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Inventory

Novelties from the herbaceous stratum in a key region for the conservation of the Southern Amazon

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Abstract: The contribution of the herbaceous stratum to tropical plant diversity is considerable, however this component remains undersampled. We investigated floristic, structural, ecological and conservation issues concerning the herbaceous component of a seasonal deciduous forest associated with granitic rock outcrops in the Cristalino Region, a key area for biodiversity conservation in the Brazilian Amazon. We installed a permanent plot of 1 ha, allocating 10 transect-lines of 20 m each. We identified the sampled individuals, measured height and projection, and verified cover and frequency per species, genera and family. We recorded 86 species, 62 genera and 25 families, with Orchidaceae being the family with the highest species richness. Among the 26 new species added to Cristalino Flora, we included *Philodendron deflexum* Poepp. ex Schott and *Griffinia nocturna* Ravenna, the latter 'Critically Endangered'. Furthermore, the occurrence of *G. nocturna* in an Amazonian forest matrix is a novelty in this study. The estimate of species diversity according to Shannon-Wiener (H') was 2.43 nats.ind.$^{-1}$ (equivalent to 11.37 ± 0.90 $IC_{95\%}$ equally common species), and according to Simpson (1/D), 6.82 (± 0.648 $IC_{95\%}$). The rarefaction and extrapolation curves for the diversity estimates tended to stabilize. Although the vegetation on rock outcrops usually presents a high number of endemic species, this pattern was not found in our study area, which can be explained by its continuous occurrence in the forest matrix. The understory of our study area consists in a mixture of floras, being composed mainly of species from the Amazon and/or Cerrado biomes. In view of the current anthropic pressure faced by the southern Amazon, we reinforce the importance of carrying out inventories of its herbaceous communities, since the risk of species loss is even more alarming when considering present undersampling of this component.
Keywords: *Floristic Survey; Forest Understory; Line Intercept Method; Southern Amazon; Plant Diversity; Species Diversity.*

Novidades do estrato herbáceo em uma região chave para a conservação da Amazônia Meridional

Resumo: A contribuição do estrato herbáceo para a diversidade de plantas tropicais é considerável, mas esse componente permanece subamostrado. Investigamos questões florísticas, estruturais, ecológicas e de conservação relacionadas ao componente herbáceo de uma floresta estacional decidual associada a afloramentos rochosos graníticos na região do Cristalino, que é uma área chave para a conservação da biodiversidade na Amazônia brasileira. Instalamos um plot permanente de 1 ha, alocando 10 linhas de 20 m cada. Identificamos os indivíduos amostrados, medimos altura e projeção e verificamos cobertura e frequência por espécie, gênero e família. Registramos 86 espécies, 62 gêneros e 25 famílias, sendo Orchidaceae a família com maior riqueza de espécies. Entre as 26 novas espécies adicionadas à Flora do Cristalino, incluímos *Philodendron deflexum* Poepp ex Schott e *Griffinia nocturna* Ravenna, esta última 'Criticamente Ameaçada'. Além disso, a ocorrência de *G. nocturna* em uma matriz florestal amazônica é uma novidade neste estudo. A estimativa da diversidade de espécies de acordo com Shannon-Wiener (H ') foi 2,43 nats / ind.-1 (equivalente a 11,37 ± 0,90 $IC_{95\%}$ espécies igualmente comuns), e de acordo com Simpson (1/D), 6,82 (± 0,648 $IC_{95\%}$). As curvas de rarefação e extrapolação para as estimativas de diversidade tenderam à estabilização.

Embora a vegetação associada a afloramentos rochosos em geral apresente um elevado número de espécies endêmicas, esse padrão não foi encontrado para a nossa área de estudo, o que pode ser explicado pela sua ocorrência contínua à matriz florestal. O sub-bosque da nossa área de estudo apresenta mistura de floras, sendo composto principalmente por espécies dos biomas Amazônia e/ou Cerrado. Diante das pressões antrópicas existentes no sul da Amazônia, reforçamos a importância da realização de inventários das comunidades herbáceas desse bioma, já que o risco de perda de espécies é ainda mais alarmante quando consideramos a subamostragem desse componente.
Palavras-chave: *Região do Cristalino; Levantamento Florístico; Método de Intersecção de Linha; Sul da Amazônia; Diversidade de Espécies; Sub-bosque Florestal.*

Introduction

Floristic and structural studies in tropical forests contemplating the woody component are common, being markedly different from the sampling effort for the herbaceous component (Linares-Palomino et al. 2009). The contribution of the herbaceous stratum to plant diversity is considerable (Gentry & Dodson 1987, Linares-Palomino et al. 2009, Pasion et al. 2018), as well as its ecological importance in the composition of vegetation strata, representing an important ecological filter as it alters environmental conditions, such as temperature and humidity, acting as a potential barrier to the emergence and establishment of tree species (Gilliam 1994; Royo & Carson 2006, George & Bazzaz 1999). Additionally, the assembly mechanisms of herbaceous and woody communities seem to be contrasting, with herbaceous showing a stronger niche-derived structure (Murphy et al. 2019). Thus, the expansion of studies of the herbaceous stratum has direct implications for the different management and conservation strategies that may be necessary for different forms of plant growth within the same community (Murphy et al. 2019).

Rock outcrops are usually surrounded by a vegetation matrix on more developed soils, contributing to the formation of vegetation mosaics, with different soil types, vegetation and microclimate (Sarthou & Villiers 1998). In addition, rock outcrops can constitute vegetation refuges, sheltering remnants of a relict flora more widely distributed in the past, presenting ecological peculiarities from their surroundings, and persisting in very particular environmental conditions (e.g. Colinvaux et al. 2000, Speziale & Ezcurra 2014). Leaves capable of desiccating and rehydrating, water reserve organs and structures capable of absorbing atmospheric moisture represent some of the characteristics that allow herbaceous plant species to thrive in rock outcrops (Lüttge et al. 2007). Thus, considering the environmental conditions in rock outcrops, such as water scarcity, nutrient deficiency, intense solar radiation, and high temperatures (Kluge & Brulfert 2000), the occurrence of species in these environments is not random, but conditioned by environmental factors, such as greater or lesser depth of soil (e.g. de Paula et al. 2015; Porembski et al. 2000). Thus, at a local scale, environmental filtering favors the presence of plant communities phylogenetically clustered in rock outcrops (Villa et al. 2018; Parmentier & Hardy 2009).

The southern Amazon border presents peculiar characteristics, arising from the mixture of rain forest, seasonal forest, and savannas, as well as the influence of well-defined precipitation seasonality (Kunz et al. 2009). The Southern Amazon encompasses the "arc of deforestation", a region with intense anthropic pressure resulting from changes in land use for mining, logging, and agriculture (Fearnside et al. 2017). In this sense, studies have highlighted the importance of expanding the sampling of vegetation in rock habitats in the south of the Amazon (Sasaki et al. 2010, Zappi et al. 2011, 2016). Based on this, samples of the woody component in Seasonal Deciduous Forest associated with rock outcrops in the Cristalino Region – focus of our study – have brought important contributions, such as the addition of species to the regional flora, expansion of species distribution areas, as well as discussions related to conservation status and endemism (Silva et al. 2020). The Cristalino Region shelters different types of vegetation and varied physiognomies that reflect its geological and geomorphological complexity, and constitutes a key area for biodiversity conservation in the Brazilian Amazon (Zappi et al. 2011, Maury et al. 2004).

We investigated the floristic, structure, ecology and conservation of the herbaceous component in a seasonal deciduous forest associated with rock outcrops in the Cristalino region, addressing the following questions: 1) What is the species composition of the herbaceous component? 2) What is the contribution of our survey to expanding the floristic list of the Cristalino Region? 3) Which and how many endemic and threatened herbaceous species occur there? 4) Which species, genera and families have the greatest frequency and cover? 5) How species-diverse is this stratum/vegetation? While answering these questions, we also addressed their implications for biodiversity conservation.

Material and Methods

1. *Study area*

The study area is located in the Cristalino region, more precisely in the Mirante da Serra Private Natural Heritage Reserve (*in portuguese*, *Reserva Particular do Patrimônio Natural*, RPPN) (Sasaki et al. 2010, Zappi et al. 2011) (Figure 1). In addition to the RPPN Mirante da Serra, the Cristalino region comprises the Cristalino, Castanheira and Gavião Real RPPNs, and the Cristalino State Park (Sasaki et al. 2010; Zappi et al. 2011). The Cristalino region is located in the far north of the state of Mato Grosso and includes part of the Rio Cristalino basin, which rises in the Serra do Cachimbo, and also part of the Nhandu river basin, both tributaries of the Teles Pires river (Zappi et al. 2011). Eight vegetation types can be found in this region: Submontane Dense Ombrophilous Forest, Submontane Open Ombrophilous Forest, Alluvial Dense Ombrophilous Forest, Semideciduous Seasonal Forest, Deciduous Seasonal Forest, *Campinarana*, Amazon *campo rupestre* and Riverine Vegetation (Sasaki et al. 2010, Zappi et al. 2011). The relief has slightly convex tops on ancient rocks of the Beneficent Group (Middle Proterozoic) and is inserted in four geomorphological units I. *Planalto do Cachimbo*; II. *Depressão do Norte de Mato Grosso*; III. *Depressão Interplanáltica dos Rios Juruena/Teles Pires* e IV. *Planaltos Residuais do Sul da Amazônia* (IBGE 2006). The main soil types of the Cristalino Region are Quartz Sands, Red-Yellow Argisols, Rock Outcrops, Litholic and Glazed Hydromorphic Neosols.

The soils are generally sandy, acidic, of medium to low fertility and susceptible to erosion (SEMA 2010). The climate is warm and humid, with a dry period of approximately four months – June to September (SEMA 2010). Average annual rainfall can range between 2,000 mm and 2,500 mm, while average annual temperatures are around 26°C (SEMA 2010). In the Cristalino region there are outcrops of arenitic and granitic rock that are scattered over sloping terrain or on top of the mountains. Granitic outcrops occur in the form of small areas associated with Seasonal Deciduous Forest, while arenitic outcrops are found in larger areas and have a distinct floristic composition (Sasaki et al.

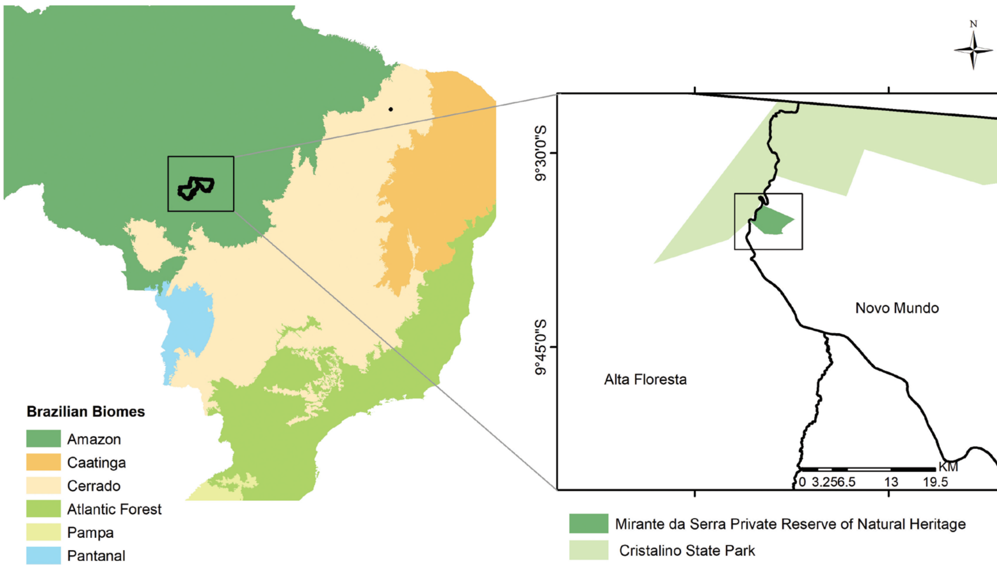

Figure 1. Mirante da Serra Private Natural Heritage Reserve (*in portuguese*, *Reserva Particular do Patrimônio Natural*, RPPN) located in the Cristalino Region, Southern Amazon.

Figure 2. Study area located in a Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (*in portuguese*, *Reserva Particular do Patrimônio Natural*, RPPN) in the Southern Amazon. A and B = Study area during rainy season; C and D = Study area during dry season.

2010). The vegetation type sampled in this study comprises Seasonal Deciduous Forest associated with granitic rock outcrops (Figure 2). The sample area is located between the coordinates 9°35'12" S and 55°54'59" W, in the municipality of Novo Mundo, MT, with an altitude varying between 280 and 350 m a.s.l..

2. Installation of sampling units

To install the permanent plot, we followed the recommendations of the RAINFOR Network (Amazon Network of Forest Inventories; Phillips et al. 2016), which develops a set of standardized actions to monitor forests in the Amazon, promoting an understanding of the dynamics of Amazon ecosystems (Phillips et al. 2016). As the RAINFOR Network method is described for the woody component, we performed adaptations for the herbaceous component, associating the line intercept method (Canfield 1941; Figure 3) with the RAINFOR Network plot delineation method. As guided by the RAINFOR Network, we delineated a 100 x 100 m (= 1 ha) plot, divided into 25 contiguous subplots (S), each measuring 20 x 20 m. We affixed iron rebars 5 mm in diameter and 1 m in length at the four ends of the permanent plot, and carried out the same procedure for the subplots.

3. Vegetation sampling and botanical material processing

To carry out the phytosociological survey, we used the line intercept method (Canfield 1941; Figure 3). This method consists of drawing lines over the vegetation to determine the composition of herbaceous species in the area (Munhoz & Felfili 2006; Figure 3). We traced 100 lines 100 m long perpendicular to the permanent plot, with 1 m intervals between them. We held a draw to define 10 subplots, and within each subplot we held another draw to mark a line (Sampling Unit – SU), totaling 10 sampled lines. Each SU was 20 m long. We then affixed iron bars, identified the lines with aluminum plates indicating the line number and subplot and georeferenced the center point of each line. We measured height, aerial part diameter and the horizontal projection of each individual that touched or came within 1 cm of the line.

We carried out 12 monthly incursions into the study area, between July 2016 and July 2017, covering all seasons. The botanical material was collected and herborized according to the methodology of Fidalgo & Bononi (1989). During the expeditions, we collected individuals in the reproductive stage within the subplots, as well as in the 10 m surrounding the plot and on the access trails to it. The surrounding matrix is composed of forest vegetation; in addition, it presents differences in soils, relief and incident light when compared to the rock outcrop area on which the permanent plot was installed.

The species were identified through consultations to the specific literature, online databases, comparisons with the collection of the Herbarium of the Southern Amazon (HERBAM) and consultations with specialists. We followed APG IV (2016) family classification. We checked the life forms and the spellings of the species names in the Flora do Brasil species list database (Flora do Brasil 2020). We verified materials deposited at HERBAM from surveys carried out during the Cristalino Flora Program (Sasaki et al. 2010, Zappi et al. 2011), as well as online searches on Reflora platforms (http://reflora.jbrj.gov.br/reflora/herbarioVirtual/) and speciesLink (https://specieslink.net/search/) to update possible new records for the area. We also verified the threatened status of the species according to the Brazilian National Center for the Conservation of Flora (CNCFlora – *Centro Nacional de Conservação da Flora*, http://cncflora.jbrj.gov.br/portal/). The material collected was incorporated into the HERBAM collection.

4. Community structure

We characterized the community structure of the herbaceous stratum through the projection on the line of intercepted individuals. To obtain the absolute cover (AC), we calculated the projection occupied by each individual in the SU and made a sum for all the SUs (Munhoz & Araújo

Figure 3. Phytosociological survey according to line intersection method (Canfield 1941) in a Seasonal Deciduous Forest associated with a granitic rock outcrop in the Southern Amazon. A = vegetation survey during rainy season; B = vegetation survey during dry season.

2011). We obtained the relative cover (CR) by dividing the absolute coverage (CA) of each species by the sum of the absolute coverage (CA) of all species, multiplying by 100. We also obtained the values of absolute and relative frequency (Munhoz & Araújo 2011).

CA_i = Absolute cover of the species "i"

$$CA_i = \sum_{i=1}^{n} P_i A$$

$\sum_{I=1}^{n} P_i A$ = sum of the species (i) projection in all SUs.

CR_i = Relative cover of the species "i"

$$CR_i = \left(\frac{CA_i}{\sum_{i=1}^{n} CA_i} \right) \cdot 100$$

$\sum_{I=1}^{n} CA_i$ = sum of all species (i) projection in all SUs.

FA_i = Absolute frequency of the species "i"

$$FA_I = \left(\frac{n_i}{n} \right) \cdot 100$$

n_i = number of SUs where species "i" occurred

n = total number of SUs sampled

FR_i = Relative frequency of the species "i"

$$FR_I = \left(\frac{FA_i}{\sum_{i=1}^{n} FA_i} \right) \cdot 100$$

$\sum_{I=1}^{n} FA_i$ = sum of the absolute frequency of all species.

5. *Species diversity*

We estimated species diversity through rarefaction and extrapolation curves (Chao et al. 2014) with the "iNEXT" package (Hsieh et al. 2016). The confidence interval used was 95%, obtained from 1,000 *bootstrap* randomizations (Chao et al. 2014). The species diversity indices we obtained were numeric richness, Shannon index (H'), Shannon Exponential (H' exp) – also known as effective number of species or number of equally common species (Peet 1974, Jost et al. 2006) – and Simpson index (1/D) (see, for example, Magurran 2013).

Results

We recorded 86 species, 62 genera and 25 families for the herbaceous component of the Mirante da Serra Private Natural Heritage Reserve – RPPN Mirante da Serra (Table 1; Figure 4). The families with the highest number of genera were Orchidaceae (16 spp.), Poaceae (11 spp.), Marantaceae (10 spp.) and Cyperaceae (seven spp.) (Table 1). The genera with the highest number of species were *Paspalum* (five spp.), *Cyperus* and *Goeppertia*, with four species each, and *Maranta*, with three species (Table 1).

There was an increase of 26 new records of species for Flora in the Cristalino region, which comprises the Cristalino State Park and 4 RPPN (Table 1). Among the species added to the Cristalino Flora, we included *Philodendron deflexum* Poepp. ex Schott. This species had already been previously collected and listed in the Cristalino Region inventories (Henicka, G.S. 125), but it was not yet fully named. We also provided the complete identification for *Griffinia nocturna* Ravenna, and this was the first report of occurrence for this species in a forest matrix in the Amazon biome.

Table 1. Herbaceous species from the Seasonal Deciduous Forest associated with a rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (*in portuguese, Reserva Particular do Patrimônio Natural*, RPPN) in the Amazon region of Mato Grosso. RPPN-MS: Mirante da Serra Private Natural Heritage Reserve; CRIST: Cristalino Region; SU: occurrence recorded from our sampling units; Random: occurrence recorded from random walk around RPPN-MS; Voucher: collector number; Occurrences in Brazilian biomes according to Flora do Brazil 2020: amz = Amazon, atl = Atlantic Forest; caa = Caatinga, cer = Cerrado, pam = Pampa, pan = Pantanal; * = new floristic occurrences for the Cristalino Region.

Family/Species	Life form	RPPN-MS	CRIST	SU or Random	Occurrence in Brazilian biomes	Voucher
ACANTHACEAE						
Acanthaceae sp.	Herb	X	–	Random	–	Gallo, S.C. 157
AMARYLLIDACEAE						
Griffinia nocturna Ravenna*	Herb	X	X	Random	cer	Gallo, S.C. 17
ARACEAE						
Anthurium affine Schott	Herb	X	X	Random	atl, caa, cer,	Gallo, S.C. 156
Anthurium bonplandii Bunting	Herb	X	X	SU	amz	Gallo, S.C. 53
Philodendron acutatum Schott	Herb	X	X	SU	atl, amz, caa, cer	Gallo, S.C. 124
Philodendron deflexum Poepp. ex Schott*	Herb	X	X	Random	amz	Henicka, G.S. 125

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Family/Species	Life form	RPPN-MS	CRIST	SU or Random	Occurrence in Brazilian biomes	Voucher
ASTERACEAE						
Ichthyothere rufa Gardner	Herb	X	X	SU	cer	Gallo, S.C. 91
Lepidaploa remotiflora (Rich.) H. Rob.	Herb	X	X	SU	cer	Gallo, S.C. 162
Lepidaploa sp.	Herb	X	–	Random	–	Gallo, S.C. 154a
Riencourtia pedunculosa (Rich.) Pruski	Herb	X		SU	amz, cer	Gallo, S.C. 62
BROMELIACEAE						
Aechmea bromeliifolia (Rudge) Baker	Herb	X	X	Random	amz, atl, caa, cer	Gallo, S.C.13
Aechmea castelnavii Baker	Herb	X	X	Random	amz, atl, cer	Gallo, S.C. 14
Ananas ananassoides (Baker) L.B.Sm.	Herb	X	X	SU	amz, atl, caa, cer	Gallo, S.C. 02
Bromelia balansae Mez	Herb	X	X	SU	amz, atl, cer, pan	Gallo, S.C. 37
Pitcairnia burchellii Mez	Herb	X	X	SU	amz, atl, caa, cer	Gallo, S.C. 81
CACTACEAE						
Epiphyllum phyllanthus (L.) Haw.	Herb	X	X	Random	amz, atl, caa, cer, pan	Gallo, S.C. 59
COMMELINACEAE						
Commelina obliqua Vah l*	Herb	X		Random	amz, atl, caa, cer, pam, pan	Gallo, S.C. 128a
Commelina sp.	Herb	X	–	Random	–	Gallo, S.C. 131
Dichorisandra hexandra (Aubl.) C.B.Clarke	Herb	X	X	SU	amz, atl, caa, cer, pam, pan	Gallo, S.C. 121
Dichorisandra villosula Mart. ex Schult.f.	Herb	X	X	Random	amz	Gallo, S.C. 60
CONVOLVULACEAE						
Ipomoea megapotamica Choisi*	Herb	X		Random	atl, caa, cer,	Da Silva, D.R. 164
COSTACEAE						
Chamaecostus lanceolatus (Petersen) C.D.Specht & D.W. Stev.	Herb	X	X	SU	amz	Gallo, S.C. 41
Chamaecostus acaulis (S.Moore) T.André & C.D.Specht	Herb	X	X	Random	amz, cer	Gallo, S.C. 44
Costus arabicus L.	Herb	X	X	Random	amz, atl, cer, pan	Gallo, S.C. 83
CYPERACEAE						
Cyperus brevifolius (Rottb.) Endl. ex Hassk*	Herb	X		Random	amz, atl, caa, cer, pam, pan	Gallo, S.C. 05
Cyperus meyenianus Kunth*	Herb	X		Random	amz, atl, caa, cer, pam, pan	Gallo, S.C. 140
Cyperus sp.3	Herb	X		Random	atl, pam	Gallo, S.C. 129
Cyperus sp.4	Herb	X		Random	amz, atl, cer,	Gallo, S.C. 160

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Eleocharis minima Kunth	Herb	X	X	SU	amz, atl, caa, cer, pam, pan	Gallo, S.C. 134
Rhynchospora pubera (Vahl) Boekeler	Herb	X	X	Random	amz, atl, cer	Gallo, S.C. 98
Cyperaceae sp.	Herb	X	–	Random	–	Gallo, S.C. 118
DIOSCOREACEAE						
Dioscorea piperifolia Humb. & Bonpl. ex Willd.	Liana	X	X	SU	amz, atl, caa, cer	Gallo, S.C. 40/43
EUPHORBIACEAE						
Microstachys corniculata (Vahl) Griseb.*	Herb	X		SU	amz, atl, caa, cer	Gallo, S.C. 04
FABACEAE						
Ancistrotropis peduncularis (Kunth) A. Delgado	Herb	X	X	Random	amz, atl, caa, cer, pam, pan	Da Silva, D.R. 174
Chamaecrista trichopoda (Benth.) Britton & Rose ex Britton & Killip*	Herb	X		Random	amz, atl, caa, cer	Gallo, S.C. 137
Mimosa skinneri Benth.	Herb	X	X	SU	amz, cer	Gallo, S.C. 66b
GESNERIACEAE						
Nautilocalyx forgetii (Sprague) Sprague	Herb	X	X	SU	amz	Gallo, S.C. 55
HAEMODORACEAE						
Xiphidium caeruleum Aubl.*	Herb	X		Random	amz, atl, cer	Gallo, S.C. 78
HELICONIACEAE						
Heliconia psittacorum L.f.	Herb	X	X	Random	amz, atl, caa, cer, pan	Gallo, S.C. 82b
HYPOXIDACEAE						
Curculigo scorzonerifolia (Lam.) Baker*	Herb	X		Random	amz, atl, cer	Gallo, S.C. 22
LENTIBULARIACEAE						
Utricularia nervosa G.Weber ex Benj.	Herb	X	X	Random	amz, atl, cer	Gallo, S.C. 74
MALVACEAE						
Sida linifolia Cav.*	Herb	X		Random	amz, atl, caa, cer, pan	Gallo, S.C. 152
MARANTACEAE						
Goeppertia allouia (Aubl.) Borchs. & S. Suárez	Herb	X		SU	amz, cer	Gallo, S.C. 58
Goeppertia gardneri (Baker) Borchs. & S.Suárez	Herb	X	X	Random	caa, cer	Gallo, S.C. 73

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Family/Species	Life form	RPPN-MS	CRIST	SU or Random	Occurrence in Brazilian biomes	Voucher
Goeppertia mansonis (Körn.) Borchs. & S. Suárez	Herb	X	X	SU	amz, cer, pan	Gallo, S.C. 38
Goeppertia ovata (Nees & Mart.) Borchs. & S.Suárez	Herb	X	X	SU	amz, cer	Gallo, S.C. 49
Ischnosiphon sp.1	Herb	X	–	Random	–	Gallo, S.C. 174
Ischnosiphon sp.2	Herb	X	–	Random	–	Gallo, S.C. 47
Maranta bracteosa Petersen*	Herb	X		SU	amz, cer	Gallo, S.C. 39
Maranta cyclophylla K.Schum.	Herb	X	X	SU	amz, cer	Gallo, S.C. 20
Maranta phrynioides Körn.	Herb	X	X	SU	amz, atl, pan	Gallo, S.C. 23
Myrosma cannifolia L.f.*	Herb	X		Random	amz, atl, caa, cer, pan	Gallo, S.C. 72
MELASTOMATACEAE						
Pseudoernestia cordifolia (O.Berg. ex Triana) Krasser	Herb	X		Random	amz	Gallo, S.C. 111
Pterolepis buraeavii Cogn.*	Herb	X		Random	amz, cer	Gallo, S.C. 114
Pterolepis perpusilla (Naudin) Cogn.*	Herb	X		Random	amz, caa, cer	Gallo, S.C. 161
ORCHIDACEAE						
Aspasia variegata Lindl.*	Herb	X		Random	amz, cer	Gallo, S.C. 16
Campylocentrum mattogrossense Hoehne*	Herb	X		Random	amz, cer	Gallo, S.C. 172
Catasetum telespirense Benelli & Soares-Lopes*	Herb	X		Random	amz	Gallo, S.C. 182
Cyrtopodium andersonii (Lamb. ex Andrews) R.Br.*	Herb	X		SU	amz	Gallo, S.C.08
Encyclia randii (Barb. Rodr.) Porto & Brade*	Herb	X		Random	amz	Gallo, S.C.15
Epidendrum stiliferum Dressler*	Herb	X		Random	amz, cer	Gallo, S.C. 143
Epidendrum strobiliferum Rchb.f.	Herb	X	X	Random	amz, cer	Gallo, S.C. 21
Laelia marginata (Lindl.) L.O. Williams	Herb	X	X	Random	amz	Gallo, S.C. 186
Orchidaceae sp.	Herb	X	–	Random	–	Gallo, S.C. 170
Polystachya concreta (Jacq.) Garay & Sweet	Herb	X	X	Random	amz, atl, caa, cer, pam, pan	Gallo, S.C. 146
Polystachya foliosa (Hook.) Rchb.f.	Herb	X	X	Random	amz, cer	Gallo, S.C. 28

Continue...

...Continuation

Prosthechea aemula (Lindl.) W.E.Higgins	Herb	X	X	Random	amz, atl, caa, cer	Gallo, S.C. 54
Scaphyglottis stellata Lodd. ex Lindl.	Herb	X	X	Random	amz, cer	Gallo, S.C. 165
Sobralia augusta Hoehne*	Herb	X		Random	amz	Gallo, S.C. 75
Solenidium lunatum (Lindl.) Schltr.	Herb	X	X	Random	amz	Gallo, S.C. 82a
Trichocentrum sprucei (Lindl.) M.W.Chase & N.H.Williams*	Herb	X		Random	amz	Gallo, S.C. 191
PIPERACEAE						
Peperomia pellucida (L.) Kunth	Herb	X	X	Random	amz, atl, caa, cer	Gallo, S.C. 88
POACEAE						
Hildaea cf *pallens* (Sw.) C. Silva & R.P. Oliveira	Herb	X	X	SU	amz, atl, caa, cer, pam, pan	Gallo, S.C. 115/153b
Hildaea tenuis (J. Presl & C. Presl) C. Silva & R.P. Oliveira*	Herb	X		SU	amz, cer	Gallo, S.C. 145
Ichnanthus calvescens (Nees ex Trin.) Döll	Herb	X		SU	amz, atl, caa, cer, pan	Gallo, S.C. 167/153a
Lasiacis ligulata Hitchc. & Chase	Herb	X	X	Random	amz, atl, caa, cer	Gallo, S.C. 155
Olyra latifolia L.	Herb	X	X	Random	amz, atl, caa, cer	Gallo, S.C. 105
Paspalum glaziovii (A.G.Burm.) S.Denham*	Herb	X		Random	cer	Da Silva, D.R. 152
Paspalum sp.2	Herb	X	–	SU		Gallo, S.C. 120
Paspalum sp.5	Herb	X	–	SU		Gallo, S.C. 117
Paspalum sp.6	Herb	X	–	SU		Gallo, S.C. 113
Paspalum sp.7	Herb	X	–	SU		Gallo, S.C. 179
Rugoloa pilosa (Sw.) Zuloaga	Herb	X	X	SU	amz, atl, caa, cer, pam, pan	Gallo, S.C. 90
RUBIACEAE						
Borreria latifolia (Aubl.) K.Schum.	Herb	X	X	Random	amz, atl, caa, cer, pam	Gallo, S.C. 127
Palicourea colorata (Willd. ex Roem. & Schult.) Delprete & J.H.Kirkbr.	Herb	X		Random	amz, atl, caa, cer	Gallo, S.C. 101
Spermacoce exilis (L.O.Williams) C.D.Adams*	Herb	X		Random	amz, atl, caa, cer	Gallo, S.C.110

Only seven species present in our study area have already had their conservation status assessed by the CNCFlora. Among them, six species were found in the 'Least Concern' category, which is not a threatened status: *Aechmea bromeliifolia* (Rudge) Baker, *Bromelia balansae* Mez, *Curculigo scorzonerifolia* (Lam.) Baker, *Epiphyllum phyllanthus* (L.) Haw., *Peperomia pellucida* (L.) Kunth and *Pterolepis perpusilla* (Naudin) Cogn.. The single species classified as threatened with extinction was *Griffinia nocturna* Ravenna, which was assigned to the 'Critically Endangered' category. However, as we are providing evidence on the increasing of its distribution area, the conservation status of this species should be recalculated. Thus, we performed an exercise with GEOCAT (Bachman et al. 2011) applying the default values of

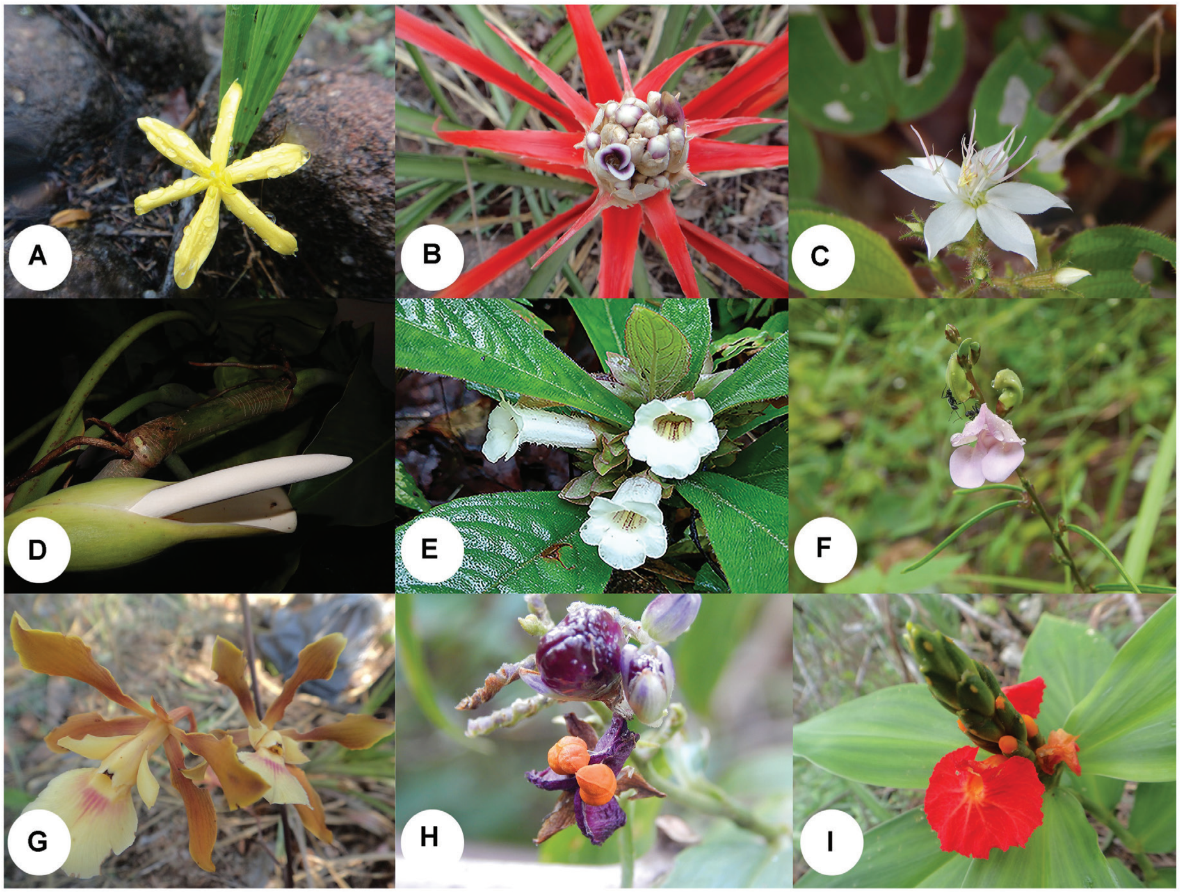

Figure 4. Herbaceous species from the Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (*in Portuguese*, *Reserva Particular do Patrimônio Natural*, RPPN) in the Southern Amazon. A = *Curculigo scorzonerifolia* (Lam.) Baker; B = *Bromelia balansae* Mez; C = *Pseudoernestia cordifolia* (O.Berg. ex Triana) Krasser; D = *Philodendron acutatum* Schott; E = *Nautilocalyx forgetii* (Sprague) Sprague; F = *Ancistrotropis peduncularis* (Kunth) A. Delgado; G = *Encyclia randii* (Barb.Rodr.) Porto & Brade; H = *Dichorisandra hexandra* (Aubl.) C.B.Clarke; I = *Chamaecostus lanceolatus* (Petersen) C.D.Specht & D.W. Stev.

the IUCN – RLS (The International Union for Conservation of Nature's Red List of Threatened Species) for Extent of Occurrence (EOO) and Area of Occupancy (AOO) analyses of *G. nocturna* (see Supplementary Material 1 for more details). According to this exercise, *G. nocturna* has an AOO of 92,000 km² (Endangered) and EOO of 1,397,712,743 km² (Least Concern). Thus, with the expansion of its geographic distribution area, *G. nocturna* would move from the 'Critically Endangered' to 'Endangered' category, thus remaining threatened with extinction.

Considering only the phytosociological survey carried out on the rock outcrop, we sampled 903 individuals of the herbaceous component, which were distributed into 31 species, 23 genera and 13 families (Table 2). The families with the highest number of species were Poaceae (eight species), Marantaceae (six species), Asteraceae and Bromeliaceae (three species each). The genera with the highest number of species were *Paspalum* (four species), *Maranta* and *Goeppertia* (three species each). *Ananas* (238), *Riencourtia* (212) and *Goeppertia* (118) were the genera with the highest number of individuals (Supplementary Material 2a), and Bromeliaceae (312), Asteraceae (244) and Marantaceae (134) were the families with the highest number of individuals (Supplementary Material 2b). The species with the highest number of individuals were *Ananas ananassoides* (238), *Riencourtia pedunculosa* (212), and *Bromelia balansae* and *Goeppertia ovata* (72 individuals each; Table 2).

Ananas, *Bromelia*, *Goeppertia* and *Riencourtia* were the genera with the highest cover value (Supplementary Material 2a), and *Ananas* and *Goeppertia* were the only genera that occurred in all SUs. Bromeliaceae, Marantaceae and Poaceae had the highest cover values and were the only families that occurred in all SUs (Supplementary Material 2b). *Ananas ananassoides*, *Bromelia balansae*, *Goeppertia ovata* and *Riencourtia pedunculosa* were the species with the highest cover values, with *A. ananassoides* being the only species that occurred in all 10 SUs (Table 2).

We found 31 (± 2.24 $IC_{95\%}$) species in the 10 sampled lines. We observed a trend towards stabilization in the rarefaction and extrapolation curves for species richness (Figure 5a; Supplementary Material 3). In this sense, if we sampled twice as many individuals, there would be an increase of 4.31% in the number of species. The species diversity was 2.43 nats.individual^{-1} (Shannon), which corresponds to 11.37 (± 0.90 $IC_{95\%}$) equally common species (Shannon exponential), while the Simpson index (1/D) was 6.82 (± 0.648 $IC_{95\%}$). The curves of the Shannon and Simpson indices also stabilized (Figure 5b and 5c).

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Table 2. Phytosociological parameters for species sampled in survey according to line intersection method (Canfield 1941) in a Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (in portuguese, *Reserva Particular do Patrimônio Natural*, RPPN) in the Amazon region of Mato Grosso.

Species	Number of individuals	Absolute frequency (%)	Relative frequency (%)m	Absolute cover (m)	Relative cover (%)
Ananas ananassoides	238	100	8.4	336	47.1
Bromelia balansae	72	80	6.7	130.8	18.3
Goeppertia ovata	72	90	7.6	48.7	6.8
Riencourtia pedunculosa	212	80	6.7	46	6.4
Goeppertia mansonis	43	70	5.9	23.8	3.3
Philodendron acutatum	25	80	6.7	22.6	3.2
Paspalum sp 2	23	60	5	16.2	2.3
Chamaecostus lanceolatus	51	40	3.4	12.1	1.7
Ichnanthus calvescens	21	60	5	11.8	1.7
Paspalum sp 5	21	40	3.4	9.8	1.4
Paspalum sp 6	10	50	4.2	8.6	1.2
Cyrtopodium andersonii	3	20	1.7	5	0.7
Hildaea tenuis	9	30	2.5	4.5	0.6
Maranta cyclophylla	7	30	2.5	4.4	0.6
Maranta phrynioides	7	50	4.2	4.5	0.6
Paspalum sp 7	9	30	2.5	4.2	0.6
Ichthyothere rufa	19	20	1.7	3.7	0.5
Rugoloa pilosa	6	40	3.4	3.8	0.5
Anturium bonplandi	3	10	0.8	1.9	0.3
Goeppertia allouia	3	20	1.7	2.3	0.3
Hildaea pallens	3	20	1.7	2.2	0.3
Microstachys corniculata	9	40	3.4	1.9	0.3
Lepidaploa remotiflora	13	20	1.7	1.3	0.2
Maranta bracteosa	2	10	0.8	1.5	0.2
Mimosa skineri	1	10	0.8	1.5	0.2
Dichorisandra hecxandra	5	20	1.7	0.6	0.1
Dioscoria piperifolia	4	10	0.8	0.5	0.1
Eleocharis minima	2	10	0.8	1	0.1
Nautilocalyx forgetii	7	30	2.5	1.1	0.1
Pitcairnia burchelli	2	10	0.8	0.6	0.1
Ancistrotropis peduncularis	1	10	0.8	0.4	<0.1

Discussion

Our study contributes to the knowledge of the herbaceous layer of the Cristalino Region, a key area for biodiversity conservation in the Amazon. Although the important project 'Flora do Cristalino' contributed to reducing the knowledge gaps about the herbaceous component of the Amazon forest in its southern limit, the sampling effort varied between the different vegetation types, being more concentrated in the Submontane Dense Ombrophilous Forest, as phytophysiognomies as the Seasonal Deciduous Forest were proportionally less sampled (Sasaki et al. 2010, Zappi et al. 2011). Thus, our study increases the sampling for the Seasonal Deciduous Forest associated with rock outcrops in the Cristalino Region.

The Orchidaceae family had the largest number of species and was also the one that most contributed to the increase of new records for the Flora of the Cristalino Region, totaling eight new records: *Aspasia*

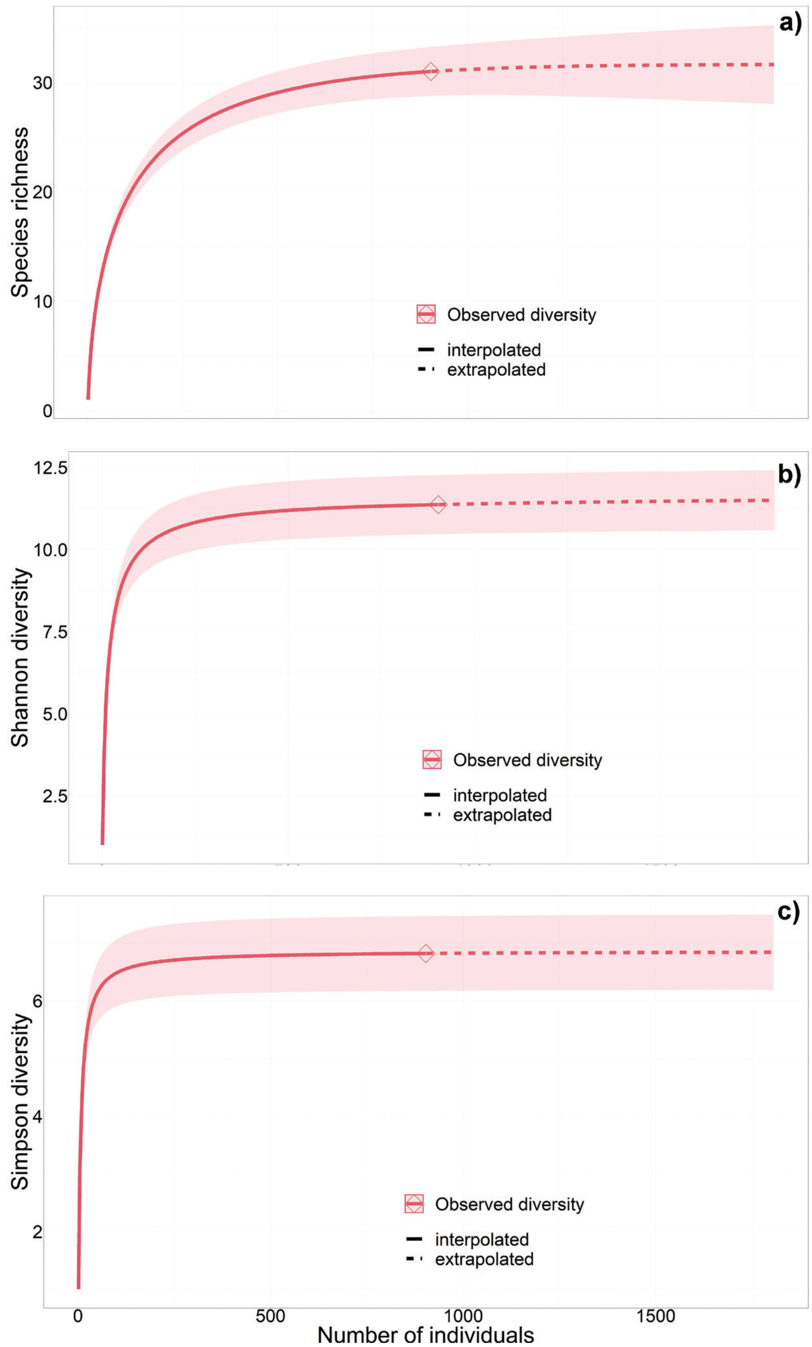

Figure 5. Interpolated and extrapolated species diversity considering twice the number of sampled species in a Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (*in portuguese, Reserva Particular do Patrimônio Natural, RPPN*) in the Amazon region of Mato Grosso. a) Species Richness; b) Shannon Exponential Diversity; c) Simpson Diversity (1/D).

variegata Lindl., *Campylocentrum mattogrossense* Hoehne., *Catasetum telespirense* Benelli & Soares-Lopes, *Cyrtopodium andersonii* (Lamb. ex Andrews) R.Br., *Encyclia randii* (Barb.Rodr.) Porto & Brade, *Epidendrum stiliferum* Dressler, *Sobralia augusta* Hoehne, and *Trichocentrum sprucei* (Lindl.) M.W.Chase & N.H.Williams. We believe that this increase in the Flora of the Cristalino Region may be related to the sampling effort, since the present study focused on a single area, with monthly visits, which facilitated the observation of different phenological phases of the species of this family, enabling collection and identification. A similar study found a similar increase in the species richness of Orchidaceae when the sampling effort was increased (Neto et al. 2007).

The low number of threatened species in our study area was likely due to the knowledge bias towards the herbaceous component. Such bias is well documented for the Amazon flora (BFG 2015). However, Silva et al. (2020), investigating woody species in the same study area as ours, also found a small number of species already assessed for threat (16 species already assessed and 102 not assessed). Thus, this seems to be a general gap – not only for the herbaceous stratum – in the threatened species assessment for the RPPN Mirante da Serra, and perhaps for the Amazon as a whole. Considering the Amazon as a whole, the general perception is that its plants are more widely distributed (BGF 2015), but we are aware that there is a knowledge gap regarding plant distribution and therefore of the conservation status of Amazonian plants.

G. nocturna, Critically Endangered (CR) (CNCFlora 2022) and commonly found in Seasonal Deciduous Forest associated with rock outcrops (Flora do Brasil 2020), had already been recorded for the Cerrado-Amazon transition and for the Amazon biome in savanna vegetation (voucher Sardelli, L. 920 and Engels, M.E. 3757). The occurrence of this species in a matrix of forest vegetation within the Amazon biome is a novelty. *G. nocturna* is considered CR due to the fact that a number of subpopulations of this species have become extinct due to environmental disturbances. In addition, the species has a commercially collected bulb (CNCFlora 2021). Thus, by expanding knowledge about the distribution area of *G. nocturna*, we provide support for management measures and protection of its remaining subpopulations.

Vegetation on rock outcrops generally has a high number of endemic species (Gröger & Huber 2007, Porembski 2007), but this pattern was not supported in our study area. In this sense, endemisms in rock outcrops may be associated with their degree of isolation in relation to similar habitats and also with the intensity of the barrier that the ecological conditions on the rock surface represent for the establishment of plants from the surrounding vegetation (Burke 2002a and b). Thus, although we have not evaluated the floristic composition of the forest matrix, the absence of endemisms in our study area may be related to its continuous occurrence in the forest matrix. On the other hand, we recorded species widely distributed in vegetation associated with rock outcrops, such as *Aechmea bromeliifolia* (Rudge) Baker, *Borreria latifolia* (Aubl.) K.Schum., *Microstachys corniculata* (Vahl) Griseb, *Philodendron acutatum* Schott, *Pitcairnia burchellii* Mez and *Sida linifolia* Cav. (Flora do Brasil 2020), as well as species widely distributed in rock outcrops and Seasonal Deciduous Forest, such as *Chamaecrista trichopoda* (Benth.) Britton & Rose ex Britton & Killip, *Commelina obliqua* Vah, *Curculigo scorzonerifolia* (Lam.) Baker, *Dichorisandra hexandra* (Aubl.) C.B.Clarke, *Ichnanthus calvescens* (Nees ex Trin.) Döll and *Polystachya concreta* (Jacq.) Garay & Sweet (Flora do Brasil 2020). The herbaceous layer of the Seasonal Deciduous Forest on a rock outcrop of the RPPN Mirante da Serra presents a mixture of floras, being composed mainly of species from the Amazon and/or Cerrado biomes, confirming the pattern found on the southern edge of the Amazon (IBGE 2004, Kunz et al. 2009).

The families with 100% frequency in the sampling units were Bromeliaceae, Marantaceae and Poaceae, and the greatest floristic richness was recorded for the Poaceae. In fact, Poaceae is among the most important families of rock outcrops worldwide, while Bromeliaceae is a typical component of South American rock outcrops (Porembski 2007). In the Deciduous Seasonal Forest, the scarcity of soil makes water a limiting factor for vegetation in the dry season, leading to the loss of leaves and, consequently, to the opening of the canopy (Sazaki et al. 2010), which may favour herbaceous species by providing more sunlight for the understorey plants. In this regard, leaf fall in tropical deciduous forests contributes to the increase in the litter layer which, when decomposing influences the fertility of the understory substrate (e.g. Jaramillo & Sanford 1995). In addition, the opening of the canopy contributes to the anemochoric dispersion (Howe & Smallwood 1982), a common syndrome in representative families in the study area, such as Asteraceae, Bromeliaceae, Cyperaceae, Orchidaceae and Poaceae.

The largest number of individuals sampled belonged to the Bromeliaceae family, with *Ananas ananassoides* (Baker) L.B.Sm. as the most abundant. This species also had the highest frequency and the greatest coverage in our study area. In a savanna area in the Amazon-Cerrado transition, Elias et al. (2017) also found high abundance and frequency of *A. ananassoides*. This abundance may be related to the fact that the propagation of *A. ananassoides* occurs both vegetative and sexually (Paula & Silva 2004). We found *A. ananassoides* both in places exposed to intense light and in shaded places, demonstrating its tolerance to different light conditions (Proença & Sajo 2007). This fact may be related to the adaptation of the species in different environments of the seasonal forest understory. In addition, its leaf structure is rigid, succulent, and thick (Crayn et al. 2015), which ensures greater resistance to water stress and high temperatures, favoring its occupation (Proença & Sajo 2007) in rock outcrops.

Marantaceae had the second largest number of individuals and was represented by two genera in the sample units, *Goeppertia* and *Ischnosiphon*, with *Goeppertia* being one of the two genera in our quantitative survey with 100% frequency. *Goeppertia* is the most diverse genus of the Marantaceae (Borchsenius et al. 2012), preferentially inhabiting humid environments. When they occur in environments with pronounced seasonality, the leaves perish in response to water deficit and are renewed at the beginning of the rainy season, using the starch reserves present in their tubers (Kennedy 1978). Among the *Goeppertia* species, *Goeppertia ovata* (Nees & Mart.) Borchs. & S.Suárez was the one with the highest number of individuals, locally known as *ariá*, with nutritious tubers often used as a source of starch in the Amazon (Barros et al. 2021).

The cover of a species in a given environment can be influenced by its morphology or way of life (Munhoz & Felfili 2008). For example, *Bromelia balansae* Mez, with leaves that can range between 89–187 x 2–2.9 cm (Araújo, 2016), and *G. ovata,* with leaves that can reach an average of 65.7–79.4 x 14.5−16.7 cm (Saka 2016), had the second and third highest relative cover (18.3 and 6.8%), respectively, although they had only 72 individuals each. In turn, *Riencourtia pedunculosa* (Rich.) Pruski, a delicate annual herb with linear and narrow leaves ranging from 1.2–7.5 x 0.1–1.6 cm, with width varying between 0.1–0.4 mm in rock outcrops (Bringel 2014), presented more than twice the number of individuals (212) in relation to the aforementioned species, but had only the fourth highest relative cover (6.4%). Thus, the size of the leaf blade seems to have been more important in determining the relative cover of these species in the study area, as species with fewer individuals, but larger leaves, had greater relative cover.

Our species diversity estimates were higher than those recorded for herbaceous communities in the Cerrado-Amazon transition (Ivanauskas et al. 2004, Melo-Santos et al. 2013). This fact seems to be related to the fact that these studies were carried out in semideciduous or evergreen forests, and in the deciduous forests the higher incidence of light contributes to the increase in the diversity of herbaceous species (*e.g.* Sagar et al. 2012). However, in Central Amazonia, Costa et al. (2005) recorded 87 species for an herbaceous community; in such a study, the higher number of species may be related to the method and sampling effort adopted, since the collections were carried out in 59 plots of 250 x 2 m, being superior to that carried out in the RPPN Mirante da Serra. When we compare our results with studies carried out in herbaceous communities located in rock outcrops of southern Amazonia, such as the Carajás National Forest (Nunes et al. 2009), the Shannon diversity values (H') of these communities were higher than the values found at the RPPN Mirante da Serra (3.3 nats.individual^{-1} and 2.43 nats. individual^{-1}, respectively). Here again, the method and sampling effort differed, and the Shannon index is strongly influenced by the variation in sampling effort (Magurran 2013). In this sense, more standardized studies in herbaceous communities in the Southern Amazon would allow a better understanding of their patterns of diversity. Herbaceous component inventory networks can be a strategy to fill this gap.

In view of the anthropic pressures faced by existing in the southern Amazon, we reinforce the importance of carrying out inventories of its herbaceous communities, since the risk of species loss is even more alarming once we consider the undersampling of this component. The increments to the Cristalino Flora, as well as the convergence of both Amazonian and Cerrado species in the study area, reinforce the need for conservation and expansion of investigations of rock outcrops.

Supplementary Material

The following online material is available for this article:

Supplementary Material 1 – *Griffinia nocturna* Ravenna had its first occurrence records in a matrix of forest vegetation within the Amazon biome.

Supplementary Material 2 – a: Phytosociological parameters for all genera sampled using the line intersection method in a Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (in portuguese, Reserva Particular do Patrimônio Natural, RPPN) in the Southern Amazon. b: Phytosociological parameters for families sampled in survey according to line intersection method in a Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (in portuguese, *Reserva Particular do Patrimônio Natural*, RPPN) in the Southern Amazon.

Supplementary material 3 – Diversity species estimates for the herbaceous component in a Seasonal Deciduous Forest associated with a granitic rock outcrop of the Mirante da Serra Private Natural Heritage Reserve (in portuguese, *Reserva Particular do Patrimônio Natural,* RPPN) in the Southern Amazon. a) Species Richness; b) Shannon Exponential Diversity; c) Simpson Diversity (1/D). qD: the diversity estimate of order q; qD.LCL and qD.UCL: the 95% lower and upper confidence limits of diversity, respectively; SC: sample coverage estimate; SC.LCL and SC.UCL: the 95% lower and upper confidence limits of sample coverage, respectively.

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Associate Editor

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Author Contributions

Sandra Cristina Gallo: led the study, carried out fieldwork and wrote the first version of the manuscript.

Mônica A. Cupertino-Eisenlohr: reviewed the floristic data, analyzed the data and contributed to the final writing.

Dennis Rodrigues da Silva: carried out field work and contributed to the review of floristic data.

Cassia Beatriz Rodrigues Munhoz: co-supervised the work and contributed to the final writing.

Pedro V. Eisenlohr: guided the work, coordinated the project, analyzed the data and contributed to the writing in all its stages.

Conflicts of Interest

None.

Ethics

Authors have complied with the guidelines established by the ethics committees of their respective research institutions.

Data Availability

All data used to run our numeric analysis are available at:

Eisenlohr, Pedro, 2022, "Replication Data for paper "Floristics and structure of herbaceous component in a deciduous seasonal forest associated with rock outcrops in the Cristalino Region, a key area for Amazon conservation", https://doi.org/10.48331/scielodata.STDRAK, SciELO Data, DRAFT VERSION, UNF:6:af7yaetZFTi7zKhGqnl2mA== [fileUNF]

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