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Influence of edaphic variables on predominance of forest species after selective logging in the Amazonian biome

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ABSTRACT: The floristic composition of fragmented landscapes can significantly influence their potential resilience and regeneration in the event of natural or anthropogenic disturbance. This study aimed to characterize soil influence on tree composition and determine the relationship of edaphic variables to the predominant species in a part of the Amazon Forest under selective logging. The fixed area method was applied to clusters of 10 × 250 m, considering trees with a DBH ≥ 10 cm. The 20 highest-importance species of the fragment composed the vegetation matrix. For the characterization of the forest soil, three soil samples composed of subunits were collected, and the edaphic variables were represented by pH H_2O, pH $CaCl_2$, P, K, Ca, Ca+Mg, Mg, Al, H, OM, SB, CEC, V%, Ca%, Mg% and TOC. Despite the low tree density found in the study, the high basal area suggests that the species present are tolerant to changes and environmental disturbances. The tree component is dominated by species characteristic of degraded environments, where the soil's chemical composition explains most of the species variation. *Qualea paraensis*, *Bellucia grossularioides*, *Cheiloclinium cognatum*, *Diplotropis purpurea* and *Erisma uncinatum* show great potential for use in degraded forest ecosystems in the Amazon Biome.
Keywords: anthropic disruption; deforestation; ecological requirements; forest ecosystem recovery; tropical rainforest.

Influência das variáveis edáficas na predominância de espécies florestais após exploração seletiva no bioma amazônico

RESUMO: A composição florística de paisagens fragmentadas pode influenciar significativamente o seu potencial de resiliência e regeneração em caso de perturbação natural ou antropogénica. O objetivo deste trabalho foi caracterizar a influencia do solo na composição arbórea e determinar a relação das variáveis edáficas com as espécies predominantes em uma parte da Floresta Amazônica sob exploração madeireira seletiva. O método de área fixa foi aplicado para aglomerados de 10 X 250 m, considerando arvores com DAP ≥ 10 cm. As 20 espécies de maior importância do fragmento compuseram a matriz vegetal. Para a caracterização do solo florestal foram coletadas três amostras de solo compostas por subunidades e as variáveis edáficas foram representadas por pHH_2O, $pHCaCl_2$, P, K, Ca, Ca+Mg, Mg, Al, H, OM, SB, CEC, V%, Ca%, Mg%, e TOC. Apesar da baixa densidade arbórea encontrada no estudo, a elevada área basal sugere que as espécies presentes são tolerantes a mudanças e pertubações ambientais. O componente arbóreo é dominado por espécies características de ambientes degradados, onde a composição química do solo explica a maior parte da variação das espécies. As espécies *Qualea paraensis*, *Bellucia grossularioides*, *Cheiloclinium cognatum*, *Diplotropis purpurea* e *Erisma uncinatum* apresentam grande potencial para utilização em ecossistemas florestais degradados na Amazónia.
Palavras-chave: perturbação antrópica; desmatamento; requerimentos ecológicos; recuperação do ecossistema florestal; floresta tropical.

1. INTRODUCTION

The world has a total forest area of 4.06 billion hectares, of which almost 45 percent are tropical; therefore, it is estimated that 420 million ha has been lost worldwide through deforestation since 1990 (FAO, 2020). Factors such as selective exploitation of forest products, deforestation for urbanization, the creation of infrastructures, or land expansion for agricultural activities, as well as the spread of fire by natural or human causes, contribute to the great loss of humid tropical forests (CABALLERO et al., 2023; PENDRILL et al., 2019). Brazil has the largest rainforest cover, which includes almost two-thirds of the Amazon, and the exploitation of these forests began more than three centuries ago.

Throughout history, the Amazon ecosystem has been degraded for human industrial activities, mainly logging, with great socio-economic importance for the region (ALBERT et al., 2023; GIULIETTI et al., 2019). However, these anthropic interventions modify the natural functioning of the physical environmental systems and their components, changing the dynamics and characteristics of the remaining adult vegetation, which hinders the natural regeneration of the soil and significantly alters the climate.

Forest degradation affects above-ground and below-ground systems and may influence soil physicochemical properties. For instance, Jiang et al. (2023) concluded that changes in soil processes may, in turn, feed back to the regrowth or succession of degraded rainforest ecosystems.

The increasing magnitude of above-ground forest degradation influences soil processes, and it is not yet clear what the specific factors affecting floristic composition related to the topographic gradient, soil physical and chemical composition, and even ecological processes behind the distribution of tree diversity (AGUIAR et al., 2019). On the other hand, the analysis of the relationship between floristic diversity and soil characteristics, based on phytosociological parameters, allows the detection of the influence of environmental conditions on the structure of the community and its populations (ELIAS et al., 2019). Thus, it is possible to make inferences about these ecosystems' biological conservation and edaphic characteristics and to have subsidies for their recovery.

In this sense, the objective of the present study was to characterize the relationship of the edaphic variables to the forest species predominant in the fragment and, along these lines, to identify and recommend species with better potential for use in the recovery of Amazonian ecosystems under the effect of selective exploitation.

2. MATERIAL AND METHODS

2.1. Study site and sampling plot characteristics

A floristic and structural survey was conducted in a fragment that suffered the effects of selective logging in the 1990s. The 32.98-ha fragment is located in the field of the Submontane Seasonal Semi-deciduous Forest from Amazon Biome (Instituto Nacional de Pesquisas Espaciais [INPE], 2020), in the municipality of Tapurah, Mato Grosso, Brazil (12°28'5.67" S; 56°33'32.14" W). The climate in the region is Am type, with a short dry winter, high annual rainfall of approximately 3,000 mm. year^{-1}, and an average annual temperature of 25°C (ALVARES et al., 2013).

The sampling scheme comprised five 10 m x 250 m clusters systematically distributed in the fragment, each subdivided into five 10 m x 50 m subunits, with a 15 m border (Figure 1). The largest size of the clusters respected the greatest variation gradient of the forest. All trees with a diameter at breast height (DBH) greater than or equal to 10 cm were measured (Tables 1 and 2).

Botanical identification was carried out in the field, and when this was not possible, botanical material of the species was collected for taxonomic analysis and identification at the herbarium of the Federal University of Mato Grosso. The delimitation of the families followed the Angiosperm Phylogeny Group IV [APG IV] classification system (2016) (APG, 2016), and all species nomenclature was according to the List of Species of Flora of Brazil (BGF, 2015).

The vegetation matrix was composed of the density of the 20 species with the highest importance value of the fragment (Appendices S1 and S2) in the 25 sample subunits studied. Five simple soil samples were collected at depths 5, 25 and 50 cm to characterize the forest soil, forming three samples composed of sample subunits (Appendix S3).

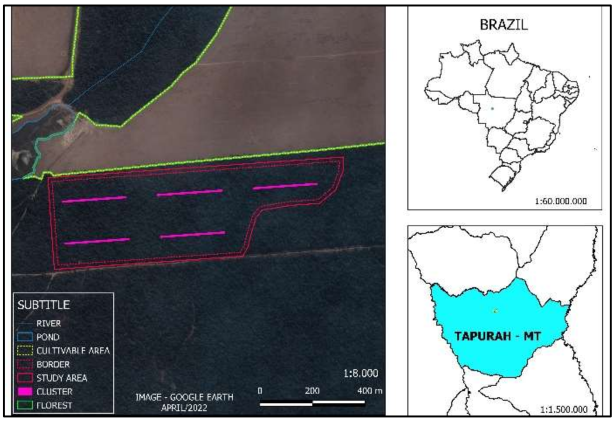

Figure 1. Allocation and scheme of sample units used to study the Seasonal Semideciduous Forest fragment under the influence of selective logging, Amazonian Biome.

Figura 1. Localização e esquema das unidades amostrais utilizadas para o estudo do fragmento de Floresta Estacional Semidecidual sob influência da extração seletiva de madeira, Bioma Amazônico.

Table 1. Descriptive characteristics of the sample subunits surveyed in a forest fragment under selective logging, Amazonian Biome (Families, Species, Trees, and N).

Tabela 1. Características descritivas das subunidades amostrais pesquisadas, em fragmento florestal sob influência de exploração madeireira seletiva, Bioma Amazônico (Famílias, Espécies, Árvores e N).

S	Families	Species	Trees	N
1	7	12	17	340
2	9	17	21	420
3	11	16	20	400
4	9	14	21	420
5	18	23	29	580
6	12	18	29	580
7	16	20	26	520
8	11	15	24	480
9	13	15	20	400
10	11	16	23	460
11	10	16	23	460
12	11	18	22	440
13	10	15	23	460
14	10	15	19	380
15	9	11	18	360
16	9	12	17	340
17	17	21	35	700
18	11	16	25	500
19	14	20	24	480
20	11	14	28	560
21	11	15	20	400
22	12	15	20	400
23	10	13	23	460
24	11	14	24	480
25	10	13	24	480
Total			575	
Average			23	460

where: S - sample subunits; N - density per hectare. Adapted from Rocha et al. (2017).

Table 2. Descriptive characteristics of the sample subunits surveyed, in a forest fragment under selective logging influence, Amazonian Biome (Dead trees, $\overline{\text{DBH}}$, max DBH, and G).
Tabela 2. Características descritivas das subunidades amostrais pesquisadas, em fragmento florestal sob influência de exploração madeireira seletiva, Bioma Amazônico (Dead trees, $\overline{\text{DBH}}$, max DBH, and G).

S	Dead trees	$\overline{\text{DBH}}$	max DBH	G
1	1	16.26	30.94	24.39
2	0	21.99	71.62	76.61
3	1	24.37	61.12	83.83
4	1	19.72	42.02	48.20
5	2	21.55	57.30	83.45
6	0	17.43	50.93	53.02
7	1	16.90	37.24	44.31
8	1	18.87	30.72	43.64
9	0	17.86	32.37	34.49
10	0	25.45	43.42	85.28
11	1	16.21	33.84	33.46
12	0	17.90	57.71	46.23
13	1	14.23	23.87	24.60
14	0	16.29	24.83	26.60
15	1	14.24	31.83	20.30
16	2	21.42	43.61	46.03
17	1	19.15	49.78	81.15
18	0	23.70	57.23	85.57
19	0	18.37	38.36	47.57
20	2	22.49	50.13	86.55
21	0	21.43	48.38	57.02
22	0	19.67	42.88	46.18
23	0	25.12	73.02	104.73
24	1	25.86	71.94	107.61
25	0	19.81	47.59	56.42
Total	16			72.36
Average		19.85	46.11	57.89

where: S - sample subunits; DBH - diameter at breast height, cm; max DBH – maximum DBH, cm; G - basal area per hectare, m² per ha. Adapted from Rocha et al. (2017).

The matrix with the edaphic variables analyzed was homogenized by the logarithmic transformation [*ln(a+1)*], especially recommended for soil nutrient data to reduce the variation in the scale of the data (PALMER, 1993). The construction of the matrix of the edaphic variables was carried out through a preliminary analysis to identify similar variables between sample subunits. Sampling subunits that had no influence were discarded. For that, the R *software*, the bpca package, was used.

Canonical analysis requires the assumption that the number of rows must be less than the number of columns ($n \leq p$) and the rank of the data matrix must be less than the number of rows minus 1 (n-1). Thus, as a first step, Principal Component Analysis (PCA) was performed with the 31 variables of the soil analysis for the sample subunits in the three depths to simplify the database. The variables that showed Pearson's correlation greater than 0.85 and influenced the analysis were selected. The variables selected in the first step were pH in water (pH H_2O) and chlorine (pH $CaCl_2$), phosphorus (P), potassium (K), calcium (Ca), calcium and magnesium (Ca + Mg), magnesium (Mg), aluminum (Al), hydrogen (H), organic matter (OM), the sum of bases (SB), cation exchange capacity (CEC), base saturation (V%), calcium (Ca%), magnesium (Mg%) and total organic carbon (TOC), at depths of 5 and 50 cm. Then, to meet the assumption of canonical analyses, a new simplification analysis was carried out in which the edaphic variables were represented by pH H_2O, pH $CaCl_2$, P, K, Ca, Ca + Mg, Mg, Al, H, OM, SB, CEC, V%, Ca%, Mg% and TOC, only at depths of 5 cm.

Before canonical analyses, the matrices of vegetation and edaphic variables were standardized using the Hellinger transformation, proposed by Legendre and Gallagher (2001). The correlation between vegetation data and environmental data was carried out through the Canonical Correlation Analysis (CCorA), which allowed confirmation of whether soil nutrients influence the presence of tree species. Finally, a redundancy analysis (RDA) was performed to assess which edaphic variables had the greatest influence on the arboreal species. The R software was used for the CCorA and RDA, with the ade4, vegan, packfor, MASS, ellipse and FactoMineR packages.

3. RESULTS

A representation of the 25 sample subunits (S) at depths 5 cm (A), 25 cm (B) and 50 cm (C) for the two main components, Dim1 and Dim2, which explain 66.3% of the variation in the data (Figure 2). The eigenvalue for the first dimension – Dim1 – is 0.419, that is, the first component explains 41.9% of the total variance. Similarly, the second component explains 24.4% of the total variance.

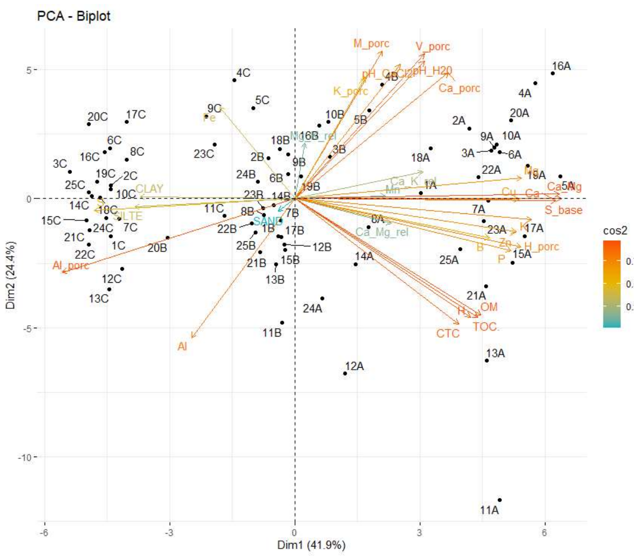

Figure 2. Ordering axes produced by the analysis of the principal components, in a forest fragment under the influence of selective logging at a depth of 5 cm (A), 25 cm (B) and 50 cm (C), Amazonian Biome.
Figura 2. Eixos de ordenação produzidos pela análise dos componentes principais, em um fragmento florestal sob influencia de exploração madeireira seletiva nas profundidades de 5 cm (A), 25 cm (B) e 50 cm (C), Bioma Amazônico.

The soil samples close to the origin - samples at a depth of 25 cm (B) - were the least influential samples in the analysis. These are points with eigenvectors ("scores") practically null for the two axes, indicating that the nutrients present in these samples were more homogeneous. Therefore, these samples were removed from the analysis. To continue the study, the PCA was again performed to meet the criteria that the number of rows is less than the number of columns ($n \leq p$) and the rank of the data matrix is less than the number of rows minus 1 ($n-1$). The variables with the greatest influence in the analysis and those with Pearson's correlation greater than 0.85 were chosen. Figure 3 is the representation of the 25 S at depths 5 cm (A) and 50 cm (C) for the two main components, which explain 89.9% of the data variation with the selected variables pH H_2O, pH $CaCl_2$, P, K, Ca, Ca+Mg, Mg, Al, H, MO, SB, CEC, V%, Ca%, Mg% and TOC. The first component explains 57.6% of the total variance, while the second component explains 32.2% of the total variance.

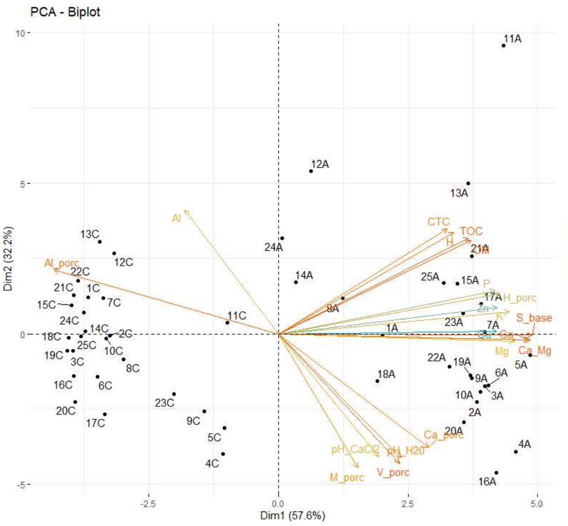

Figure 3. Ordering axes produced by analyzing the principal components in a forest fragment under selective logging influence at a depth of 5 cm (A) and 50 cm (C), Amazonian Biome.
Figura 3. Eixos de ordenação produzidos pela análise dos componentes principais, em um fragmento florestal sob influência de exploração madeireira seletiva, nas profundidades de 5 cm (A) e 50 cm (C), Bioma Amazônico.

Samples at a depth of 50 cm (C) showed little association with the edaphic variables analyzed. As illustrated in Figure 3 above, except for Al% and Al, samples at a depth of 50 cm are on the opposite side of the axes of the variables. Therefore, samples from a depth of 50 cm (C) were removed from the analysis.

The vegetation matrices (Y) and edaphic variables (X) presented ranks 20 and 13 for CCorA, respectively. Hence, they accepted the criterion that the rank of the matrix must be less than the number of lines minus one, *max (20.13) ≤ 25-1*. The variability of edaphic variables explains 80% of the variability of species ($R^2X|Y = 0.80$), while the inverse is weak ($R^2X|Y = 0.52$).

The greater the vector length, the more influential it will be for the analysis (BELLIER, 2012). In this context, it can be concluded that the species *Vochysia vismiifolia* Spruce ex Warm. (Y4), *Pseudolmedia laevigata* Trécul (Y6), *Ocotea acutangula* (Miq.) Mez (Y9) and *Helicostylis tomentosa* (Poepp. & Endl.) Rusby (Y19), and the edaphic variables phosphorus (X3), calcium and magnesium (X5), calcium (X6) and sum of bases (X11), are the most influential for CCorA (Figures 4 and 5).

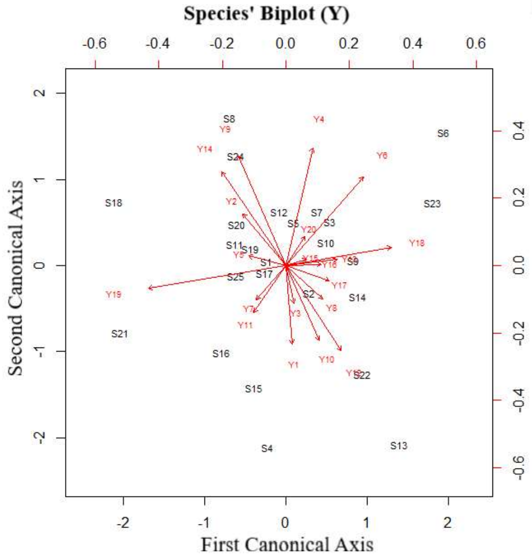

Figure 4. Biplot built by canonical correlation analysis (CCorA) of the 20 species with the highest importance value (Y), in a forest fragment under the influence of selective logging, Amazonian Biome.
Figura 4. Biplot construído por analise de correlação canónica (CCorA) das 20 espécies com maior valor de importância (Y), em fragmento florestal sob influência de exploração madeireira seletiva, Bioma Amazônico.

Tapirira guianensis Aubl. (Y15) was located closest to the origin, making it the least influential in the analysis. Only ten individuals of the species were sampled, and they were distributed across all quadrants – S1, S4, S5, S7, S9, S10, S12, S19, and S22 – the vector of the species remaining close to S9, which has the largest number of individuals (Figure 4). The closer the point of the species to that of S, the more associated they are. The individual with the highest DBH of the species *Inga* sp. 3 (Y12) occurs on the S22.

The calcium saturation variable (X14) is isolated together with the phosphorus variable (X3), and these variables are representative of the sample subunits present in this quadrant. Note that S3, S5 and S10 are the most associated for calcium saturation (X14) and S6 for phosphorus (X3). The highest levels of phosphorus (X3), 2.3 mg dm^{-3}, are found in S6 and S11, justifying the variable vector being very close to the first canonical axis (Figure 5).

The variables closest to the origin, organic matter (X10), base saturation (X13) and total organic carbon (X16), were the least influential in the analysis. This suggests that these variables were homogeneous in the analysis. Still, the S with the highest levels of organic matter (X10) and, consequently, total organic carbon (X16), are in opposite quadrants, 64.9 g dm^{-3} of organic matter and 38.6 g kg^{-1} of total organic carbon in S11 and 44.5 g dm^{-3} of organic matter and 26.2 g kg^{-1} of total organic carbon in S13, which may also have forced the variable to be close to the origin (Figure 4).

The coefficient of determination (R^2) and adjusted coefficient of determination (R^2_a) calculated for the RDA among the 20 species with the highest importance value and the edaphic variables were 0.69 and 0.07, respectively. The first three canonical axes together explain 33.39% of the total accumulated variance in the weighted average of the 20 species in relation to the edaphic variables analyzed, with the first axis accounting for 12.34%. In the present study, the proportion of the total variance of the response data explained by the RDA corresponded to 48.29%.

In both Figure 6 and Figure 7, the importance of the chlorine pH variable (X2) in the dispersion of S along the first axis and the magnesium variable (X7) on the second axis can be verified.

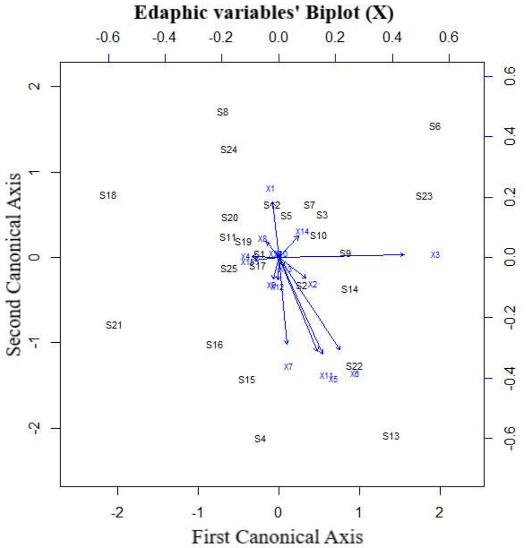

Figure 5. Biplot built by the canonical correlation analysis (CCorA) of the edaphic variables (X), in a forest fragment under the influence of selective logging, Amazonian Biome.
Figura 5. Biplot construído pela análise de correlação canônica (CCorA) das variáveis edáficas (X), em fragmento florestal sob influência de exploração madeireira seletiva, Bioma Amazônico.

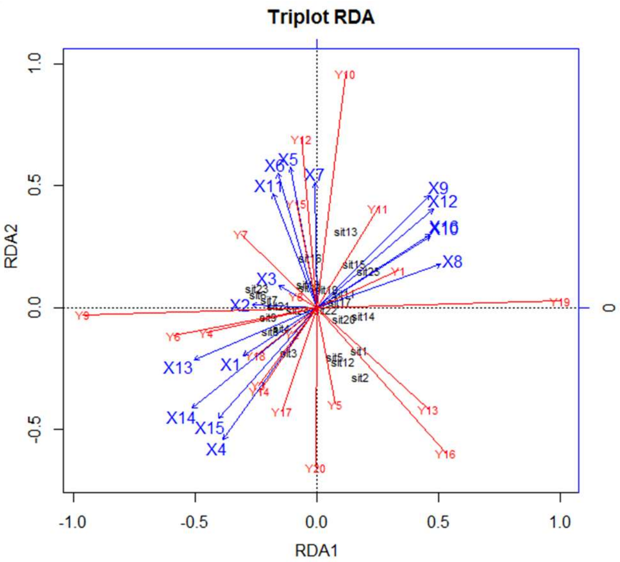

Figure 6. Distance triplot (scaling 1) constructed by redundancy analysis (RDA) with eigenvectors of the 20 species with the highest importance value (Y) and edaphic variables (X) after the transformation of hellinger, in a forest fragment under the influence of selective logging, Amazonian Biome.
Figura 6. Triplot de distância (escala 1) construído por analise de redundância (RDA) com autovetores das 20 especies com maior valor de importância (Y) e variáveis edáficas (X) apos a transformação de hellinger, em um fragmento florestal sob influencia de exploração madeireira seletiva, Bioma Amazônico

In both figures, the variables occur along the first and second axes, respectively. The points of the variables hydrogen (X9), organic matter (X10), cation exchange capacity (X12) and total organic carbon (X16) are very close, representing that they are highly correlated (Figure 6). Such behavior is also observed between the variables calcium and magnesium (X5), calcium (X6) and the sum of bases (X11), and between calcium saturation (X14) and magnesium saturation (X15).

Pouteria guianensis Aubl. (Y5), *Erisma uncinatum* Warm. (Y13) and *Diplotropis purpurea* (Rich.) Amshoff (Y16) are associated with each other (Figure 7), late secondary species (Appendices S1 and S2), and related to S1, S2, S5, S12, S14, S20 and S22, which are not characterized by any edaphic variable. These species, together with *Bellucia grossularioides* (L.) Triana (Y17) and *Cheiloclinium cognatum* (Miers) A.C.Sm. (Y20), are not correlated with any edaphic variable, indicating that they are related to intermediate ecological conditions.

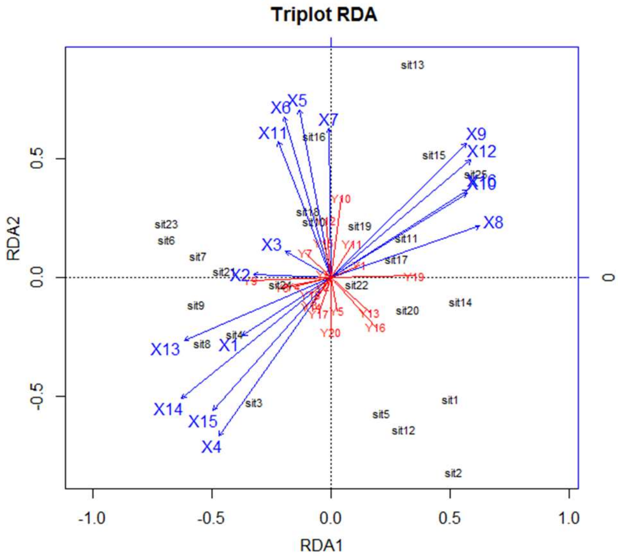

Figure 7. Correlation triplot (scaling 2) constructed by redundancy analysis (RDA) with eigenvectors of the 20 species with the highest importance value (Y) and edaphic variables (X) after the transformation of hellinger, in a forest fragment under the influence of selective logging, Amazonian Biome.
Figura 7. Triplot de correlação (escala 2) construído por analise de redundância (RDA) com autovetores das 20 espécies com maior valor de importância (Y) e variáveis edáficas (X) após a transformação de hellinger, em fragmento florestal sob influência de exploração madeireira seletiva, Bioma Amazônico.

Qualea paraensis Ducke (Y1) is correlated with the variables aluminum (X8), organic matter (X10) and total organic carbon (X16) and associated with S11, S15, S17, S19 and S25, of which S11 and S15 suffer edge effect. With the exception of *O. acutangula* (Y9), *Tachigali vulgaris* L.G.Silva & H.C.Lima (Y10), *Inga* sp. 3 (Y12), *D. purpurea* (Y16), *H. tomentosa* (Y19) and *C. cognatum* (Y20), the other species are close to their origin, indicating that they are well distributed over the forest fragment.

4. DISCUSSION

The existence of distribution patterns associated with edaphic variables suggests that tropical forest species specialize in different parts of environmental gradients. The edaphic variables used partially explain the floristic-structural variations of the forest fragment, and the chemical composition of the soil may act as an environmental filter on smaller spatial scales. The remaining variance may be associated with unrecorded environmental variables, indicating that multiple rather than single environmental factors explain the distribution of tropical tree species (TOLEDO et al., 2012).

The formation of a distinct group was not observed (Figures 6 and 7). In general, there are no sharp limits in an environmental gradient and, probably, species more tolerant to changes showed a less evident distribution pattern (RODRIGUES et al., 2007; SILVA et al., 2024). On the other hand, the richness of the species is linked to soil fertility, indicating that more species occur when soil conditions are good (van der SANDE et al., 2018; BARROS et al., 2020).

Although this study revealed a low tree density, the high basal area suggests that the species present are tolerant to changes and disturbances resulting from tree cutting (Tables 1 and 2). This increase in the basal area indicates that the species effectively exploited favorable conditions, such as increased light availability following canopy opening after forest exploitation. It is important to consider that other factors, in addition to solar radiation, such as physiological conditions, phenological events, degrees of disturbance in the forest, predation, mortality, and recruitment, also influence the greater growth of these species (AGUIAR et al., 2019)

The OM was also high (Appendix S3). The accumulation of OM in the superficial horizon is probably due to the greater biomass from the residues of the exploitation and root intensity. This process feeds back, that is, the permanence of species characteristic of the environment is favored by the cycle. However, OM contributed the least to the structuring of variables in the multivariate analysis due to the homogeneous condition of organic matter in the soil (Figure 5). This is consistent with van der Sande et al. (2018), who argue that OM should increase with litter quantity after logging or natural treefall because this represents organic matter input and decrease with litter quality because more palatable leaves speed up decomposition.

P values are associated with the organic cycle since there is a relationship between the P and the OM levels. One of the most limiting factors for land use is the low levels of P (FEARNSIDE (2020), and Jakovac et al. (2015) after collecting samples for soil chemical and physical analysis in the Amazon Secondary Forest, observed that the soils in general low fertility, low pH, low P availability and high aluminum content which affects the recovery of forest structure related to management intensity, soil texture and soil acidity.

On the other hand, the literature suggests that rhizosphere microorganisms might play an important role in driving and regulating the activation of soil nitrogen (N) and phosphorus (P) (CAI et al., 2023). Although our study did not directly investigate this interaction, the species that appear to benefit from these conditions include *Q. paraensis* (Y1) and *Sterigmapetalum obovatum* Kuhlm. (Y11), which exhibits low levels of P and high levels of OM; and the species *Xylopia* sp. 1 with low levels of P (Figure 7).

Small SB values were observed regarding the relationship between SB and OM, ranging from 0.3 to 0.6 $cmol_c$ dm^{-3}. This indicates a potentially resource-limited environment due to site saturation, which may promote severe competition. The only species that correlated with SB in the study was *Xylopia* sp. 1 (Figure 7). This observation suggests that, although rhizosphere interactions were not directly examined, they may influence nutrient availability and competition among species.

High levels of Al found in this study, between 0.7 and 2.0 $cmol_c$ dm^{-3}, corroborate other studies that suggest a tendency to lower P with the increase of Al concentrations. In disturbed Amazonian forests, conditions of high levels of Fe and Al in the soils are common. This could also lead to P restriction for plants and the productive or natural environment in the Amazon Biome (FINK et al., 2016). The only species that positively correlated with Al were *Q. paraensis* (Y1) and *H. tomentosa* (Y19).

Qualea genus presents generalist species, which are not very demanding regarding the variation of soil edaphic factors, which have high growth rates and dispersion potential, and a high degree of tolerance to different environments (FERREIRA et al., 2017). It is worth emphasizing that the species and the correlation with aluminum occurred in subunits that suffer from edge effects. In fact, to characterize the species in relation to their preferred habitat, it is necessary for the trends presented by the species in a study to be observed elsewhere (ROCHA et al., 2015), but for the *Q. paraensis* species a similar behavior was observed.

Variance not explained by the edaphic variables used (“noise”) did not compromise the results, since the correlations were high and significant. According to Ter Braak (1987), “noise” can be considered common in vegetation data, mainly in very heterogeneous areas, as is the case here. This high remaining variance is expected in ordering ecological data, given the complexity of the factors involved in determining the floristic and structural composition of plant formations (LEGENDRE; GALLAGHER, 2001). In addition, the first unrestricted eigenvalue (Dim1) is relatively small, meaning it has no important residual structure of the response data.

A reasonable amount of variance not explained by environmental variables can occur due to the stochasticity of the phenomena of establishment and growth of species, or even the non-use of important variables, which are not always perceptible or measurable, such as those associated with the availability of light and dispersion of species (MACHADO et al., 2008). The studied fragment showed a correlation between species distribution and edaphic variables. However, conclusions about species distribution patterns in relation to them should only approach a generalization after many repetitions of the same pattern in several areas.

Although in the present study, it was not possible to consider the effect of anthropic interferences as variables due to the difficulty of measurement, it is worth mentioning that the analyzed fragment is subject to different types of pressure, with its own history, difficult to be considered in the interpretation of gradients or vegetation classes. Amazonian forests seem relatively more likely to experience some retraction or die-back due to environmental, natural or anthropogenic changes (ZELAZOWSKI et al., 2011). The floristic composition, mainly the soil seed bank, can significantly influence these places' potential resilience and regeneration in the event of natural or anthropogenic disturbance (SOUSA et al., 2017).

5. CONCLUSIONS

The tree component is altered and dominated by species characteristic of degraded environments, in which the chemical composition of the soil explains most of the species' variation that occurs ($R^2X|Y = 0.80$).

The species *Q. paraensis* stands out for its ecological importance and its adaptability to high levels of Al and OM and low levels of P; behavior that qualifies the species as a potential use in degraded forest ecosystems in the Amazon. Due to their presence not being associated with edaphic variables, the species *B. grossularioides*, *C. cognatus*, *D. purpurea*, and *E. uncinatum* can also be indicated for the same purpose.

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