorphic areas is made to depend on the adaptation strategies and selectivity of the species (Duarte et al., 2020).

In general, it has been shown by the study of floristics that Euphorbiaceae was the family with the highest number of individuals, which is common in alluvial environments (Aimi et al., 2017; Kieras et al., 2018; Loebens et al., 2018). *Gymnanthes klotzschiana* has been found to have adaptations to tolerate the stress of water saturation and can compose from 60 to 80% of the arboreal vegetation of this formation (Barddal et al., 2004; Guidini et al., 2014; Kanieski et al., 2017; Martins Bassaco et al., 2019). It has been shown by the phytosociological descriptors that this species tends to increase with the elevation of the piezometric level. Thus, it is considered that the highest values of basal area, in the sampling units with greater water influence, are directly related to the greater number of individuals of this species.

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Ligustrum lucidum is widely dispersed as an invasive alien species in the study area. The hydromorphic condition is adapted to by this species, with expressive phytosociological descriptors. Rapid growth is exhibited by this species, which can settle and survive in the shaded understory, and high phenotypic plasticity is possessed, allowing its dispersal in a wide range of environments (Ishii et al., 2021). The occurrence of this species in the study area is justified by the dispersal of seeds by rainwater, as well as by the numerous individuals that were inadequately introduced into the urban forests of the municipality. Additionally, it is dispersed by the local fauna, as it is a zoochorous species (Bilmayer et al., 2017; Fernandez et al., 2020). It is further corroborated by studies that water availability in the deep soil of small watersheds is lower in forests invaded by *Ligustrum lucidum* than in natural forests, suggesting reduced groundwater recharge. As a consequence, the flow may also be altered, reducing water supply services in dry seasons (Fernandez et al., 2020).

Most species were not related to more humid environments. In these places, there is less richness and greater dominance (C) of species, while in well-drained places, there is greater species richness and greater diversity (H'). These ecological indices indicate low overall diversity for the community, which is typical in alluvial environments affected by urbanization, consistent with findings from other studies (Barddal et al., 2004; Braga et al., 2019). This may be explained by the segmentation of the alluvial environment, restricted to a hydromorphic micro-environment, diversely to species poverty (Barddal et al., 2004).

Thus, the arboreal component is organized in a floristic-structural gradient form, in which the river flooding regime and the presence of zones of greater soil hydromorphism are relevant to the designation of a micro-environment, which influences the distribution of species (Loebens et al., 2018). And excess soil water saturation enables the development of species adapted to these environments (Martins Bassaco et al., 2019). Likewise, as proposed by Rodrigues et al., (2016), the occurrence of a water and edaphic gradient is evident, which reflects on the vegetation, with a higher concentration of nutrients in the sampling units close to the river. The base saturation is higher in these sampling units due to the greater deposition of sediments in the lower areas. Consequently, the pH is higher, and this behavior is inversely proportional to aluminum saturation in the soil (Tavares et al., 2019).

Therefore, it is indicated by these results that in more humid areas, the equitability of species decreases and so entails a greater dominance of species able to develop in these environments, justifying the presence of *Gymnanthes klotzschiana*, *Ligustrum lucidum*, and *Allophylus edulis*, common in these areas. In this sense, it is possible to deduce that these three species have characteristics capable of developing in soils with high water saturation. The relation of the basal area with these species is the result of the high density and size of the individuals of *Gymnanthes klotzschiana* present in these sampling units.

The canonical correspondence analysis showed that in alluvial environments with high water influence, continuous and practically exclusive populations are formed by *Gymnanthes klotzschiana*. The occurrence of *Allophylus edulis*, despite being more correlated with the water table level, also presents a distribution in sampling units with lower water incidence. It is indicated by studies that *Allophylus edulis* is associated with environments with short periods of inundation, which explains its greater abundance in temporarily flooded forests. While the occurrence of the species in forests flooded for long periods is conditioned by the occurrence of micro-environments protected from long floods (Duarte et al., 2020).

A canonical correspondence analysis supported the findings obtained through clustering analysis. *Gymnanthes klotzschiana*, *Ligustrum lucidum*, and *Allophylus edulis* were strongly correlated with variables showing higher values of V%, pH, basal area (G), moisture, and piezometric level. Conversely, species such as *Schinus terebinthifolius*, *Ilex theezans*, *Prunus myrtifolia*, *Cinnamodendron dinisi*, *Vitex megapotamica*, and *Zanthoxylum rhoifolium* showed a strong correlation with compacted soils, high penetration resistance values, and higher species diversity, which is justified by their presence in soil sample units with intermediate drainage characteristics.

Moreover, the presence of well-drained areas contributes to increased local diversity by favoring the establishment of species less tolerant to water saturation. On the other hand, *Matayba elaeagnoides*, *Ocotea puberula*, and dead trees showed an opposite pattern to the variables represented on axis 1. The occurrence of these species in areas farther from watercourses, away from direct influence of flooding events (Loebens et al., 2018), suggests a preference for soils with lower water saturation.

In conclusion, this research presents some limitations that could be addressed in future studies. Expanding the geographical scope, conducting long-term monitoring, including more detailed analyses of species in forest regeneration and plant-soil interactions, as well as further investigating the impact of anthropogenic activities and invasive species, are essential recommendations to deepen the understanding of ecological dynamics in these environments. These approaches may provide a more comprehensive and accurate view of alluvial forests, contributing to more effective conservation strategies.

4 CONCLUSIONS

Four groups were formed according to environmental characteristics based on density data. *Gymnanthes klotzschiana*, *Ligustrum lucidum* (a high-density invasive exotic species), and *Allophylus edulis* were predominant in the sampling units with greater water influence, while *Matayba elaeagnoides* and *Ocotea puberula* showed the highest indices in sampling units with better drainage conditions. The canonical correspondence analysis corroborated the results found through the groups technique. In view of this, it was observed that the environmental variables substantiated in this work influenced the establishment of species adapted to flood pulses, resulting in greater dominance, while conditions of greater soil drainage influenced a different establishment of species and greater diversity. Thus, indicating that hydromorphism exerts influence on the establishment of the forest community.

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