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Scientific Article

THE ROLE OF PROTECTED AREAS IN PRESERVING CARAJÁS RUPESTRIAN VEGETATION "CANGA" IN THE BRAZILIAN AMAZON

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ABSTRACT

The rupestrian vegetation on rocky hematite outcrops in the Brazilian Amazon has the smallest geographic distribution and highest endemism in the region. This study aimed to characterize the floristic composition and vegetation structure of these formations, locally known as Canga. The floristic inventory included both natural regeneration and the tree and shrub layers. Species richness and individual abundance were significantly lower in the rupestrian fields outside protected areas. Moreover, the dominant species differed markedly between protected and unprotected sites. Species typical of well-preserved habitats within protected areas were either absent or had drastically reduced abundance outside. Plant composition was entirely different between the two settings. The observed reduction in species richness, abundance, and changes in floristic composition is likely associated with human-induced disturbances.

Keywords: Endemic species; Floristic composition; Ironstone outcrops

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A IMPORTÂNCIA DAS ÁREAS PROTEGIDAS NA PRESERVAÇÃO DA VEGETAÇÃO RUPESTRE DE "CANGA", CARAJÁS, NA AMAZÔNIA BRASILEIRA

RESUMO A vegetação de campos rupestres na Amazônia Brasileira que ocorre em afloramentos rochosos de substrato hematítico possui a menor distribuição geográfica e grande número de espécies endêmicas na Amazônia. O objetivo da pesquisa foi caracterizar a composição florística e a estrutura da vegetação de campos rupestres localmente denominado de "Canga". O inventário florístico incluiu regeneração natural (plantas com até 30 cm de altura) e estrato arbóreo e arbustivo (plantas já estabelecidas) A abundância de indivíduos e a riqueza de espécies foram significativamente menores nos campos rupestres fora das áreas protegidas em comparação com o interior. As espécies mais abundantes são diferentes entre os locais. As espécies típicas abundantes em campos rupestres em bom estado de conservação dentro da área protegida desaparecem ou têm uma redução drástica da abundância. A composição florística foi diferente entre os campos rupestres dentro e fora da área protegida. A redução na riqueza, abundância de espécies e mudança na composição florística provavelmente está correlacionada aos impactos das atividades humanas.

Palavras-Chave: Afloramentos ferríferos; Composição florística; Espécies endêmicas

1. INTRODUCTION

Rainforest is the predominant vegetation type in the Amazon region. It can be divided into dense ombrophilous forest and open physiognomies, and classified according to topographic position as alluvial, lowland, submontane, or montane formations (Veloso et al., 1991). However, non-forest vegetation types are also commonly found in the Amazon biome. Among the most important are savannas, grasslands, campinas, campinaranas, pioneer formations, and "rupestrian fields". These are open vegetation formations with a savanna-like structure, typically found in mountainous regions above 500 meters in elevation, and associated with rocky outcrops of quartzite, sandstone, or hematitic substrates (Viana et al., 2016).

Among the types of rupestrian fields in Brazil, the rarest are those associated with hematitic rocky outcrops rich in iron ore (Secco & Mesquita, 1983). The most representative examples of this vegetation occur in the "Iron Quadrangle" of Minas Gerais State within the Atlantic Forest biome (Jacobi et al., 2008), and in the "Carajás Ranges" of Pará State in the Brazilian Amazon (Viana et al., 2016). This rupestrian vegetation is known by various terms, including ferruginous fields (Rizzini, 1997), canga vegetation (Silva et al., 1996), steppe grasslands (IBAMA, 2004), and metallophilous savannas (Vicent et al., 2004).

The flora of canga is highly adapted to extreme edaphic conditions and shows distinct physiological, morphological, and reproductive adaptations, such as sclerophylly, tolerance to cyclical drought and hydration (Giulietti et al., 2000), and the ability to grow in soils with high metal concentrations (Corrêa et al., 2016). Rupestrian fields are a priority for conservation because of their high levels of endemism and are considered biodiversity hotspots in both the Atlantic Forest and Amazon biomes (Vidal & Mascarenhas, 2020; Carmo & Kamino, 2023).

In the Amazon, the largest occurrence of these fields is in the Serra dos Carajás in Pará State, which includes three mountain ranges: North, South, and East (Viana et al., 2016; Mota et al., 2018). All rupestrian fields of the North and South Ranges are located within the Carajás National Forest, where the mining company Vale S.A. extracts iron ore, among other minerals (IBAMA, 2004). This activity is permitted under Law No. 9,985 of 2000 (SNUC, 2000), which established the National System of Conservation Units and regulates mineral extraction in certain sustainable use conservation areas, including National Forests.

Within the Carajás Ranges, some species found in the rupestrian fields are considered threatened with extinction, such as the vines *Ipomoea carajasensis* D.F.

Austin and *Ipomoea cavalcantei* D.F. Austin (Convolvulaceae), and the shrub *Erythroxylum nelson-rosae* Plowman (Erythroxylaceae) (Secco & Mesquita, 1983; Porto & Silva, 1989; MMA, 2024). Additionally, several species remain undescribed (Viana et al., 2016; Cleef & Silva, 1994).

Several botanical studies have characterized the floristic composition and vegetation structure of these formations (Secco & Mesquita, 1983; Porto & Silva, 1989; Morelato & Rosa, 1991; Silva et al., 1996; Silva & Rosa, 1985; Chaves & Ferreira, 2014; Viana et al., 2016; Mota et al., 2018; Silva et al., 2023). However, no previous study has assessed the impact of human activity on the floristics and structure of Amazonian rupestrian fields or the role of protected areas in their preservation.

Ferreira et al. (2005), Soares-Filho et al. (2010), and Pereira & Ferreira (2021) have demonstrated the effectiveness of protected areas and Indigenous lands in limiting deforestation in the Brazilian Amazon. In the Amazon biome, to improve the protection of the rupestrian fields, the Chico Mendes Institute for Biodiversity Conservation (ICMBio) created the Ferruginous Fields National Park (Vidal & Mascarenhas, 2020; Silva et al., 2023).

However, another important rupestrian field located in the Eastern Carajás Range lies outside the current network of protected areas in Pará State., being subject to various human disturbances, including logging, cattle grazing, and fire.

The objective of this study is to document differences in floristic composition and vegetation structure between rupestrian fields inside (Carajás National Forest) and outside protected areas. The aim is to evaluate the importance of land-use designation for the preservation of this rare Amazonian vegetation type.

2. MATERIAL AND METHODS

Two study sites were selected: one within the Carajás National Forest (North Range) and one outside the protected area (East Range), both located in Pará State, Brazil (Fig. 1).

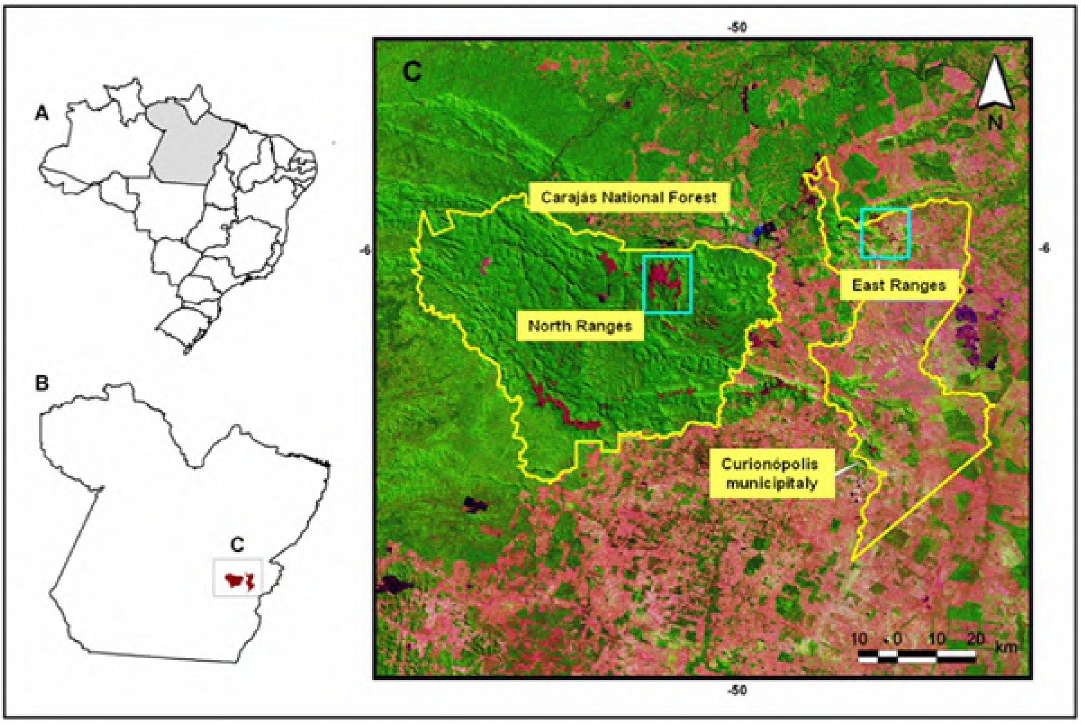

Figure 1. Location of the study area (C) in the State of Pará (B) and in Brazil (A), highlighting the rupestrian fields in the North Range (approx. 42.8 km²; Silva et al., 2023) and the East Range (approx. 6.2 km²; estimated in this study)

Figura 1. Sítio de estudo (C) no Estado do Pará (B) e no Brasil (A), destacando os campos rupestres das Serras Norte, totalizando cerca de 42,8 km^2 (Silva et al, 2023) e Leste, totalizando cerca de 6,2 km^2 (calculado por esse estudo)

In each site, three sampling areas were established: N4, N5, and N6 in the North Range, and L1, L2, and L3 in the East Range. In each sampling area, 25 plots were distributed, totaling 75 plots per site, with a minimum spacing of 500 meters between plots. The criterion for selecting inventory areas was the degree of conservation of vegetation cover.

The vegetation in both sites occurs on iron oxide rocky outcrops (hematitic canga) on plinthosol soils (Corrêa et al., 2016), at elevations ranging from 400 to 750 meters (Mota et al., 2018). The mean annual rainfall is approximately 1,900 mm with strong seasonality, the dry season occurs from June to September, with mean monthly precipitation below 100 mm, while the rainy season extends from October to May, with monthly precipitation above 200 mm (IBAMA, 2004). In the Carajás ranges, rupestrian fields occur in isolated patches of varying sizes, surrounded by forest, and exhibit two main physiognomies: open herbaceous vegetation and denser shrub and small tree formations (Viana et al., 2016).

2.1 Data Collection

The floristic inventory was conducted in March and April 2023. Two vegetation strata were sampled: (1) Natural regeneration using plots of 1 × 1 m in which all life forms were identified and counted and (2) Tree and shrub layer, where all individuals with diameter at neck height (DNH) ≥ 1 cm were measured and identified. Botanical classification followed APG IV (Chase et al., 2016). All fertile specimens were deposited at the Herbarium João Murça Pires of the Museu Paraense Emílio Goeldi (MG), with duplicate specimens donated to the Herbarium of Carajás (HCJS), FLONA Zoobotanical Park.

2.2 Data Analysis

Differences in species richness and individual density between sites were assessed using Student's t-test. Normality of dependent variables was tested using the Shapiro-Wilk test (Zar, 2010). All analyses were performed in Systat 12 (Systat Software, Inc., 2007) Species similarity between sites and vegetation strata was analyzed using non-metric multidimensional scaling (NMDS), based on Jaccard similarity indices and Bray-Curtis distance. NMDS was performed using PC-ORD version 6 (McCune & Mefford, 2011).

3. RESULTS

In the natural regeneration stratum, the total number of individuals ranged from 91 to 165 in the East Range and from 525 to 829 in the North Range. In the tree and shrub layer, the number of individuals ranged from 361 to 446 in the East Range and from 725 to 866 in the North Range (Table 1). The total number of species in the natural regeneration stratum varied from 20 to 25 in the East Range and from 29 to 31 in the North Range. In the tree and shrub layer, species richness ranged from 12 to 14 in the East Range and from 20 to 22 in the North Range (Table 1).

There was an 81% reduction in individual abundance in the natural regeneration stratum in the East Range (outside the protected area) compared to the North Range (inside the protected area) (Table 2).

Table 1. Number (N) of plots, individuals, and species in the natural regeneration and tree-shrub strata of the East sites (L1, L2, L3) and North sites (N4, N5, N6)
Tabela 1. Número (N) de parcelas, indivíduos e espécies em regeneração natural e campo rupestre arbóreo-arbustivo dos sítios Leste (L1, L2 e L3) e Norte (N4, N5 e N6)

Natural Regeneration				
Range	**Sites**	**N of plot**	**N of ind**	**N of spp**
East	E1	25	120	20
	E2	25	91	20
	E3	25	165	25
North	N4	25	525	32
	N5	25	581	29
	N6	25	829	31

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Shrubs and trees				
Range	**Sites**	**N of plot**	**N of ind**	**N of spp**
East	E1	25	361	12
	E2	25	446	13
	E3	25	372	14
North	N4	25	725	20
	N5	25	782	22
	N6	25	866	21

Table 2. Total density and relative variation in the number of individuals by life form in the natural regeneration stratum of the rupestrian fields in the North and East Ranges
Tabela 2. Densidade total e variação relativa do número de indivíduos divididos nas formas de vida da regeneração natural dos campos rupestres do Norte e Leste

Life forms	North	East	%Variation (East/North)
Shrub	243	225	-7%
Epiphyte	209	23	-89%
Herb	1.423	102	-93%
Vine	60	26	-57%
Total	1.935	376	-81%

The most abundant species in the natural regeneration stratum accounted for 84.3% and 83.2% of total individuals in the protected and unprotected areas, respectively (Table 3 and Appendix 1). *Axonopus purpusii* (Mez) Chase (Poaceae) was the most abundant species inside the protected area, while *Bauhinia pulchella* Benth. (Fabaceae) was most abundant outside. Only *Mimosa acutistipula* var. *ferrea* (Mart.) Benth. (Fabaceae) appeared as a dominant species in both areas.

Two threatened vine species, *Ipomoea carajasensis* D.F. Austin and *Ipomoea cavalcantei* D.F. Austin, considered vulnerable and endangered, respectively, according to IUCN criteria (Martinelli & Moraes 2013). were absent from the rupestrian fields of the unprotected East Range.

Abundance and species richness in the natural regeneration stratum were significantly higher within the conservation unit compared to outside ($t = 13.04$; $p = 0.0001$ and $t = -2.86$; $p = 0.005$, respectively) (Figure 2).

Table 3. Life forms of the ten most abundant species in the natural regeneration stratum, with relative density (RD), in the rupestrian fields of the North (N) and East (E) Ranges
Tabela 3. Formas de vida das dez espécies de regeneração natural com maior densidade relativa (DR) nos campos rupestres do Norte (N) e Leste (E)

Family	Scientific name	Life forms	RD (N)
Poaceae	*Axonopus purpusii* (Mez) Chase	Herb	42,1
Araceae	*Anthurium bonplandii* Bunting	Herb	10,4
Orchidaceae	*Sobralia liliastrum* Lindl.	Epiphyte	8,5
Lythraceae	*Cuphea antisyphilitica* Kunth	Herb	5,1
Euphorbiaceae	*Croton tomentosus* (Lour.) Müll.Arg.	Herb	4,7
Fabaceae	*Mimosa acutistipula* var. *ferrea* Barneby	Herb	4,4
Bromeliaceae	*Dyckia duckei* L.B.Sm.	Herb	3,0
Velloziaceae	*Vellozia glochidea* Pohl.	Shrub	2,8
Fabaceae	*Dioclea virgata* var. *crenata* R.H.Maxwell	Vine	1,7
Fabaceae	*Periandra mediterranea* (Vell.) Taub.	Shrub	1,7
	% total of individuals		84,3
	% total of herbs		65,3

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Family	Scientific name	Life forms	RD (E)
Fabaceae	*Bauhinia pulchella* Benth.	Shrub	26,9
Rubiaceae	*Perama carajensis* J.H.Kirkbr.	Shrub	15,7
Asteraceae	*Lomatozona* sp.	Herb	8,5
Melastomataceae	*Siphanthera* sp.	Shrub	7,4
Araceae	*Anthurium bonplandii* Bunting	Herb	7,2
Orchidaceae	*Sobralia liliastrum* Lindl.	Epiphyte	4,8
Fabaceae	*Mimosa acutistipula* var. *ferrea* Barneby	Shrub	3,5
Malpighiaceae	*Banisteriopsis stellaris* (Griseb.) B.Gates	Vine	3,5
Euphorbiaceae	*Croton tomentosus* (Lour.) Müll.Arg.	Herb	3,2
Bignoniaceae	*Anemopaegma scabriusculum* Mart. ex DC.	Vine	2,7
	% total individuals		83,2
	% total of herbs		18,9

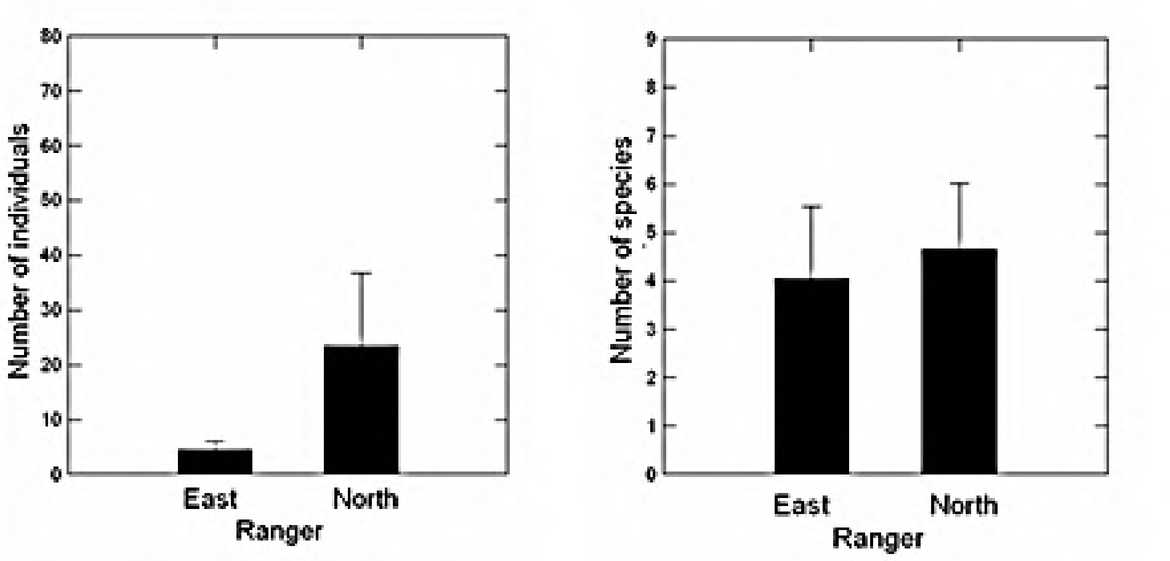

Figure 2. Mean and standard deviation of the number of individuals and species in the natural regeneration stratum in the rupestrian fields of the North and East Ranges
Figura 2. Média e desvio padrão do número de indivíduos e espécies da regeneração natural nos campos rupestres das Serras Norte e Leste

A total of 35 species were identified in the tree and shrub layer: 30 in the North Range and 18 in the East Range. Only 13 species (37%) were shared between both ranges. The 10 most abundant species accounted for 94% and 98.3% of all individuals inside and outside the protected area, respectively. *Callisthene microphylla* Warm. (Vochysiaceae) and *Mimosa acutistipula* var. *ferrea* Barnaby (Fabaceae) were most abundant in the North Range (25% and 20.9%), whereas *Mimosa acutistipula* var. *ferrea* Barnaby (Fabaceae) and *Alchornea schomburgkii* Klotzsch (Euphorbiaceae) were most abundant in the East Range (40.5% and 14.2%). *Vellozia glochidea* Pohl. (Velloziaceae), Norantea goyasensis Cambess (Marcgraviaceae), and *Mimosa acutistipula* var. *ferrea* Barnaby (Fabaceae) occurred as dominant species in both areas. Notably, *Mimosa acutistipula* var. *ferrea* Barnaby (Fabaceae) had higher relative density in the East Range (Table 4 and Appendix 1).

Abundance and species richness in the tree and shrub layer were also significantly higher inside the conservation unit compared to outside ($t = 13.04$; $p = 0.0001$ and $t = -9.82$; $p = 0.0001$, respectively) (Figure 3).

NMDS analysis revealed a clear separation in species composition of both vegetation strata between the North and East Ranges. The x-axis explained approximately 45% of the variation, while the y-axis explained about 54% (Figure 4).

Table 4. Life forms of the ten most abundant species in the tree-shrub layer, with relative density (RD), in the rupestrian fields of the North (N) and East (E) Ranges
Tabela 4. Formas de vida das dez espécies do estrato arbustivo-arbóreo com maior densidade relativa (DR) nos campos rupestres das Serras Norte (N) e Leste (L)

Family	Scientific name	Life forms	NDR
Vochysiaceae	*Callisthene microphylla* Warm.	Shrub	25,0
Fabaceae	*Mimosa acutistipula* var. *ferrea* Barnaby	Shrub	20,9
Velloziaceae	*Vellozia glochidea* Pohl	Shrub	16,9
Malpighiaceae	*Byrsonima eugeniifolia* Sandwith	Shrub	10,6
Marcgraviaceae	*Norantea goyasensis* Cambess.	Shrub	7,0
Sapotaceae	*Pouteria ramiflora* Radlk.	Shrub	4,8
Fabaceae	*Dalbergia subcymosa* Ducke	Shrub	3,9
Melastomataceae	*Tibouchina aspera* Aubl.	Shrub	3,1
Erythroxylaceae	*Erythroxylum ligustrinum* var. *carajasense* Plowman	Shrub	1,9
	% total individuals		94,0
Family	**Scientific name**	**Life forms**	**EDR**
Fabaceae	*Mimosa acutistipula* var. *ferrea* Benth.	Shrub	40,5
Euphorbiaceae	*Alchornea schomburgkii* Klotzsch	Shrub	14,2
Velloziaceae	*Vellozia glochidea* Pohl	Shrub	13,8
Erythroxylaceae	*Erythroxylum nelson-rosae* Plowman	Shrub	7,9
Caesalpinaceae	*Bauhinia pulchella* Benth.	Shrub	7,0
Marcgraviaceae	*Norantea goyasensis* Cambess.	Shrub	5,9
Myrtaceae	*Eugenia punicifolia* (Kunth) DC.	Shrub	4,2
Bignoniaceae	*Anemopaegma scabriusculum* Mart. ex DC.	Vine	2,6
Simarubaceae	*Simarouba amara* Aubl.	Shrub	1,4
Apocynaceae	*Himatanthus articulatus* (Vahl). Wood.	Shrub	0,7
	% total individuals		98,3

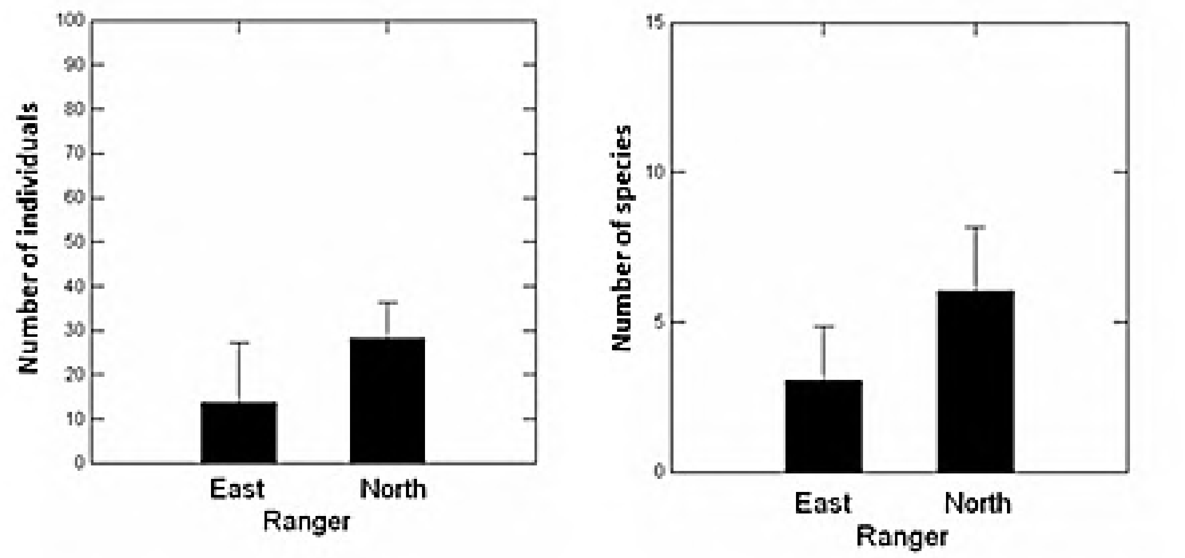

Figure 3. Mean and standard deviation of the number of individuals and species in the tree-shrub layer in the rupestrian fields of the North and East Ranges
Figura 3. Mean and standard deviation of the number of individuals and the species of the shrub-tree layer in the rupestrian fields of the North and East Ranges

4. DISCUSSION

There was a marked reduction in species richness and individual density in both the natural regeneration and tree-shrub strata in the East Range (outside the Carajás National Forest) compared to the North Range (inside the protected area). This indicates significant human impact on local flora and vegetation

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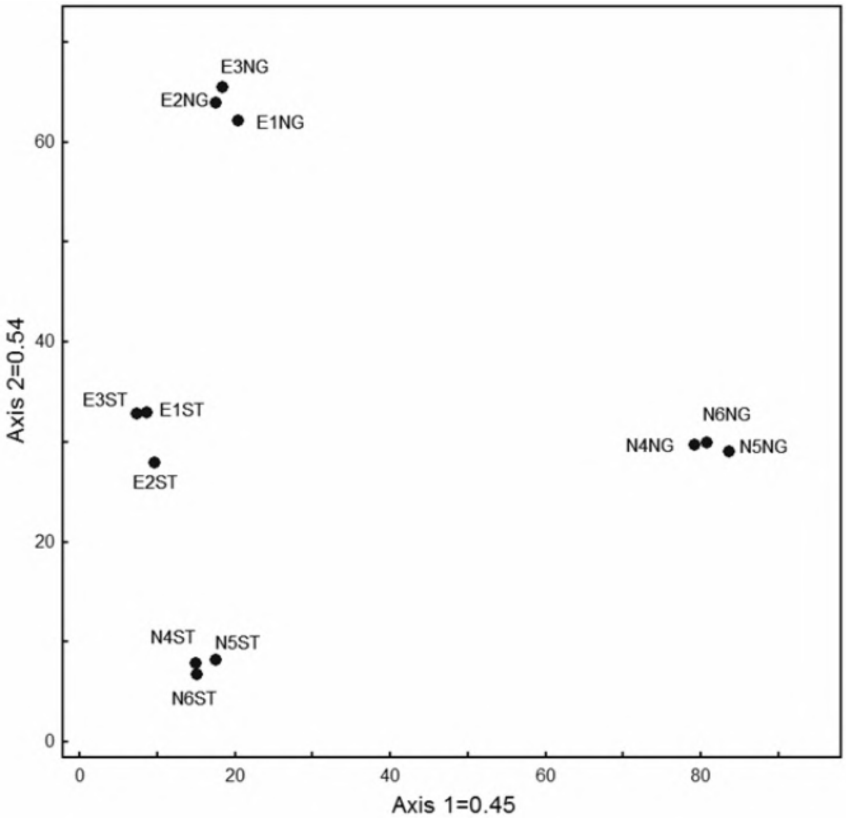

Figure 4. NMDS ordination showing species similarity in the natural regeneration (NR) and shrub-tree layers (ST) of the rupestrian fields in the North Range (N4, N5, and N6; dashed squares) and the East Range (L1, L2, and L3; solid squares)
Figura 4. Análise de ordenação da similaridade de espécies da regeneração natural (RN) e arbustivo-arbórea (ST) nos campos rupestres da Serra Norte (N4, N5 e N6, quadrados tracejados) e da Floresta Nacional de Carajás e Serra Leste (E1, E2 e E3, quadrados contínuos)

cover, likely due to extensive cattle grazing, fire, ornamental plant collection (e.g., orchids and bromeliads), and unsustainable land use practices commonly observed in unprotected Amazonian areas (Ferreira et al., 2005; 2012).

In the East Range, livestock activities and inadequate soil management including the use of fire for pasture are the main drivers of degradation. (Viana et. al., 2016) Fires often spread into rupestrian fields, causing high mortality among native species. The natural regeneration stratum showed the most pronounced reduction in individual density, especially among herbaceous plants, which are particularly vulnerable to fire.

Another notable difference was the presence of secondary forest species in the natural regeneration plots of the East Range species absent from the North Range including *Vismia baccifera* (L.) Triana & Planch. (Hypericaceae), *Aparisthmium cordatum* (A. Juss.) Baill. (Euphorbiaceae), *Cecropia palmata* Willd. (Urticaceae), and *Tapirira guianensis* Aubl. (Anacardiaceae). Additionally, pasture grasses of African origin, such as *Urochloa brizantha* (Hochat ex. A.Rich.) R.D.Webster and *Melinis minutiflora* P. de Beauv. (Poaceae), were also recorded. These compositional differences are not explained by abiotic factors like rainfall or soil, as all surveys were conducted simultaneously on similar substrates.

Another key finding was the absence of the endangered species *Ipomoea carajasensis* D.F. Austin and *Ipomoea cavalcantei* D.F. Austin (Convolvulaceae) in the East Range. Also concerning was the sharp decline in *Ipomoea marabaensis* D.F. Austin & Secco. These species are listed as endangered by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, 2004) and the Pará State Secretariat for the Environment (SEMA, 2008).

Their absence and/or reduced abundance in the East Range is likely due to heavy human impact, combined with the limited geographic distribution of these species, which are restricted to hematite-rich outcrops in the Serra dos Carajás (Mota et. al., 2018) Another striking result was the absence of *Callisthene microphylla* Warm. (Vochysiaceae) in the East Range, despite being one of the most abundant species in the North Range. Chaves & Ferreira (2014) also reported its high abundance in the North and South Ranges within the Carajás National Forest. The seeds of this species are dispersed by birds, such as *Poecilurus* sp. (Furnariidae) and *Zonotrichia* sp. (Emberizidae), which may also be absent due to anthropogenic pressures in the East Range (Vasconcelos & Diego, 2015; Vasconcelos, 2011).

The conservation of rupestrian fields on hematitic outcrops currently under threat from mining is intensely debated, both in the Iron Quadrangle of Minas Gerais and the Serra dos Carajás in Pará (Chase et al., 2016). In Minas Gerais, the lack of protection has already resulted in the loss of unique vegetation types (Jacobi et al., 2008). Our results underscore the importance of the Carajás National Forest in conserving these ecosystems and highlight the urgent need to expand protection to the East Range.

As many species in these ecosystems are restricted to small patches, conservation planning should prioritize complementarity maximizing species conservation with minimal redundancy (Vane-Wright et al., 1991; Pressey et al., 1993). When resources are limited, the selection of areas for protection should focus on complementary attributes (species, habitats, landscapes), avoiding duplication (Anacleto et al., 2005). Mourão & Stehmann (2007), working in the Iron Quadrangle, emphasized the need to preserve as many remnants of this vegetation as possible.

5. CONCLUSION

This study demonstrates that the floristic composition and vegetation structure of the rupestrian fields in the North and East Ranges of the Serra dos Carajás differ significantly, with markedly lower species richness and plant abundance in the unprotected East Range. The absence or reduced density of threatened and endemic species outside the protected area highlights the urgent need for conservation measures.

While the Carajás National Forest currently contributes to the preservation of this unique vegetation through partnerships between Vale and ICMBio, additional protection is needed for the East Range. Its complementary flora, which includes distinct species not found or less abundant in the protected areas, underscores the importance of expanding the conservation network to include these vulnerable habitats.

6. ACKNOWLEDGEMENTS

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AUTHOR CONTRIBUTIONS

Ferreira, L.V.: Project administration, Investigation, Writing – original draft; Salomão, R.P.: Investigation, Supervision; Cunha, D.A.: Formal analysis; Supervision; Matos, D.C.L.: Investigation, Review; Parolin, P.: Supervision, traduction; Jardim, M.A.G.: Writing – review & editing.

DATA AVAILABILITY

The entire dataset supporting the findings of this study has been published within the article.

7. REFERENCES

Anacleto, T.S.C., Ferreira, A.A., Diniz Filho, J.A.F., & Ferreira, L.G. (2005). Seleção de áreas de interesse ecológico através de sensoriamento remoto e de otimização matemática: um estudo de caso no município de Cocalinho, MT. *Acta Amazonica, 35*(4), 437-444. https://doi.org/10.1590/S0044-59672005000400008.

Carmo, F.F., & Kamino, L.H.Y. (2023). Controversies and hidden risks in biodiversity offsets in critically threatened Canga (ironstone) ecosystems in Brazil. *Oryx, 57*(1), 63-71. https://doi.org/10.1017/S0030605322000333

Chase, M.W., Christenhusz, M.J.M., Fay, M.F., Byng, J.W., Judd, W.S., Soltis, D.E., Habberley, A.N., Sennikov, A.N., Soltis, P.S., & Stevens, P.F. (2016). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Botanical Journal of the Linnean Society, 181* (1), 1-20. https://doi.org/10.1111/boj.12385

Chaves, P.P. & Ferreira, L.V. (2014). Variação da riqueza e composição de espécies da vegetação arbustiva dos campos rupestres da serra norte na Floresta Nacional de Carajás, Pará. *Pesquisas Botânica, 65*, 201-216, ISSN-0373-840X

Cleef, A., & Silva, M.F.F. (1994). Plant communities of the Serra dos Carajás (Pará), Brazil. Boletim do Museu Paraense Emílio Goeldi, *Série Botânica, 10*(2), 269-281.

Corrêa, G.R.C.E.R.G., Schaefer, G.F., Corrêa, R.J., Gilkes, B.A.F., Mendonça, J.A., & Nunes, P. (2016). Caracterização de solos derivados de rochas máficas na Serra de Carajás. Boletim do Museu Paraense Emílio Goeldi. *Ciências Naturais, 11*(1),33-47. https://doi.org/10.46357/bcnaturais.v11i1.458

Ferreira, L.V., Pereira, J.L.G., Cunha, D.A., Matos, D.C.L., & Sanjuan, P.M. (2012). A vocação da Amazônia é florestal e a criação de novos estados pode levar ao aumento do desflorestamento na Amazônia Brasileira. *Estudos Avançados, 26*(74), 187-193. https://doi.org/10.1590/S0103-40142012000100013

Ferreira, L.V., Venticinque, E., & Almeida, S.S. (2005). O desmatamento na Amazônia e a importância das áreas protegidas. *Estudos Avançados, 19*(53), 1-10. https://doi.org/10.1590/S0103-40142005000100010

Giulietti, A.M.; Harley, R.M.; Queiroz, L.P.; Wanderley, M.G.L. & Pirani, J.R. (2000). Caracterização e endemismos nos campos rupestres da Cadeia do Espinhaço. In: Cavalcanti, T. B. & Walter, B. M. T. (org.). *Tópicos atuais em botânica.* 1ª ed. SBB/CENARGEN, Brasília. pp. 311-318.

IBAMA - Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (2004). *Plano de Manejo para Uso Múltiplo da Floresta Nacional de Carajás*. Brasília: Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis.

Jacobi, C.M., Carmo, F.F., & Vicent, R. (2008). Estudo fitossociológico de uma comunidade vegetal sobre canga como subsídio para a reabilitação de áreas mineradas no quadrilátero ferrífero, MG. *Revista Árvore, 32*(2), 345-353. https://doi.org/10.1590/S0100-67622008000200017

Martinelli, G., & Moraes, M.A. (2013). *Livro vermelho da flora do Brasil*. Ed. Rio de Janeiro: Andrea Jakobsson: Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, 1100p.

McCune, B., & Mefford, M.J. (2011). PC-ORD. Multivariate analysis of ecological data. Version 6. MjM Software. Oregon: Gleneden Beach, 78p.

MMA - Ministério do Meio Ambiente. *Lista oficial da Flora Brazileira ameaçadas de extinção*. https://www.mma.gov.br/estruturas/ascom_boletins/_arquivos/83_19092008034949.pdf

Morelato, P.C., & Rosa, N.A. (1991). Caracterização de alguns tipos de vegetação na região amazônica, Serra dos Carajás, Pará, Brasil. *Revista Brasileira de Botânica, 14*(1), 1-14.

Mota, N.F.O, Watanabe, M.T.C., Zappi, D.C., Hiura, A.L, Pallos, J. Viveros, R.S., Giulietti, A.M. & Viana, P.L. (2018). Cangas da Amazônia: a vegetação única de Carajás evidenciada pela lista de fanerógamas. *Rodriguésia, 69*(3), 1435-1488. https://doi.org/ 10.1590/2175-7860201869336

Mourão, A., & Stehmann, J.R. (2007). Levantamento da flora do campo rupestre sobre canga hematítica couraçada remanescente na mina do Brucutu, Barão de Cocais, Minas Gerais, Brasil. *Rodriguésia, 58*(4), 775-786.

Pereira, J.L.G. & Ferreira, L.V. (2021). The effectiveness of the categories of protected areas in containing deforestation in the legal Amazon. *Boletim de Geografia, 39*, 70-85. https://doi.org/10.4025/bolgeogr.v39.a2021.e58064

Porto, M.L., & Silva, M.M.F. (1989). Tipos de Vegetação metalófila em áreas da Serra de Carajás e Minas Gerais, Brasil. *Acta Bot. Bra., 3*(2), 13-21. https://doi.org/10.1590/S0102-33061989000200002

Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., Williams, P.H. (1993). Beyond opportunism: key principles for systematic reserve selection. *Tree, 8*(4), 124-128.

Rizzini, C.T. (1997). *Tratado de Fitogeografia do Brasil*. 2.ed. São Paulo: HUCITEC/Universidade de São Paulo; 230 p.

Secco, R.S., & Mesquita, A.L. (1983). Notas sobre a vegetação de canga da Serra Norte. Bol. do Museu Paraense Emilio Goeldi, *Série Botânica, 59*(2), 1-13.

SEMA – Secretaria do Estado do Meio Ambiente e Sustentabilidade (2008). Decreto nº 802. 20/2/2008. DOE nº 31.112, 21/2/2008. Programa Estadual de Espécies Ameaçadas de Extinção - Programa Extinção Zero. https://www.semas.pa.gov.br/legislacao/files/pdf/602.pdf

Silva, L.G., Lovo, J., Fonseca-da-Silva, T.L., Ruil, P., Silva-Luz, C.L. & Zappi, D.C. (2023). Floristic data to support conservation in the Amazonian canga. *Biota Neotropica, 23*(4), 1-15. https://doi.org/10.1590/1676-0611-BN-2023-1517

Silva, M.F.F., & Rosa, N.A. (1985). Análise do estrato arbóreo da vegetação sobre jazidas de cobre na Serra dos Carajás - PA. Boletim do Museu Paraense Emílio Goeldi, *Série Botânica, 5*(2),175-205.

Silva, M.F.F., Secco, R.S., & Lobo, M.G. (1996). Aspectos ecológicos da vegetação rupestre da Serra dos Carajás, Estado do Pará, Brazil. *Acta Amazonica, 26* (1/2),17-44.

SNUC - Sistema Nacional de Unidades de Conservação (2000). Lei 9.985 de 18 de julho de 2000. Ministério do Meio Ambiente. https://legislacao.presidencia.gov.br/atos

Soares-Filho, B., Moutinho, P., Nepstad, D., Anderson, A., Rodrigues, H., Garcia, R., Dietzsch, L., Merry, F., Bowmman, M., Hissa, L., Silvestrini, R., & Maretti, C. (2010). Roley of Brazilian Amazon protected áreas in clima change mitigation. *PNAS, 107* (24),10821-10826. https://doi.org/10.1073/pnas.0913048107

SYSTAT Software, Inc. (2007). SYSTAT 12 for Windows. Versão 12.0. Chicago, IL: Systat Software, Inc.

Vane-Wright, R.I., Humphries, C.J., Williams, P.H. (1991). What to protect? systematics and the agony of choice. *Biological Conservation, 55*(3), 235-54. https://doi.org/10.1016/0006-3207(91)90030

Vasconcelos, M.F. (2011). O que são campos rupestres e campos de altitude nos topos de montanhas do leste do Brazil? *Braz. J. Bot., 34*(2), 241-246. https://doi.org/10.1590/S0100-84042011000200012

Vasconcelos, M. & Diego, H, (2015). Avifauna das vegetações abertas e semiabertas associadas a geossistemas ferruginosos do Brasil: levantamento, conservação e perspectivas para futuros estudos. In: Carmo, F.F. do & Kamino, L.H.Y. (Eds.). *Geossistemas Ferruginosos do Brasil: áreas prioritárias para conservação da diversidade geológica e biológica, patrimônio cultural e serviços ambientais*, pp.259-287. 3i Editora.

Veloso, H.P., Rangel-Filho, A., & Lima, J.C.A. (1991). *Classificação da vegetação Brasileira, adaptada a um sistema universal.* Rio de Janeiro: IBGE, 180 p.

Viana, P.L., Mota, N.F.O., Gil, A.S.B., Salino, A., Zappi, D.C., Harley, R.M., Ilkiu-Borges, A.L., Secco, R.S., Almeida, T.E., Watanabe, M.T.C., Santos, J.U.M., Trovó, M., Maurity C., & Giulietti, A.M. (2016). Flora of the cangas of the Serra dos Carajás, Pará, Brazil: history study area and methodology. *Rodriguésia, 67*(5), 1107-1124. https://doi.org/10.1590/2175-7860201667501

Vicent, R.C., Jacobi, C., & Antonini, Y. (2004). Diversidade na adversidade. *Ciência Hoje, 31* (3),4-67.

Vidal, M.R., & Mascarenhas, A.L.S. (2020). Mapeamento geoecológico no Parque Nacional dos Campos Ferruginosos de Carajás/Pará-Brasil. *Ateliê Geográfico, 14* (3), 218-238. https://doi.org/10.5216/ag.v14i1.59613

Zar, J.H. (2010). *Biostastical Analysis*. 5.ed. New Jersey: Prentice-Hall, 145 p.