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Woody vegetation associated with rocky outcrops in Southern Amazonia: a starting point to unveil a unique flora

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Abstract: Vegetation associated with rocky outcrops is responsible for increasing floristic and landscape diversity, since its flora can be different from the adjacent landscape. Our objective was to characterize the woody vegetation associated with the rocky outcrop of the RPPN Mirante da Serra, Cristalino region, Mato Grosso State, Brazil. In a Deciduous Seasonal Forest associated with granite outcrops, we demarcated a plot of 1ha. We performed collections on this plot, installed for conducting monitoring studies, and also random collections on trails near the plot to better represent the outcrop flora. We totaled 126 species, 95 genera and 39 families. Overall, 18 species were increased to the Flora of Cristalino - with seven new records to the flora of Mato Grosso and four new records to the Amazon Domain. We found two threatened and 17 Brazilian endemic species. The rocky outcrop present in the RPPN Mirante da Serra is an important conservation area for a continuous execution of floristic studies in a manner to enable a monitoring program of the area, considering the new occurrence records and also because it contains threatened species.
Keywords: *Conservation; Cristalino; Deciduous Seasonal Forest; Floristics.*

Vegetação lenhosa associada a afloramentos rochosos na Amazônia Meridional: um marco inicial que revela uma flora única

Resumo: A vegetação que se associa a afloramentos rochosos é responsável por incrementar a diversidade florística e de paisagens, uma vez que a flora pode ser distinta da paisagem circundante. Nosso objetivo foi caracterizar a vegetação lenhosa sobre o afloramento rochoso da RPPN Mirante da Serra, região do Cristalino, estado de Mato Grosso, Brasil. Em uma Floresta Estacional Decidual associada a afloramento granítico, demarcamos uma parcela de 1 ha. Realizamos coletas nesse *plot*, instalado para a realização de estudos de monitoramento e, ainda, coletas aleatórias em trilhas próximas da parcela para melhor representar a flora do afloramento. A amostragem resultou em um total de 126 espécies, 95 gêneros e 39 famílias. Ao todo, 18 espécies foram incrementadas à Flora do Cristalino, das quais sete são novos registros à flora do estado de Mato Grosso e quatro ao Domínio da Amazônia. Encontramos duas espécies ameaçadas e 17 endêmicas do Brasil. O afloramento rochoso presente na RPPN Mirante da Serra é uma importante área de conservação para uma contínua realização de estudos florísticos de modo a possibilitar um programa de monitoramento da área, considerando os novos registros de ocorrência e, também, por conter espécies ameaçadas.
Palavras-chave: *Conservação; Cristalino; Floresta Estacional Decidual; Florística.*

Introduction

Rocky environments are characterized by temperature fluctuations, desiccant winds, water scarcity and high evaporation rates (Porembski & Barthlott 2000, Oliveira & Godoy 2007), as they can occur in places exposed to the sun, winds and frosts, as well as in permanently dark and humid places (Fernandes & Baptista 1988, Porembski 2007). These attributes allow environments to condition the spatial distribution of plants, forming suitable microhabitats so that they germinate and settle. It means that species do not occur randomly because rocky microhabitats affect species distribution due to the influence of soil depth, with greater sediment accumulation in flattened areas and shallower or absent soils in more rugged locations (Jumpponem et al. 1999, Conceição & Pirani 2005). In fact, the vegetation of environments like this differs markedly from that of the surroundings (Porembski et al. 1997, Barthlott & Porembski 2000).

The absence of large accumulations of soil and the little storage of rainwater that is lost quickly with runoff is exacerbated, especially in places with a steep slope. Rocky environments often make it possible to observe displacement of individual plants and entire clumps, which are susceptible to detaching from the rocky substrate when saturated with water during heavy rains (Porembski 2007). In contrast, other rocky environments may have sites with higher sediment and nutrient accumulation, which are more conducive to the occurrence and densification of tree-shrub strata, in contrast to the steeper areas with smaller soil layer or larger portion of exposed rock, favoring smaller plant species or promoting most sparse distribution among species (Conceição & Pirani 2005). Rocky outcrops also interfere with water flow, with rapid loss of runoff water on steep slopes and water retention in flat and semi-concave areas (Benites et al. 2003). Other factors such as evolution, potential solar radiation, substrate type, area and age of outcrop, anthropogenic factors and microclimate also influence the distribution of vegetation in rocky outcrops, promoting specialization of organisms occurring in these habitats, contributing to the formation of vegetative mosaics and also protecting species from environmental changes (Wiser 1998, Moura et al. 2011, Silveira et al. 2015), making these environments a priority for conservation.

Thus, studies with vegetation associated with rocky outcrops seek to associate plant species mainly with topography, substrate, water availability and climate severity. These factors provide several possible microhabitats for plant establishment, elucidating the role of environmental filters in the structuring of outcrop communities (Silva 2016). In addition, rocky outcrops can provide possible places of refuge during climate change, thus contributing to maintaining the high species diversity of tropical regions (Colinvaux et al. 2000, Speziale & Ezcurra 2014). In fact, the diversity of occurrence sites and the factors that influence species distribution are the main premises that have aroused a growing interest in the investigation of vegetation on rocky environments in Brazil (Moura et al. 2011). Rocky environments are present in all phytogeographic domains of Brazil, as well as the transition bands between these domains, thereby providing geologic, geomorphologic, climatic and phytophysiognomic diversity (IBGE 2001, Ab'Sáber 2003).

Vegetation-related investigations of Brazilian rocky outcrops have been conducted mainly in Central Brazil, Southeast region and Chapada Diamantina (Bahia), addressing the smaller vegetation of the grassland and savannah formations on granites, quartzites, sandstones and cangas (e.g., Scarano 2002, Caiafa & Silva 2005, Conceição & Pirani 2005, Oliveira & Godoy 2007, Viana & Lombardi 2007, Messias et al. 2012, Viana et al. 2016). However, there is a demand for studies aimed at understanding the Amazon forest formations that occur on these outcrops, such as dry forests or seasonal forests (Scarano 2007, Melo et al. 2014).

In the state of Pará, the so-called Amazon rocky grassland (in portuguese - *pt*, '*campo rupestre da Amazônia*'), a low vegetation with few trees on canga in Serra dos Carajás, was investigated (Silva et al. 1996). The terrain relief associated with the impermeability of the canga retains water in the soil, directly influencing the vegetation physiognomy and its floristic composition (Silva et al. 1996). In eastern Mato Grosso State, the rocky cerrado (in *pt*, '*cerrado rupestre*') with quartzite predominance has high basal area and species diversity and structural stability of the woody community due to the fact that this phytophysiognomy is present in a transition region between Cerrado and Amazon, and because of the good preservation status of the conservation unit in which the area is located (Maracahipes et al. 2011). Also in Mato Grosso state, two savannas on sandstone rocks were compared with low nutrient concentration, showing low floristic similarity. The first savanna was called "Transitional Rocky Cerrado" (in *pt*, '*cerrado rupestre de transição*') because it occurs in a transition area between Cerrado and Amazon, with great influence of the Cerrado flora of Central Brazil, while the second was called "Rocky Savannah Amazon" (in *pt*, '*savana amazônica rochosa*') because its floristic composition is influenced by Amazon vegetation types, which occur surrounding this vegetation type (Pessoa 2014).

In northern Mato Grosso state, previous diagnosis of rocky outcrops in areas of the Cristalino and Xingu State Parks were performed (Sasaki et al. 2010, Zappi et al. 2011, 2016). These studies emphasized the need to intensify the vegetation sampling and the floristic composition determination on the rocky outcrops that occur in Mato Grosso. Such environments occur in small portions in a fragmented way; the preliminary results, in the case of Cristalino region, are surveys performed mainly on trails for ecotourism. In this sense, our objective was to characterize the woody vegetation of a rocky outcrop of the 'RPPN Mirante da Serra', located in the Cristalino region, Southern Amazon, and to verify its conservation relevance. In order to achieve this goal, we elaborated the following questions: 1) What are the floristic characteristics of the rocky outcrop in the RPPN Mirante da Serra? 2) Are there endemic and threatened species in this area?

Material and Methods

1. Study Area

We conducted this study in an area of Deciduous Seasonal Forest associated with granitic rocky outcrop in the RPPN Mirante da Serra, Cristalino region (Figure 1), located in the Novo Mundo municipality, near the Alta Floresta border, in the northernmost region of the state of Mato Grosso (09°35'12 "S, 55°54'59" W; elevation ~248-351 m). The Cristalino region is a term locally used to refer to the Mato Grosso part of the Cristalino River Basin, which flows into the Teles Pires River (Zappi et al. 2011). The areas constituting the region are the Cristalino State Park (PEC) and the four Private Natural Heritage Reserves (RPPNs according to the Brazilian Legislation) managed by the Cristalino Ecological Foundation (FEC), called Cristalino, Gavião Real, Castanheira and Mirante da Serra.

In the study region, the climate is warm, seasonally dry (three to five months per year), with annual average temperatures above 26ºC

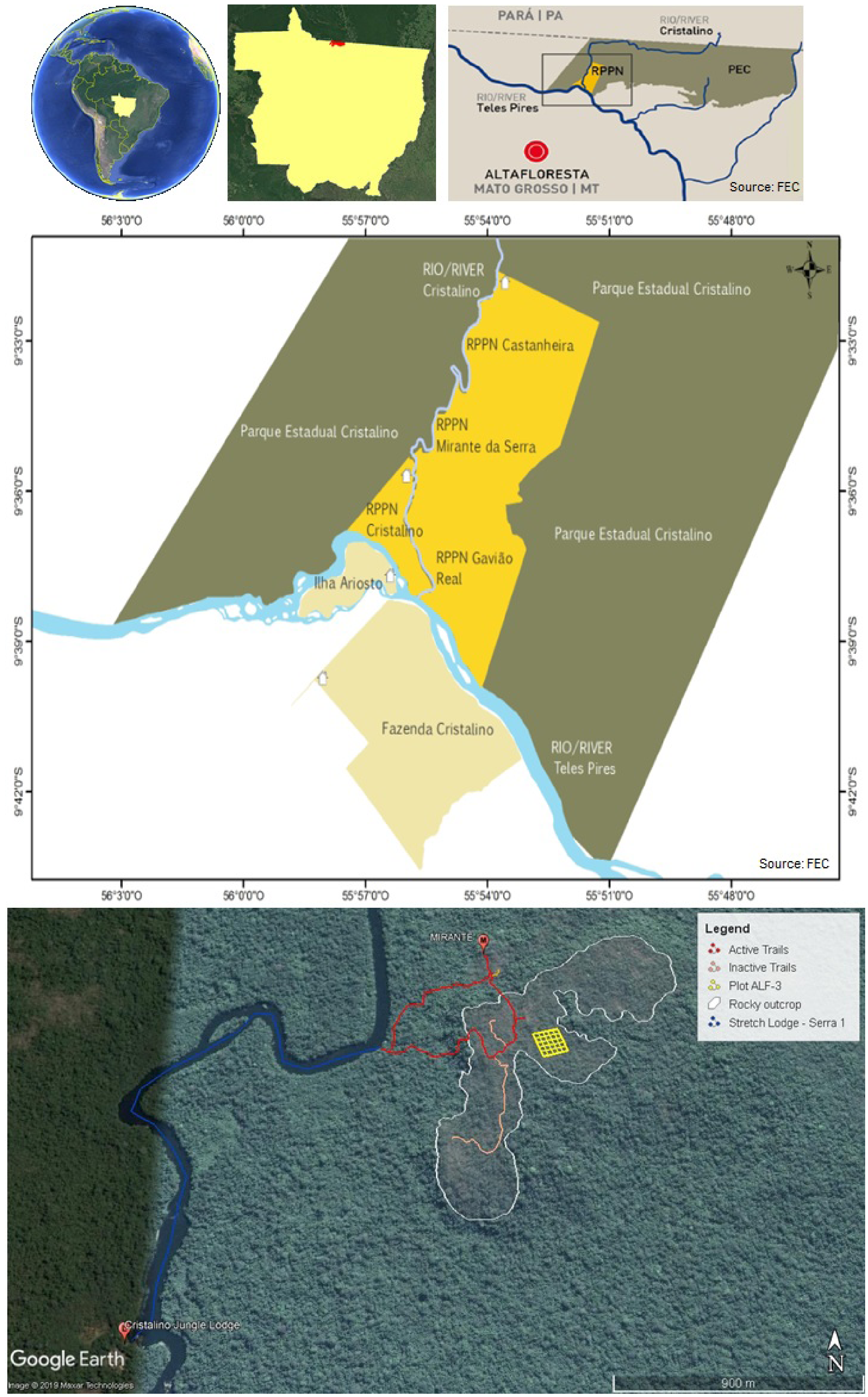

Figure 1. Location of the RPPN Mirante da Serra (study area) in the Cristalino Region, Southern Amazon, Mato Grosso, Brazil.

and mean annual rainfall between 2,400 mm and 2,800 mm (Alvares et al. 2013, Oliveira-Filho 2017). During this study (July 2016 - July 2017), the total annual rainfall was 2,080.27 mm, with the rainy period from September to April and the dry period – months with precipitation <100 mm – from May to August. February was the month with the highest precipitation (350.28 mm), August with the lowest (22.1 mm) and the months of June and July showed no precipitation. The average annual temperature during the study was 26.52 ºC, with the highest temperatures in April (minimum mean = 22.35 ºC) and August (maximum mean = 36.08 ºC). These data were obtained from station A-924, municipality of Alta Floresta-MT, at 61.5 km from the study area, approximately. In the rocky outcrop studied, the temperatures in the drought period can reach 43 ºC (E. Gressler, personal observation).

The relief forms of the region are structurally complex, varying from flat to mountainous, being characterized in four geomorphological units: I. Cachimbo Plateau; II. Northern Depression of Mato Grosso; III. Interplanaltic depression of the Juruena/Teles Pires; and IV. Rivers – Residential Plateaus of the Southern Amazon (IBGE 2006). The sampled area is situated in this last geomorphological unit. Considering the entire Cristalino region, soils are generally acidic, medium to low fertility, sandy and susceptible to erosion; low nutrient and water availability quartzarenic neosols predominate, with dystrophic red-yellow argisols, alic red-yellow argisols, dystrophic lithic neosols and dystrophic dark red oxissols (Mato Grosso 2001). The studied outcrop presents a litholic neossol formed mainly by granite.

The vegetation of the Cristalino region has areas of ecological tension, characterized by contacts between rainforest and seasonal forest; seasonal forest and savanna (Figure 2); and rainforest and savanna. Sasaki et al. (2010) and Zappi et al. (2011) described eight phytophysiognomies for the region. The vegetation associated with the rocky outcrop studied here was described by Sasaki et al. (2010) and Zappi et al. (2011) as a Dry Forest, found on the higher slopes or occasionally on the tops of the mountains, presenting most of the trees fully or almost totally leafless during the dry season. The canopy is relatively open (20 - 25 m high) with emerging trees up to 30 m high and the understory ranging from dense to open.

2. *Data collection*

Based on the RAINFOR network methodology described by Phillips et al. (2016), we allocated a permanent plot of 1-ha area, installed for conducting monitoring studies. The plot was located at 335 m altitude and marked by iron rebar (5 mm in diameter and 1 m in length) fixed to the ground. During the period from July 2016 to July 2017 we collected the individuals in reproductive stage found in the plot, in the access paths and in the 10 m surrounding the plot. We provided the habits of each species based on basic books of plant morphology (e.g., Gonçalves & Lorenzi 2011); in particular, we considered as trees the freestanding individuals >3m height (Oliveira-Filho 2017). We used IBGE (2012) as the phytogeographic classification system to assign each species to its respective vegetation type, a step in which we were also supported by Sasaki et al. (2010) and Zappi et al. (2011). To compose the botanical collection, we followed the procedures recommended by Fidalgo & Bononi (1989) and IBGE (2012). The collected materials were incorporated into the collection of the Southern Amazon Herbarium - HERBAM, Mato Grosso State University, Alta Floresta - MT.

Species were identified through partnerships with botanists experienced in the regional flora, as well as the use of dichotomous keys in review works (Goldenberg et al. 2012, Oliveira et al. 2012, Zappi et al. 2017), comparison with materials deposited in the HERBAM collection and online herbarium databases that provide expertly reviewed exsiccate images (e.g., Reflora, SpeciesLink, Tropicos, Kew Herbarium Collection, New York Botanical Garden - NYBG Virtual Herbarium, and Field Museum). We also consulted specialists in some more complex groups, such as the Myrtaceae families (Marcos Sobral, Carolyn Proença and Marla Ibrahim), Malvaceae (Sue Frisby), Rubiaceae (Daniella Zappi), Fabaceae (José M. Fernandes) and Melastomataceae (Fernandes Guimarães and Renato Goldenberg). In order to obtain greater confidence and success in identifying infertile individuals that were measured in the plot, we collected an individual sample for comparison with the HERBAM scientific collection, whose collection consists mainly of samples from the regional flora, including those from the Cristalino State Park.

The species list was structured from the compilation of our random collections, the composition of the 1-ha plot, the species occurring within 10 m around the 1-ha area and the materials deposited in HERBAM from previous surveys carried out during the 'Flora Cristalino Program'. We validated the accepted and correct spelling of the scientific names and their authors based on Flora do Brasil 2020 em construção (2019); APG IV (2016) was consulted for the genealogical classification of botanical groups. We also obtained information regarding conservation status and endemism of each species from the Red List of 'Centro Nacional de Conservação da Flora' (CNCFlora; http://www.cncflora.jbrj.gov.br) to provide a quantitative relevance of the Cristalino region for biodiversity conservation.

Results and Discussion

From the compilation of the data in our study and the materials deposited in HERBAM, we listed 126 woody species, 95 genera and 39 families for the vegetation associated with the RPPN Mirante da Serra rocky outcrop. Considering these species, eight were identified to the genera level due to the complexity of the groups and the absence of fertile material (Table 1). The families with the largest number of species were Fabaceae (20), Malvaceae (13), Apocynaceae and Rubiaceae (eight species each), and Bignoniaceae and Myrtaceae (seven each).

The largest representativeness of Fabaceae is expected because it is one of the most diverse families in inventories from Brazil and the Amazon (BFG 2015). Furthermore, in several studies conducted in the Cerrado (e.g., Campos et al. 2006; Walter & Guarino 2006; Ferreira-Júnior et al. 2008) and in the Cerrado-Amazon transition (e.g., Ivanauskas et al. 2004; Haidar et al. 2013), Fabaceae is also highlighted as one of the richest in species, denoting the high establishment capacity of this family in the most varied types of environments. A study evaluating the soils of the area studied here will possibly confirm the idea that nitrogen fixation capacity is a good strategy for legume maintenance in areas whose soil has low fertility conditions, such as slopes and tops of hills. However, not all legume species have this capability. When we consider the classic classification of Fabaceae into three subfamilies, species of the Papilionoideae subfamily have higher nodulation potential, whereas in Mimosoideae species nitrogen fixation is common and Caesalpinioideae is more uncommon (Colleta 2010; Macedo 2010).

Figure 2. Aspects of the Deciduous Seasonal Forest associated with rocky outcrop in the RPPN Mirante da Serra, Cristalino Region, Southern Amazon, Mato Grosso, Brazil. A: Study area in the rainy season. B: Study area in the dry season. C: Saxicolous Tree. D: Rocky outcrop Tree. E: Arboreal individuals in shallow soil.

Among the 20 species of Fabaceae recorded in the investigated area, 10 belong to the Papilionoideae subfamily. Therefore, at least 50% of Fabaceae can be potential nitrogen-fixing potentials whether we consider the classic classification as well as the new classification (LPWG 2017) that divides legumes into six subfamilies. On the other hand, the scarcity of studies conducted on deciduous forests associated with rocky outcrops hampers comparisons with more similar areas. Indeed, there is a poverty of data from rocky outcrops in Brazilian Amazon as a whole (Silva 2016). One of the few studies in this regard, which was not conducted in Amazon or Cerrado-Amazon transition, but in the core area of Cerrado, found the same pattern of high floristic relevance of Fabaceae (Felfili et al. 2007). In other locations in South America (e.g. the inselbergs of the Guyanes and of Venezuela), in a rank of 10 families, respectively, the most representative were Cyperaceae, Poaceae, Bromeliaceae, Rubiaceae, Melastomataceae, Orchidaceae, Fabaceae, Apocynaceae, Euphorbiaceae and Myrtaceae (Barthlott & Porembski 2000). However, this comparison is generalized, because the authors do not define whether such ranking refers to savannas or deciduous forests associated with rocky environments. However, Fabaceae is the seventh family in this rank and the first three families are monocotyledons, represented essentially by herbaceous plants, a group that was not addressed in our study.

The genera with the greatest species richness in the studied area were *Eugenia* L. (Myrtaceae), with five species, and *Aspidosperma*

Table 1: Woody species of Deciduous Seasonal Forest associated with rocky outcrop in the RPPN Mirante da Serra, Cristalino region, Southern Amazon. Threatened categories according to CNC Flora (DD: Deficient Data; LC: Least Concern; NE: Not Evaluated; VU: Vulnerable). *Taxa added to the Cristalino flora as result of our sampling survey.

Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
Anacardiaceae														
Astronium lecointei Ducke	NE	not endemic	tree			x	x					x	x	Indivíduo 628
Spondias mombin L.	NE	not endemic	tree				x			x		x	x	*in loco*
Apocynaceae														
Aspidosperma macrocarpon Mart. & Zucc.	LC	not endemic	tree				x	x				x	x	Da Silva, D.R. 128
A. multiflorum A.DC.	NE	endemic	tree				x	x		x		x	x	Sasaki, D. 2248
A. subincanum Mart.	NE	not endemic	tree				x					x		Indivíduo 360
Aspidosperma sp.			tree				x					x		Indivíduo 349
Mandevilla scabra (Hoffmanns. ex Roem. & Schult.) K.Schum.	NE	not endemic	liana				x					x	x	Da Silva, D.R. 146
Marsdenia cf. macrophylla (Humb. & Bonpl.) E.Fourn.	NE	not endemic	shrub, liana				x					x	x	Da Silva, D.R. 118
M. weddellii (Fourn.) Malme	NE	unkown	liana				x					x	x	Da Silva, D.R. 137
Odontadenia sp.			liana				x					x		Morfotipo 71
Arecaceae														
Bactris acanthocarpa Mart.	NE	not endemic	palm	x				x				x	x	Sasaki, D. 1180
Syagrus cocoides Mart.	NE	endemic	palm				x					x	x	Da Silva, D.R. 141
Aristolochiaceae														
Aristolochia sp.			liana				x					x		Morfotipo 28
Bignoniaceae														
Adenocalymma impressum (Rusby) Sandwith	NE	not endemic	liana				x					x		Ribeiro, R.S. 250
Fridericia cinnamomea (DC.) L.G.Lohmann	NE	not endemic	liana				x			x		x		*in loco*

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Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
Handroanthus capitatus (Bureau & K.Schum.) Mattos	NE	not endemic	tree				x					x	x	Da Silva, D.R. 119
H. serratifolius (Vahl) S.Grose*	NE	not endemic	tree				x					x		Koch, A.K. 843
Pyrostegia venusta (Ker Gawl.) Miers	NE	not endemic	liana			x	x	x		x		x	x	*in loco*
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	NE	not endemic	tree				x	x				x		Henicka, G.S. 107
Tynanthus polyanthus (Bureau ex Baill.) Sandwith	NE	not endemic	liana			x	x	x				x	x	Sasaki, D. 1625
Bixaceae														
Cochlospermum orinocense (Kunth) Steud.	NE	not endemic	tree				x	x				x	x	Sasaki, D. 1337
C. regium (Mart. ex Schrank) Pilg.	LC	not endemic	shrub				x					x	x	Da Silva, D.R. 95
Calophyllaceae														
Kielmeyera regalis Saddi	NE	endemic	tree, shrub					x	x	x		x	x	Henicka, G.S. 111
Caricaceae														
Jacaratia digitata (Poepp. & Endl.) Solms	NE	not endemic	tree			x		x				x	x	Morfotipo 10
Clusiaceae														
Clusia panapanari (Aubl.) Choisy	NE	not endemic	shrub, hemiepiphyte				x					x	x	Sasaki, D. 1606
C. weddelliana Planch. & Triana	NE	not endemic	tree, hemiepiphyte				x		x	x		x	x	Da Silva, D.R. 186
Combretaceae														
Buchenavia tomentosa Eichler	NE	not endemic	tree				x			x		x	x	Gallo, S.C. 190
Combretum laxum Jacq.	NE	not endemic	liana		x	x	x				x	x	x	Da Silva, D.R. 184

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Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
Connaraceae														
Connarus coriaceus G.Schellenb.	NE	not endemic	liana			x	x			x		x		Sasaki, D. 2234a
Cucurbitaceae														
Siolmatra pentaphylla Harms*	NE	not endemic	liana, subwoody vine				x					x		Gallo, S.C. 69
Erythroxylaceae														
Erythroxylum anguifugum Mart.	LC	endemic	tree, shrub				x			x		x	x	Da Silva, D.R. 138
E. leptoneurum O.E.Schulz	NE	not endemic	shrub				x					x		Da Silva, D.R. 125
Euphorbiaceae														
Croton hadrianii Baill.*	NE	endemic	shrub				x					x	x	Da Silva, D.R. 168
Manihot anomala Pohl	NE	not endemic	shrub				x					x		Gallo, S.C. 71
M. tristis Müll.Arg.	NE	endemic	shrub, liana				x			x		x	x	Da Silva, D.R. 145
Maprounea guianensis Aubl.	NE	not endemic	tree					x				x		*in loco*
Fabaceae														
Amburana cf. *acreana* (Ducke) A.C.Sm.	VU	not endemic	tree					x				x		Indivíduo 878
Anadenanthera peregrina (L.) Speg.	NE	not endemic	tree				x		x	x		x	x	Da Silva, D.R. 134
Bauhinia cf. *brevipes* Vogel*	NE	not endemic	tree, shrub				x					x		Da Silva, D.R. 180
B. depauperata Glaz.	unkown	unkown	shrub				x			x		x		Henicka, G.S. 17
Bauhinia cf. *rufa* (Bong.) Steud.*	NE	not endemic	shrub				x					x		Da Silva, D.R. 181
Camptosema ellipticum (Desv.) Burkart	NE	not endemic	liana, subwoody vine				x		x	x		x	x	Gallo, S.C. 123
Chamaecrista cf. *brevicalyx* (Benth.) H.S.Irwin & Barneby*	DD	endemic	shrub				x					x		Da Silva, D.R. 163
Chloroleucon acacioides (Ducke) Barneby & J.M.Grimes	NE	not endemic	tree				x					x	x	Da Silva, D.R. 188

Continue...

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Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
Dalbergia gracilis Benth.	NE	not endemic	shrub, liana				x				x	x	x	Sasaki, D. 1618
Enterolobium maximum Ducke	NE	not endemic	tree					x				x		Nascimento, J. 34
Erythrina fusca Lour.	NE	not endemic	tree				x	x				x	x	Gallo, S.C. 190
E. ulei Harms	NE	not endemic	tree				x					x	x	Da Silva, D.R. 93
Galactia striata (Jacq.) Urb.*	LC	not endemic	shrub, subwoody vine				x					x		Da Silva, D.R. 148
Hymenaea courbaril L.	LC	not endemic	tree	x	x		x	x				x	x	PFC. 241
Machaerium acutifolium Vogel	NE	not endemic	tree				x					x	x	Gallo, S.C. 34
M. amplum Benth.	NE	not endemic	tree; shrub; liana				x					x		Gallo, S.C. 193
Periandra coccinea (Schrad.) Benth.	NE	endemic	liana, subwoody vine				x					x		Da Silva, D.R. 175
Platymiscium trinitatis Benth.	NE	not endemic	tree				x					x	x	PFC. 239
Senegalia polyphylla (DC.) Britton & Rose	NE	not endemic	tree			x	x	x			x	x	x	*in loco*
S. tenuifolia (L.) Britton & Rose	NE	not endemic	shrub, liana				x					x		*in loco*
Lamiaceae														
Amasonia lasiocaulos Mart. & Schauer ex Schauer*	NE	not endemic	shrub				x					x		Ribeiro, R.S. 219
Vitex polygama Cham.	NE	endemic	tree				x					x	x	Da Silva, D.R. 132
Loganiaceae														
Strychnos araguaensis Krukoff & Barneby	NE	not endemic	liana				x					x		Nascimento, J. 32
Lythraceae														
Physocalymma scaberrimum Pohl	LC	not endemic	tree				x					x		PFC. 289
Malpighiaceae														
Banisteriopsis megaphylla (A.Juss.) B.Gates	NE	endemic	liana				x					x	x	Da Silva, D.R. 143

Continue...

...Continuation

Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
B. stellaris (Griseb.) B.Gates	NE	endemic	liana				x					x	x	Sasaki 1936
Diplopterys lutea (Griseb.) W.R.Anderson & C.C.Davis	NE	not endemic	liana				x					x		PFC. 466
Janusia janusioides (A.Juss.) W.R.Anderson*	NE	not endemic	liana				x					x		Da Silva, D.R. 193
Malvaceae														
Ceiba samauma (Mart.) K.Schum.	NE	not endemic	tree				x					x	x	Da Silva, D.R. 153
C. speciosa (A.St.-Hil.) Ravenna	NE	not endemic	tree				x					x	x	Henicka, G.S. 32
Eriotheca globosa (Aubl.) A.Robyns	NE	not endemic	tree				x	x				x	x	Sasaki, D. 2465
Helicteres brevispira At.St.-Hil.	NE	not endemic	shrub				x					x	x	Koch, A.K. 849
H. muscosa Mart.	NE	endemic	shrub				x					x	x	Da Silva, D.R. 922
H. pentandra L.	NE	not endemic	shrub				x			x		x	x	Da Silva, D.R. 194
Luehea candicans Mart. & Zucc.	LC	not endemic	tree				x					x	x	Da Silva, D.R. 124
Mollia lepidota Spruce ex Benth.	NE	not endemic	tree				x					x	x	Da Silva, D.R. 139
Pachira paraensis (Ducke) W.S.Alverson	NE	not endemic	tree	x			x			x		x	x	Da Silva, D.R. 190
Peltaea sp.			shrub				x			x		x	x	Da Silva, D.R. 171
Pseudobombax longiflorum (Mart.) A.Robyns	NE	not endemic	tree	x			x			x		x	x	Da Silva, D.R. 189
P. tomentosum (Mart.) A.Robyns*	LC	not endemic	tree				x					x		Da Silva, D.R. 185
Theobroma speciosum Willd. ex Spreng.	NE	not endemic	tree	x				x				x	x	Da Silva, D.R. 98
Marcgraviaceae														
Norantea guianensis Aubl.	NE	not endemic	tree, shrub, liana				x			x		x	x	Da Silva, D.R. 116
Melastomataceae														
Ernestia sp.			shrub				x					x		Da Silva, D.R. 150
Mouriri apiranga Spruce ex Triana	NE	not endemic	tree			x	x		x		x	x	x	Gallo, S.C. 188
Tibouchina barbigera (Naudin) Baill.	NE	not endemic	tree				x			x		x	x	Da Silva, D.R. 162

Continue...

...Continuation

Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
Meliaceae														
Cedrela odorata L.	VU	not endemic	tree	x			x					x	x	Gallo, S.C. 185
Menispermaceae														
Odontocarya cf. *tamoides* (DC.) Miers	NE	not endemic	liana				x					x		Morfotipo 55
Moraceae														
Ficus amazonica (Miq.) Miq.	LC	not endemic	tree				x					x	x	Da Silva, D.R. 94
Ficus obtusifolia Kunth	NE	not endemic	tree, hemiepiphyte				x					x	x	Sasaki, D. 2028
Ficus schumacheri (Liebm.) Griseb.*	DD	not endemic	tree, hemiepiphyte				x					x		Da Silva, D.R. 167
Ficus sp.			tree, hemiepiphyte				x					x		Indivíduo 5
Myristicaceae														
Compsoneura ulei Warb.	NE	not endemic	tree	x	x	x		x				x	x	Sasaki, D. 1225
Iryanthera juruensis Warb.	NE	not endemic	tree	x	x		x					x	x	Nascimento, J. 36
Myrtaceae														
Campomanesia grandiflora (Aubl.) Sagot*	NE	not endemic	tree				x					x		Gallo, S.C. 29
Eugenia aurata O.Berg	LC	endemic	tree				x					x	x	Gallo, S.C. 100
E. dysenterica (Mart.) DC.*	NE	endemic	tree				x					x		Da Silva, D.R. 129
E. flavescens DC.	NE	not endemic	tree; shrub				x					x	x	Da Silva, D.R. 121
E. stictopetala Mart. ex DC.	NE	not endemic	tree				x					x	x	Da Silva, D.R. 131
Eugenia sp.			tree				x					x		Indivíduo 1035
Myrcia rufipes DC.	NE	endemic	tree; shrub				x		x	x		x	x	Da Silva, D.R. 97
Ochnaceae														
Ouratea sp.			tree				x					x		Da Silva, D.R. 100
Opiliaceae														
Agonandra brasiliensis Miers ex Benth. & Hook.f.	NE	not endemic	tree				x					x		Indivíduo 994
Polygalaceae														
Bredemeyera floribunda Willd.	NE	not endemic	liana				x			x		x	x	Da Silva, D.R. 187

Continue...

...Continuation

Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
B. lucida (Benth.) Klotzsch ex Hassk.	NE	endemic	liana				x			x		x	x	Ribeiro, R.S. 135
Securidaca diversifolia (L.) S.F.Blake	NE	not endemic	liana				x		x	x		x	x	Ribeiro, R.S. 134
Rhamnaceae														
Gouania colurnifolia Reissek*	NE	not endemic	liana				x					x		Da Silva, D.R. 177
Rubiaceae														
Bertiera guianensis Aubl.	NE	not endemic	tree, shrub				x		x	x		x	x	Da Silva, D.R. 130
Cordiera sessilis (Vell.) Kuntze	NE	not endemic	tree				x	x		x		x	x	Zappi, D.C. 1445
Coutarea hexandra (Jacq.) K.Schum.	NE	not endemic	tree				x	x	x	x		x	x	Da Silva, D.R. 140
Dialypetalanthus fuscescens Kuhlm.	NE	not endemic	tree				x	x		x		x	x	Da Silva, D.R. 127
Guettarda spruceana Müll.Arg.*	NE	not endemic	tree				x					x	x	Sasaki, D. 1850
Randia armata (Sw.) DC.	NE	not endemic	tree, shrub			x	x	x			x	x	x	Gallo, S.C. 24
Rudgea crassiloba (Benth.) B.L.Rob.	NE	not endemic	tree				x					x		Indivíduo 134
Simira rubescens (Benth.) Bremek. ex Steyerm.	NE	not endemic	tree				x		x	x		x	x	Sasaki, D. 1607
Rutaceae														
Ertela trifolia (L.) Kuntze	NE	not endemic	shrub				x					x	x	Sasaki, D. 1535
Esenbeckia pilocarpoides Kunth	LC	not endemic	tree, shrub				x	x				x	x	Sasaki, D. 1218
Metrodorea flavida K.Krause	NE	not endemic	tree	x		x	x	x				x	x	*in loco*
Zanthoxylum rhoifolium Lam.	NE	not endemic	tree				x	x				x	x	Sasaki, D. 1216
Salicaceae														
Casearia gossypiosperma Briq.	LC	not endemic	tree				x					x	x	PFC. 261
C. pitumba Sleumer	NE	not endemic	tree				x					x		Indivíduo 151
Sapindaceae														
Allophylus racemosus Sw.	NE	not endemic	shrub				x					x	x	Ribeiro, R.S. 223

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...Continuation

Family *Species*	Threatened category (CNCFlora)	Endemic to Brazil	Habit	Submontane Rainforest ('Floresta Ombrófila Densa Submontana')	Alluvial Rainforest ('Floresta Ombrófila Densa Aluvial')	Submontane Open Rainforest ('Floresta Ombrófila Aberta Submontana')	Deciduous Seasonal Forest ('Floresta Estacional Decidual')	Semideciduous Seasonal Forest ('Floresta Estacional Semidecidual')	'Campinarana Florestada/Gramíneo-lenhosa'	'Campo Rupestre da Amazônia'	Pioneering Formations with River Influence ('Formações Pioneiras com Influência Fluvial')	RPPN 'Mirante da Serra'	Parque Estadual Cristalino	Voucher
Trigoniaceae														
Trigonia laevis Aubl.*	NE	not endemic	liana				x	x			x	x		Da Silva, D.R. 157
T. nivea Cambess.	NE	not endemic	liana			x	x					x	x	Ribeiro, R.S. 136
Urticaceae														
Cecropia sciadophylla Mart.	NE	not endemic	tree	x			x					x	x	*in loco*
Urera baccifera (L.) Gaudich. ex Wedd.	NE	not endemic	shrub					x		x		x	x	*in loco*
Vitaceae														
Cissus duarteana Cambess.	NE	endemic	subwoody vine		x	x	x					x	x	Da Silva, D.R. 147
C. erosa Rich.	NE	not endemic	liana				x		x	x		x	x	Da Silva, D.R. 142
C. tinctoria Mart.*	NE	not endemic	liana				x					x		Da Silva, D.R. 176
Vochysiaceae														
Callisthene fasciculata Mart.	NE	not endemic	tree				x					x	x	Da Silva, D.R. 133
Qualea dinizii Ducke*	NE	unkown	tree					x				x		Da Silva, D.R. 192

Mart. & Zucc. (Apocynaceae) and *Ficus* L. (Moraceae), with four species each. These three genera are among the most important of their respective families, with wide distribution and high diversity in the Neotropical region, being *Ficus* and *Eugenia* pantropical ones (TROPICOS 2017). In Brazil, 387 species of *Eugenia* have been reported, of which 302 are endemic (BFG, 2015). However, as taxonomic treatments are finalized, there is a growing tendency for information to be updated by the Flora do Brasil 2020 project. Currently, 386 species (299 endemic) are reported for *Eugenia*, with the highest concentration found in the Atlantic Forest (257) and the Amazon (92) (Flora do Brasil 2020 em construção, 2019). For *Aspidosperma*, there are 67 species (31 endemic), while 85 (23 endemic) are reported for the *Ficus* genus, both with higher concentrations in the Amazon (37 and 55 species, respectively) (Flora do Brasil 2020 em construção 2019). *Aspidosperma* (Salis et al. 2004) and *Eugenia* (Ivanauskas et al. 1999) are also among the species-richest ones.

From this study we added 18 taxa (1.3%) to Flora do Cristalino, which now totals 1,383 species (Zappi et al. 2011). Our sampling was concentrated in a Deciduous Seasonal Forest, a forest formation that corresponds to less than 5% of the total area of Cristalino. This was one of the least sampled phytophysiognomies (80 species) from the inventories of the Cristalino Flora Program (Sasaki et al. 2010, Zappi et al. 2011). Among the 18 species added to Flora do Cristalino, seven are trees, four are shrubs, five are lianas and two species were recorded with life-form variation, namely, *Bauhinia* cf. *brevipes* registered as tree and shrub, and *Galactia striata*, registered as shrub and subwoody vine. *Croton hadrianii* and *Pseudobombax tomentosum* had their identifications complemented from the collections made during our study. These two species were collected from previous inventories, but were deposited in HERBAM at a generic level. Other species that we highlight in the present survey are *Campomanesia grandiflora* and *Eugenia dysenterica*, both belonging to the family Myrtaceae. The species *C. grandiflora* comprises a new registry for the State of Mato Grosso, whose distribution in Brazil was restricted to the states of the Northern Region, Bahia and Maranhão (Sobral et al. 2015). *Eugenia dysenterica* is a new record for the Amazon, whose distribution is confirmed in the most varied savannah and forest formations in Brazil and Bolivia, but in Brazil its occurrence is only cited for the Cerrado, Caatinga and Atlantic Forest Domains (Sobral et al. 2015). These plant species found in a specific locality surrounded by various sections of another ecosystem are called “relictual” (Ab’Sáber 2003).

In this study we compiled 65 tree species (including four hemiepiphytes: *Clusia weddelliana* (Clusiaceae), *Ficus obtusifolia*, *Ficus* cf. *schumacheri* and *Ficus* sp. (Moraceae)), 18 shrubs (including the hemiepiphyte *Clusia panapanari*), 29 lianas (including the subwoody vines) and two palm species. In addition, four species were recorded as shrubs and lianas: *Marsdenia* cf. *macrophylla* (Apocynaceae), *Manihot tristis* (Euphorbiaceae), *Dalbergia gracilis* and *Senegalia tenuifolia* (Fabaceae); seven as trees and shrubs: *Kielmeyera regalis* (Calophyllaceae), *Erythroxylum anguifugum* (Erythroxylaceae), *Eugenia flavescens* and *Myrcia rufipes* (Myrtaceae), *Bertiera guianensis* and *Randia armata* (Rubiaceae) and *Esenbeckia pilocarpoides* (Rutaceae). The species *Machaerium amplum* (Fabaceae) and *Norantea guianensis* (Marcgraviaceae) were found as trees, shrubs and lianas. The variability of life forms of these species represents their competitive strategies and high adaptability to the conditions imposed by the environment (Via et al. 1995). Considering these authors, we believe that the isolation, allied to the pedological characteristic and the regional climatic seasonality, are factors that favor the plasticity of the species life form in the studied area.

Among the 126 species compiled in this study, 66 were unique to the Deciduous Seasonal Forest, 50 were shared with neighboring phytophysiognomies and nine species were recorded only in neighboring phytophysiognomies (Table 1). However, we emphasize that there may be an influence of the intensified sampling effort on the area of rocky outcrops studied here. Moreover, during the elaboration of Flora do Cristalino, the collections intensified in the areas of Rainforest, while smaller sampling effort was allocated for the outcrop areas (e.g., Zappi et al. 2011). Nevertheless, the authors showed differences in species diversity between these areas.

Regarding the conservation status and endemism of the species we obtained from the CNCFlora (2019) and Flora do Brasil 2020 databases under construction (2019), respectively, the following information could be assessed: 1 - In the Cristalino region there are two species classified in the ‘Vulnerable’ threat category and 12 species classified in the category of ‘Least Concern’, two species as ‘Deficient Data’ and the others were not evaluated (see Table 1). 2 - In the Cristalino region there are 17 species classified as endemic in Brazil, three species whose endemism is unknown and the others are not endemic. The occurrence of endemic and threatened species confirms the importance of the protected areas (State Park Cristalino and four private reserves) in the Cristalino region, especially taking into account the rapid deforestation rate associated with slow development, and dissemination of studies on biological diversity in the South Amazon region.

Final considerations

The species increment results for Flora do Cristalino, with some being new records for Mato Grosso and others composing new records for the Amazon, as well as the presence of endemic and threatened species, reinforce the need for investigations of these outcrops that occur forming a corridor of rocky outcrop vegetation islands amid the rainforests from the South Amazon border. This corridor of rocky vegetation, covering the northern region of Mato Grosso and the southern portion of Pará, may be determinant for a broader distribution of some species, such as those with anemochoric dispersion.

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Authors’ Contributions

Dennis Rodrigues da Silva: Substantial contribution in the concept and design of the study; contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Célia Regina Araújo Soares-Lopes: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation.

Eliana Gressler: Contribution to data analysis and interpretation; Contribution to critical revision, adding intellectual content.

Pedro V. Eisenlohr: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intellectual content.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Ethics

The authors declare that they have complied with the guidelines established by the ethics principles. In this sense, there is no sort of plagiarism, double submissions, already published articles and possible frauds in research.

Data availability

Data obtained in field collections are deposited in ‘Sistema Nacional de Gestão do Patrimônio Genético e do Conhecimento Tradicional Associado - SISGEN’ from Brazilian Government and are also in process of incorporation into ‘speciesLink’ database.

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