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The tree-shrub vegetation in rocky outcrop *cerrado* areas in Goiás State, Brazil

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ABSTRACT – (The tree-shrub vegetation in rocky outcrop *cerrado* areas in Goiás State, Brazil). We describe the floristic composition of the tree-shrub vegetation in 10 areas of rocky outcrop *cerrado* in Goiás State, Brazil. Ten 20 × 50 m plots (totaling 1 ha) were established and all of the individuals with diameters at 30 cm above soil level (DB_{30}) ≥ 5 cm were included in the sampling. Comparative analyses of the flora were realized using similarity indices (Sørensen and Czekanowski), classification analysis (TWINSPAN), and the Mantel test. A total of 13,041 tree-shrub individuals were sampled, distributed among 219 species, 129 genera and 55 families. Fabaceae was the most well-represented family, followed by Myrtaceae, Melastomataceae, Vochysiaceae, Malphigiaceae, and Rubiaceae. Fully 42.3% of the comparisons evaluated by the Sørensen index were > 0.50, while all the values were < 0.50 for the Czekanowski index, with the exception of Jaraguá and Mara Rosa areas. The TWINSPAN classification generated four divisions and, in general, only the differences in the size of the population were responsible for the groupings. The Mantel test indicated that there was no relationship between floristic similarity and the distances between the areas ($r = 0.32$, $P = 0.05$). It therefore appears that the areas of rocky outcrop cerrado in Goiás State are relatively floristically homogeneous and that they are principally distinguished by the differences in the sizes of the populations of their dominant species, and the presence of exclusive species in certain areas.

Key words - biodiversity, *Cerrado* biome, floristic composition, floristic similarity, rocky outcrops

INTRODUCTION

The *Cerrado* (Brazilian cerrado) biome originally occupied approximately 2,000,000 km² (22%) of the country (Oliveira Filho & Ratter 2002, Ribeiro & Walter 2008), but its area has been reduced over the years to only 60.5% of its original extent (Sano et al. 2009). The diversified phytophysiognomic mosaic of Cerrado includes open field formations characterized by herbaceous plants (principally grasses), cerrado formations characterized by grasses with scattered and thin trees and sub-arboreal plants, and forest formations dominated by arboreal species (Ribeiro & Walter 2008). According to Sano et al. (2009), approximately 61% of the natural areas of Cerrado are cerrado formations, 32% are forest formations, while 7% are open herbaceous areas.

One of the principal phytophysiognomic types of the biome is cerrado sensu stricto, the category classified as cerrado, which demonstrates well-defined arboreal and shrub-herbaceous layers (Ribeiro & Walter 2008) with arboreal coverage varying from 10% to 60% (Eiten 1992). According to Ribeiro & Walter (2008), cerrado sensu stricto can be divided into four subtypes depending on the density of the tree-shrub component and local environmental conditions: dense cerrado, typical cerrado locally called cerrado típico, thin cerrado, and rocky outcrop *cerrado* locally called "cerrado rupestre".

Rocky outcrop cerrados generally occurs in environments with rock outcrops (Ribeiro & Walter 2008) with predominantly shallow, poorly evolved and litholic neosols, with the A horizon lying directly on the rock surface, or with a very thin C horizon (Reatto et al. 2008). The root systems of the plants growing there cannot penetrate very deeply, so that woody individuals are predominately found in cracks and crevices that have accumulated larger volumes of substrate (Romero 2002, Reatto et al. 2008). The rocky outcrop cerrado vegetation is characterized by tree-shrub species with heights between 2 and 4 m covering between 5% and 20% of the surface; the subshrub-herbaceous layer is thin, with species typical of this vegetation type (Ribeiro & Walter 2008).

Rocky outcrop cerrados cover approximately 6.6% of Goiás and are distributed throughout the state (Lima 2008), but only limited studies have been conducted in this important phytophysiognomy of the Cerrado biome (Manoel 1999, Amaral et al. 2006, Miranda et al.

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2007, Moura et al. 2007, 2010, Pinto et al. 2009, Lima et al. 2010), and is still little-known and incompletely explored scientifically. Studies of floristic composition furnish basic information for understanding different plant formations and are essential for subsequent detailed studies (Van den Berg & Oliveira Filho 2000).

We describe here the floristic composition of the tree-shrub vegetation in 10 areas of rocky outcrop cerrado in Goiás State, Brazil, present a checklist of the species that can be used to evaluate the contributions of the different taxa and the floristic composition of these environments, and evaluate the floristic similarities between the areas surveyed. To that end, we have assumed that the rocky outcrop cerrado is a differentiated environment, principally in relation to its edaphic conditions: poor and thin soils with low pH and high concentrations of exchangeable aluminum (Benites et al. 2003, Reatto et al. 2008) – and should therefore demonstrate a unique floristic composition. In addressing these objectives, the following questions were formulated: What tree-shrub species grow in the rocky outcrop cerrado areas of Goiás State? Does the rocky outcrop cerrado in that area contain an elevated floristic richness of tree-shrub species? Are the study areas floristically similar? Is the tree-shrub vegetation of this phytophysiognomy composed of generalist species or species specialized for a specific habitat?

MATERIAL AND METHODS

Study area – The current study was undertaken in 10 areas of rocky outcrop cerrado in Goiás State (GO), in the central western region of Brazil (figure 1) (12°23'46" to 19°29'42" S and 45°58'36" to 53°14'53" W). The regional climate is type Aw by the Köppen classification system, and is characterized by dry winters and rainy summer seasons, with annual average temperatures varying from 18 °C to 26 °C and annual precipitation rates oscillating between

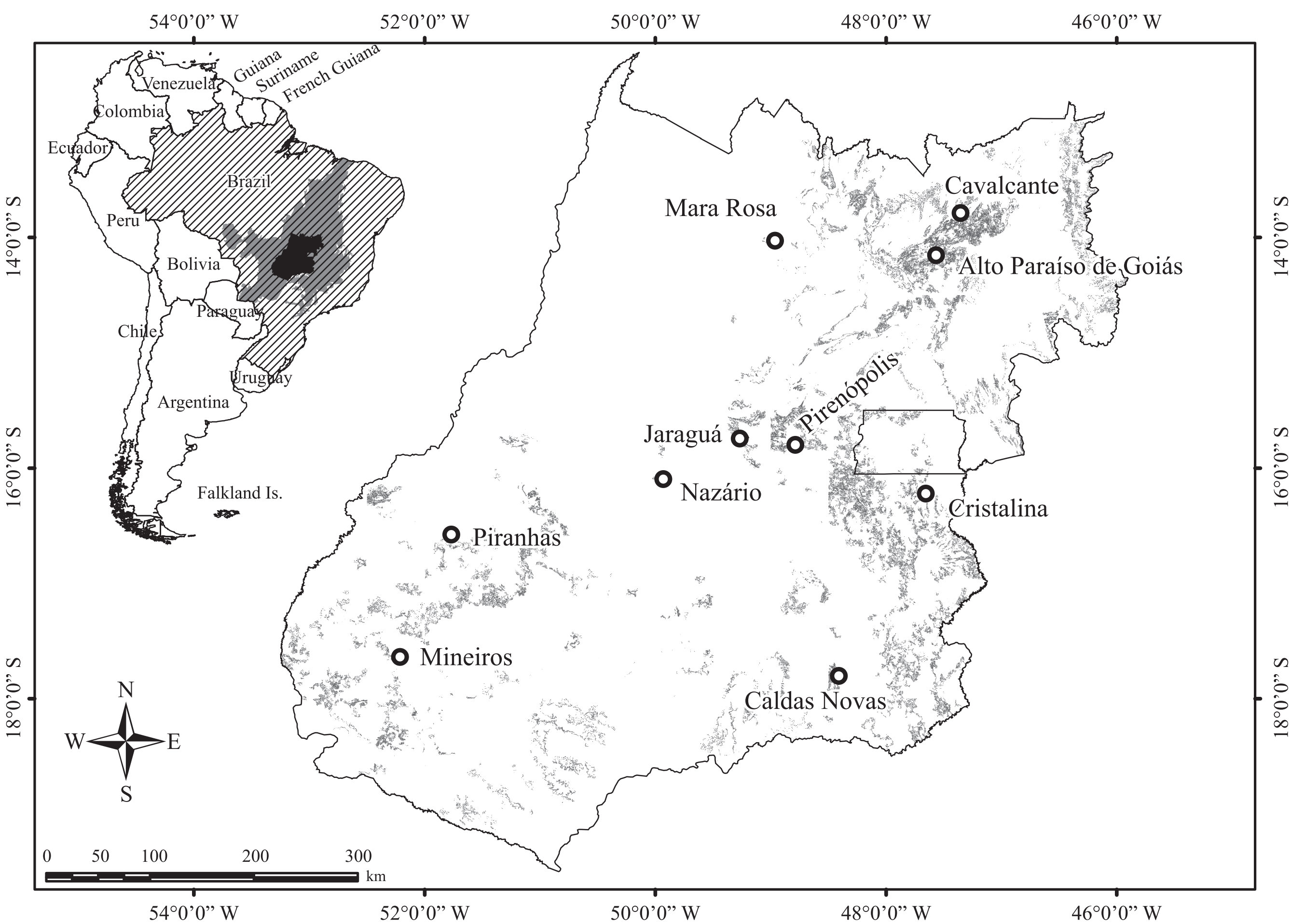

Figure 1. Location of the rocky outcrop cerrado areas sampled (●) in the Goiás State (GO), where: hatched = Brazil; dark grey = Cerrado biome; black = Goiás State; light grey in Goiás = regions with potential occurrence of rocky outcrop cerrado, according to Lima (2008).

1,200 and 2,500 mm (Sieg 2009). The highest elevation in the state is Morro Alto in the region of Chapada dos Veadeiros (approximately 1,921 m), while the lowest altitudes are found in the Araguaia region (approximately 182 m) (Sieg 2009) (table 1). Litholic neosols, upon which rocky outcrop cerrado vegetation normally develops, occupy approximately 8% of the state (Sano et al. 2006).

According to Lima (2008), rocky outcrop cerrado areas cover approximately 6.6% of Goiás State. These areas occur throughout the state, with greater frequency in the northeast in the micro-regions of Chapada dos Veadeiros, in the northern section of Brasília and Porangatu neighborhood. The present study surveyed areas in different regions where rocky outcrop cerrado occurs in Goiás State: in the northeast (three areas), southeast (two areas), southwest (two areas), and central region (three areas). The northwestern region of the state was excluded as there are few records of rocky outcrop cerrado there (Lima 2008).

Table 1. Spatial characteristics of the 10 rocky outcrop cerrado areas surveyed in Goiás State, Brazil.

Areas	Latitude (S)	Longitude (W)	Altitude (m)	Precipitation (mm)	Average temperature (°C)	Lithology
Alto Paraíso de Goiás	14°09’25”	47°36’25”	865	1,799	21.7	quartzite
Caldas Novas	17°47’42”	48°39’50”	670	1,386	23.0	sandstone
Cavalcante	13°47’29”	47°23’41”	900	1,720	23.6	sandstone
Cristalina	16°43’31”	47°41’50”	1,100	1,368	20.8	quartzite
Jaraguá	15°47’33”	49°20’35”	1,400	1,658	23.6	sandstone
Mara Rosa	14°01’53”	49°00’11”	650	1,849	24.9	sandstone
Nazário	16°41’00”	49°45’33”	650	1,467	23.4	sandstone
Piranhas	16°26’99”	51°53’99”	750	1,700	23.4	granite
Pirenópolis	15°48’13”	48°49’39”	850	1,564	20.8	sandstone
Mineiros	17°39’53”	52°16’39”	800	1,642	22.8	basalt

Vegetation survey – We established ten 20 × 50 m plots, totaling 1 ha for each site, in each of the 10 areas inventoried, following the protocols established for the Network of Permanent Plots in the Cerrado and Pantanal Biomes (Felfili et al. 2005). All the individuals with diameter 30 cm above soil level (DB_{30}) ≥ 5 cm were considered tree-shrub plants and included in the sampling, as recommended by Felfili et al. (2005). The botanical identifications were made in the field and by consulting the specific appropriate literature and herbaria samples stored at the Universidade de Brasília and Instituto Brasileiro de Geografia e Estatística, as well as specialists. The APG III (2009) classification system was adopted for the botanical families. The revision and updating of the taxa names was performed following Forzza et al. (2010). The classification of the species as well as their habits (the characteristics or appearances of plants: vines, subshrubs, shrubs, treelets, and trees) followed Mendonça et al. (2008).

Data analysis – The qualitative Sørensen index (Brower & Zar 1977) and the quantitative Czekanowski index (Kent & Coker 1992) were used to analyze the floristic similarities among the 10 areas inventoried. According to Kent & Coker (1992), the Sørensen and Czekanowski index values vary between zero and one, with values greater than 0.5 indicating high similarities between the communities. Additionally, the Mantel test (Legendre & Legendre 1998), using the PC-ORD 4 software program (McCune & Mefford 1999), was used to evaluate if the floristic similarity values generated by the Czekanowski index were related to the geographical distances between the areas. To evaluate the significance of the Mantel test, 1,000 random Monte Carlo permutations were run. TWINSPAN (Kent & Coker 1992) analysis was used to identify divisions and grouping patterns among areas based on floristic characteristics, which indicated and identified the preferential and indicator species of each area.

RESULTS AND DISCUSSION

A total of 13,041 tree-shrub individuals were surveyed, distributed among 219 species, 129 genera, and 55 botanical families; 196 (84.49%) of these taxa were identified to the species level, 17 (7.76%) to the genus level, five (2.28%) to the family level; one plant remained without definitive indication (table 2). In terms of their habits, 113 (57.65%) species were considered trees, 24 (12.24%) shrubs, 18 (9.18%) treelets, 15 (7.65%) trees/shrubs, 13 (6.63%) treelets/shrubs, six (3.06%) subshrubs, five (2.65%) trees/treelets, one (0.51%) shrub/subshrub, and one (0.51%) tree/vine.

According to Mendonça et al. (2008), the Cerrado biome as a whole contains 11,627 species of vascular phanerogams, 4,346 of which are considered tree-shrub. As such, the species recorded in the 10 rocky outcrop cerrado areas sampled here represent approximately

Table 2. Tree-shrub species ($DB_{30} \geq 5$ cm) with their respective densities, sampled in 10 areas of rocky outcrop cerrado (ten 20 × 50 m plots) in Goiás State, Brazil. The species are arranged in alphabetical order of their botanical families, where: * = widely distributed species in the Cerrado biome (Ratter et al. 2003); ** = specialist species in a specific habitat (Munhoz & Proença 1998, Ratter et al. 2000, Silva et al. 2001, Ribeiro & Walter 2008, Pinto et al. 2009); □ = forest species; ○ = not abundant regionally. The regions in which the species were found are represented by the letters NE (northeast), SE (southeast), SW (southwest) and CE (central).

Family/species	Habit	Number of areas
ANACARDIACEAE		
Anacardium occidentale L.	tree	NE(1); SW(1); CE (2)
Astronium fraxinifolium Schott*□	tree	NE (1); SW (1)
Tapirira guianensis Aubl. □○	tree	NE (1)
ANNONACEAE		
Annona coriacea Mart.*	tree/shrub	NE (1); SE (2); SW (1)
Annona crassiflora Mart.	tree	SW (1)
Guatteria sellowiana Schltdl. □	tree	CE (1)
Xylopia aromatica (Lam.) Mart.*	tree	NE (1); SE (2); SW (1); CE (2)
APOCYNACEAE		
Aspidosperma macrocarpon Mart.	tree	NE (1); SE (2); SW (2); CE (3)
Aspidosperma multiflorum A.DC.	tree	NE (2)
Aspidosperma ramiflorum Müll. Arg. □○	tree	SE (1)
Aspidosperma subincanum Mart. ex A.DC. □	tree	SW (1)
Aspidosperma tomentosum Mart.*	tree	NE (2); SE (2); SW (2); CE (3)
Aspidosperma sp.	–	CE (1)
Hancornia speciosa Gomes*	tree	NE (2); SE (2); SW (2); CE (2)
Himatanthus obovatus (Müll. Arg.) Woodson*	tree	NE (1); SE (1); CE (2)
AQUIFOLIACEAE		
Ilex congesta H.W.Li □	shrub	NE (1)
Ilex conocarpa Reissek □	tree	CE (1)
Ilex sp.	–	SW (1)
ARALIACEAE		
Schefflera burchellii (Seem.) Frodin & Fiaschi ○	tree	NE (1)
Schefflera macrocarpa (Cham. & Schltdl.) Frodin	tree	NE (2); SE (2); CE (3)
Schefflera vinosa (Cham. & Schltdl.) Frodin & Fiaschi ○	tree	SW (1)
ARECACEAE		
Acrocomia aculeata (Jacq.) Lodd. ex Mart. □	tree	SW (1)
Butia sp.	–	SW (1)
Syagrus comosa (Mart.) Mart.	shrub	NE (2); SW (1); CE (1)
Syagrus flexuosa (Mart.) Becc.	shrub	NE (3); SE (1); SW (1)
ASTERACEAE		
Eremanthus glomerulatus Less.	tree	NE (2); SE (2); CE (2)
Eremanthus goyazensis (Gardner) Sch. Bip.	treelet	NE (1); SE (1)
Piptocarpha rotundifolia (Less.) Baker	treelet	SW (1)
Wunderlichia cruelsiana Taub.**	tree	NE (2); CE (2)
Wunderlichia mirabilis Riedel ex Baker **	treelet	NE (1); SE (2); SW (1); CE (1)
Asteraceae NI 1○	–	SE (1)
Asteraceae NI 2	–	SW (1)
BIGNONIACEAE		
Handroanthus ochraceus (Cham.) Mattos*	tree	NE (1); SE (2); CE (3)
Handroanthus serratifolius (Vahl) S.O.Grose	tree	NE (1); SE (1); SW (1); CE (2)
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore*	tree	NE (1); SW (1); CE (2)
Tabebuia sp.	–	SE (1)

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Family/species	Habit	Number of areas
CALOPHYLLACEAE		
Kielmeyera coriacea Mart. & Zucc.*	tree	NE (3); SE (2); SW (2); CE (3)
Kielmeyera lathrophyton Saddi	tree	NE (2)
Kielmeyera rubriflora Cambess.	shrub	NE (2); SW (1); CE (1)
Kielmeyera speciosa A.St.-Hil.	tree	NE (1); SE (2); SW (1); CE (3)
CARYOCARACEAE		
Caryocar brasiliense Cambess.*	tree	NE (2); SE (1); SW (2); CE (2)
Caryocar cuneatum Wittm.	tree	NE (1)
CELASTRACEAE		
Plenckia populnea Reissek	tree	NE (2); SE (2); SW (1); CE (3)
Salacia crassifolia (Mart. ex Schult.) G.Don	tree/treelet	NE (2); SE (1); CE (2)
Salacia elliptica (Mart. ex Schult.) G.Don □	tree	SE (1)
CHRYSOBALANACEAE		
Couepia grandiflora (Mart. & Zucc.) Benth. ex Hook.f.	tree	NE (3); SE (1); SW (1)
Hirtella glandulosa Spreng. □○	tree	NE (1)
Licania humilis Cham. & Schltdl. □	tree	SE (2)
CLUSIACEAE		
Clusia weddelliana Planch. & Triana**	tree	NE (1); CE (1)
COMBRETACEAE		
Buchenavia tomentosa Eichler □	tree	SW (1)
Terminalia argentea Mart. □	tree	SW (1)
CONNARACEAE		
Connarus suberosus Planch.*	shrub	NE (3); SE (2); SW (2); CE (2)
Rourea induta Planch.	treelet	NE (2); SW (1); CE (1)
DILLENIACEAE		
Curatella americana L.*	tree	NE (1); SW (2)
Davilla elliptica A.St.-Hil.*	tree	NE (2); SE (2); SW (2); CE (2)
EBENACEAE		
Diospyros burchellii Hiern	tree	NE (1); SW (1); CE (2)
Diospyros sericea A.DC. □	tree	NE (1)
Diospyros sp. ○	–	NE (1)
ERICACEAE		
Agarista chapadensis (Kin.-Gouv.) Judd	treelet	NE (1)
ERYTHROXYLACEAE		
Erythroxylum anguifugum Mart. ○	treelet	NE (1)
Erythroxylum daphnites Mart. □	treelet	NE (1); SW (1)
Erythroxylum deciduum A.St.-Hil.	tree/treelet	NE (2); SW (1); CE (3)
Erythroxylum engleri O.E.Schulz ○	treelet	SW (1)
Erythroxylum suberosum A.St.-Hil.*	treelet	NE (3); SE (1); SW (2); CE (3)
Erythroxylum tortuosum Mart.	treelet	NE (1); SE (2); CE (1)
Erythroxylum sp. 1	–	NE (1)
Erythroxylum sp. 2 ○	–	NE (1)
EUPHORBIACEAE		
Alchornea triplinervia (Spreng.) Müll.Arg. □	tree	CE (1)
Maprounea guianensis Aubl. □	tree	SE (1); CE (1)
Euphorbiaceae NI	–	SW (1)
FABACEAE		
Acosmium sp.	–	SW (1)
Andira paniculata Benth.	tree	NE (2); SE (1); SW (1); CE (1)
Andira vermifuga Mart. ex Benth.	tree	NE (2); SE (1); CE (2)
Bauhinia pulchella Benth.	shrub	NE (1)
Bowdichia virgilioides Kunth*	tree	NE (2); SE (1); SW (2); CE (2)

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Family/species	Habit	Number of areas
Chamaecrista orbiculata (Benth.) H.S.Irwin & Barneby	treelet/shrub	NE (2); SE (1); SW (1); CE (2)
Chamaecrista pachyclada (Harms) H.S.Irwin & Barneby	subshrub	NE (1); CE (1)
Chamaecrista sp. 1	–	NE (1)
Chamaecrista sp. 2	–	SW (1)
Copaifera langsdorffii Desf. □	tree	SE (1); SW (1); CE (1)
Copaifera oblongifolia Mart.	treelet/shrub	NE (2)
Dalbergia miscolobium Benth.	tree	NE (1); SE (2); SW (1); CE (1)
Dimorphandra mollis Benth.*	tree	NE (2); SE (1); SW (1); CE (1)
Dipteryx alata Vogel □	tree	SO (1)
Hymenaea stigonocarpa Mart. ex Hayne*	tree	NE (1); SE (2); SW (2); CE (3)
Leptolobium dasycarpum Vogel*	tree/treelet	NE (2); SE (2); SW (2); CE (3)
Luetzelburgia praecox (Harms ex Kuntze) Harms	tree	NE (1); SW (1)
Machaerium acutifolium Vogel*	tree	NE (1); SW (1)
Machaerium opacum Vogel	tree	NE (2); SE (1); CE (1)
Mimosa claussenii Benth.	shrub	NE (2); SE (1)
Mimosa decorticans Harms ex Glaz.	treelet	SE (1)
Mimosa manidea Barneby	treelet	NE (1)
Mimosa setosissima Taub.**	shrub	CE (1)
Mimosa ulei Taub.	shrub	NE (1)
Peltogyne confertiflora (Mart. ex Hayne) Benth. □	tree	NE (1); SE (1); SW (1); CE (2)
Plathymenia reticulata Benth.*	tree	NE (1); SE (2); SW (2); CE (2)
Platypodium elegans Vogel □	tree	SW (1); CE (1)
Pterodon emarginatus Vogel □	tree	NE (1); SW (1)
Pterodon pubescens (Benth.) Benth.	tree	NE (1); SE (2); CE (2)
Senna velutina (Vogel) H.S. Irwin & Barneby	treelet/shrub	NE (1)
Stryphnodendron polyphyllum Mart.	tree/shrub	SE (1); SW (1)
Stryphnodendron rotundifolium Mart. ○	tree	SW (1)
Tachigali aurea Tul.*	tree	NE (1); SW (1)
Tachigali vulgaris L.G.Silva & H.C.Lima	tree	NE (3); SE (2); SW (1); CE (2)
Vatairea macrocarpa (Benth.) Ducke*	tree	NE (2); SE (1); SW (2); CE (2)
HUMIRIACEAE		
Humiria balsamifera Aubl. □	tree	NE (1)
ICACINACEAE		
Emmotum nitens (Benth) Miers □	tree	NE (2); SE (1); SW (1)
LAMIACEAE		
Aegiphila lhotskiana Cham.	tree/shrub	SE (2); SW (2); CE (2)
Hyptis pachyphylla Epling**	shrub	NE (1)
LAURACEAE		
Aniba heringeri Vattimo □○	tree	NE (1)
Endlicheria paniculata (Spreng.) J.F.Macbr. □	tree	SE (1)
Mezilaurus crassiramea (Meisn.)Taub. ex Mez ○	tree	SW (1)
Ocotea pomaderroides (Meisn.) Mez □	tree	NE (1); CE (1)
LOGANIACEAE		
Antonia ovata Pohl	shrub	SW (1)
Strychnos pseudoquina A.St.-Hil.	tree	SW (1)
LYTHRACEAE		
Lafoensia pacari A.St.-Hil.*	tree/shrub	NE (1); SE (2); SW (1); CE (2)
MALPHIGIACEAE		
Banisteriopsis latifolia (A.Juss.) B.Gates	treelet	NE (3); SW (1); CE (3)
Byrsonima basiloba A.Juss.	shrub	SW (1)
Byrsonima coccolobifolia Kunth*	tree	NE (3); SE (2); SW (2); CE (2)

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Family/species	Habit	Number of areas
Byrsonima crassifolia (L.) Kunth ○	tree/shrub	SE (1)
Byrsonima intermedia A.Juss.	tree/shrub	NE (1)
Byrsonima pachyphylla A.Juss.*	treelet/shrub	NE (3); SE (2); SW (1); CE (3)
Byrsonima verbascifolia (L.) Rich. ex Juss.*	tree	NE (1); SW (1); CE (1)
Byrsonima sp.	–	SW (1)
Heteropteris byrsonimifolia A.Juss.	treelet/shrub	NE (3); SE (1); SW (1); CE (3)
Tetrapterys microphylla Nied. ○	shrub	NE (1)
MALVACEAE		
Eriotheca gracilipes (K.Schum.) A.Robyns* □	tree	NE (2); SE (1); SW (2); CE (1)
Eriotheca pubescens (Mart. & Zucc.) Schott & Endl.	treelet/shrub	NE (1); SE (2); SW (1); CE (1)
Luehea candicans Mart. ○	tree	SW (1)
Pseudobombax longiflorum (Mart. & Zucc.) A. Robyns □	tree	NE (1); SE (1); CE (2)
Pseudobombax tomentosum (Mart. & Zucc.) Robyns □	tree	SW (1)
MARCGRAVIACEAE		
Norantea guianensis Aubl.	tree/vine	SW (2)
Schwartzia adamantium (Cambess.) Bedell ex Giraldo-Cañas**	tree/treelet	NE (2); SE (2); SW (1); CE (2)
MELASTOMATACEAE		
Macairea radula (Bonpl.) DC.	treelet	NE (1); CE (3)
Miconia albicans (Sw.) Triana	treelet	NE (2); SE (2); SW (1); CE (1)
Miconia burchellii Triana	tree	NE (2); SE (1); CE (1)
Miconia ferruginata DC.	tree	NE (3); SE (2); SW (1); CE (2)
Miconia irwinii Wurdack	tree	NE (1)
Miconia leucocarpa DC.○	tree	CE (1)
Miconia pepericarpa Mart. ex A.DC. ○	tree/shrub	SE (1)
Miconia rubiginosa (Bonpl.) DC.	shrub	NE (1); SE (1)
Mouriri elliptica Mart.	treelet	SW (2)
Tibouchina papyrus (Pohl) Toledo**	treelet/shrub	SW (1); CE (1)
Tibouchina sp. 1	–	NE (1)
Tibouchina sp. 2	–	SW (1)
Tibouchina villosissima Cogn. ○	shrub	CE (1)
MORACEAE		
Brosimum gaudichaudii Trécul*	tree/shrub	NE (1); SE (1); CE (1)
Ficus guaranitica Chodat □	tree	SE (1)
Ficus sp. ○	–	SW (1)
MYRISTICACEAE		
Virola sebifera Aubl. □	tree	SE (1); SW (1)
MYRSINACEAE		
Myrsine guianensis (Aubl.) Kuntze	tree	NE (1); SE (1); SW (1); CE (1)
MYRTACEAE		
Blepharocalyx salicifolius (Kunth) O.Berg	tree/shrub	NE (2); SE (1)
Eugenia aurata O.Berg	shrub	SW (1)
Eugenia involucrata DC. □○	tree/shrub	SE (1)
Eugenia punicifolia (Kunth) DC.	shrub	NE (1); SW (1); CE (1)
Myrcia bella Cambess.	shrub	NE (1); SE (1)
Myrcia cordifolia O.Berg	shrub/subshrub	CE (1)
Myrcia fenzliana O.Berg □	tree	CE (1)
Myrcia multiflora (Lam.) DC.	tree/shrub	CE (1)
Myrcia splendens (Sw.) DC.	tree	NE (1); SW (1)
Myrcia tomentosa (Aubl.) DC.	tree	SW (1); CE (1)
Myrcia uberavensis O.Berg	shrub	SE (1)
Myrcia variabilis DC.	subshrub	SE (1); SW (1)

continue

continuation

Family/species	Habit	Number of areas
Myrcia sp.	–	NE (1)
Myrtaceae NI	–	SW (1)
Psidium myrsinoides O.Berg	shrub	NE (3); SE (2); CE (3)
Psidium laruotteanaum O.Berg	treelet/shrub	SE (1); SW (1); CE (1)
Psidium sp. ○	–	SE (1)
Siphoneugena densiflora O.Berg □	tree	SE (1); CE (1)
NOT IDENTIFIED		
Not identified	–	SW (1)
NYCTAGINACEAE		
Guapira graciliflora (Schmidt) Lundell	tree	NE (2); SE (2); CE (3)
Guapira noxia (Netto) Lundell	tree	NE (2); SE (2); CE (2)
Neea theifera Oerst.	tree	NE (3); SE (2); SW (1); CE (2)
OCHNACEAE		
Ouratea glaucescens Engl.	tree/shrub	NE (2)
Ouratea hexasperma (A.St.-Hil.) Baill.*	treelet/shrub	NE (3); SE (2); SW (1); CE (3)
Ouratea spectabilis (Mart. ex Engl.) Engl.	tree	NE (1); SW (2); CE (1)
OLACACEAE		
Heisteria ovata Benth.	tree	SW (1); CE (1)
OPILIACEAE		
Agonandra brasiliensis Miers ex Benth. & Hook.f. □	tree/shrub	NE (1); CE (2)
PENTAPHYLACACEAE		
Ternstroemia carnosa Cambess.	tree/shrub	NE (1)
PRIMULACEAE		
Cybianthus gardneri (A.DC.) G.Agostini □○	tree	NE (1)
PROTEACEAE		
Roupala montana Aubl.*	tree	NE (2); SE (1); SW (1); CE (3)
RUBIACEAE		
Alibertia edulis (Rich.) A.Rich. ex DC.	shrub	NE (1); SW (1)
Chomelia ribesioides Benth. ex A.Gray	shrub	SE (2); SW (1); CE (2)
Cordiera concolor (Cham.) Kuntze	shrub	SE (2)
Cordiera elliptica (Cham.) Kuntze	shrub	NE (1)
Cordiera sessilis (Vell.) Kuntze □	treelet	NE (1); SW (1); CE (1)
Ferdinandusa elliptica Pohl	tree	NE (2)
Palicourea rigida Kunth	treelet/shrub	NE (3); SE (1); SW (1); CE (3)
Rudgea viburnoides (Cham.) Benth. □	treelet/shrub	SE (1); SW (1)
Tocoyena formosa (Cham. & Schltdl.) K.Schum.*	treelet	NE (2); SE (2); CE (3)
Rubiaceae NI	–	CE (1)
SALICACEAE		
Casearia sylvestris Sw.*	treelet/shrub	SE (2); SW (1)
SAPINDACEAE		
Magonia pubescens A.St.-Hil.	tree	SW (1)
Matayba elaeagnoides Radlk. □○	tree	SW (1)
Matayba guianensis Aubl. □	tree	NE (1)
SAPOTACEAE		
Pouteria ramiflora (Mart.) Radlk.*	tree	NE (1); SE (2); SW (1); CE (2)
Pouteria torta (Mart.) Radlk.	tree	SE (1)
SIMAROUBACEAE		
Simarouba versicolor A.St.-Hil. □	tree	NE (2); SE (2); SW (1); CE (2)
SIPARUNACEAE		
Siparuna guianensis Aubl. □	tree ou shrub	NE (1)
SOLANACEAE		
Solanum lycocarpum A.St.-Hil. ○	treelet/shrub	SE (1)

continue

continuation

Family/species	Habit	Number of areas
STYRACACEAE		
Styrax ferrugineus Nees & Mart.	tree/treelet	NE (1); SW (1); CE (1)
SYMPLOCACEAE		
Symplocos nitens (Pohl) Benth. □	tree	SE (1)
URTICACEAE		
Cecropia pachystachya Trécul □	tree	SW (1); CE (1)
VELLOZIACEAE		
Vellozia albiflora Pohl ○	subshrub	SE (1)
Vellozia squamata Pohl	subshrub	NE (3); SE (1); CE (2)
Vellozia tubiflora (A.Rich.) Kunth**	subshrub	NE (2)
Vellozia variabilis Mart. ex Schult.f.**	subshrub	NE (1); SW (1)
VOCHYSIACEAE		
Callisthene fasciculata Mart. □	tree	SW (1)
Callisthene major Mart. □	tree	SW (1)
Callisthene mollissima Warm.	tree	NE (2)
Callisthene sp.	–	NE (1)
Qualea grandiflora Mart.*	tree	NE (2); SE (2); SW (2); CE (2)
Qualea multiflora Mart.*	tree	NE (1); SE (2); SW (2); CE (3)
Qualea parviflora Mart.*	tree	NE (3); SE (2); SW (2); CE (3)
Salvertia convallariodora A.St.-Hil.*	tree	NE (1); SW (1); CE (1)
Vochysia elliptica Mart.	tree	NE (1); SE (1); SW (1); CE (1)
Vochysia gardneri Warm.	tree	NE (3); SW (1)
Vochysia rufa Mart.	tree	NE (2); SE (2); SW (1); CE (2)
Vochysia thyrsoidea Pohl	tree	NE (1); SE (1); CE (1)

5.03% of all of the tree-shrub species recorded for the entire biome. In terms of the cerrado (sensu lato), these species represent 9.55% of the recorded species, and for the rocky fields (sensu lato) they represent 17.39%. This data indicates the high floristic representivity of the rocky outcrop cerrado vegetation in Goiás State in terms of the tree-shrub components of the cerrado formations of the Cerrado biome. Considering that rocky field environments represent only 6.6% of Goiás State (Lima 2008), their floristic representivity becomes even more apparent.

The local floristic richnesses varied from 61 (in the municipalities of Nazário, Piranhas and Pirenópolis) to 84 species (Mineiros). This range is considered normal among cerrado formations (cerrado sensu stricto), which usually have less than 100 species per hectare (Felfili et al. 2004). The municipality of Mineiros is located in the Paraná Guimarães eco-region proposed by Arruda et al. (2008), with both sedimentary and volcanic rock formations (such as basalt – which is rich in iron/magnesium minerals) (Reatto et al. 2008). According to Benites et al. (2007), areas with rock outcrops can demonstrate considerable edapho-environmental diversity, reflected in vegetation mosaics that are largely determined by the local topography and by micro-environmental aspects. As such, the regional environmental heterogeneity contributed to the high floristic richness observed in Mineiros.

In general, the tree-shrub species richnesses observed in each of the sampling areas was greater than that reported in other studies of rocky outcrop cerrado using similar survey methodologies. A study by Amaral et al. (2006) in the Federal District, for example, reported 51 species, and by Miranda et al. (2007) in the Serra Dourada-GO recorded 54 species, by Pinto et al. (2009) in Cocalzinho, GO (65), by Moura et al. (2007, 2010) in Pirenópolis, GO (56 and 65 species respectively), and studies by Moura (2010) in the Rio Preto State Park, MG, in the Sete Cidades National Park-PI and in Cáceres, MT listed 42, 47 and 69 species respectively. The high richness values encountered in these areas demonstrate the necessity protecting rocky outcrop cerrado sites to ensure the preservation of their unique biodiversity. According to Benites et al. (2007), cerrado/rocky field environments are not suitable for agricultural and are therefore natural refuges for the regional flora and fauna – and should be considered priority areas for biodiversity conservation.

Among the 10 areas sampled, Fabaceae was the most representative plant family in terms of the numbers of species (35), followed by Myrtaceae (18), Melastomataceae (13), Vochysiaceae (12), Malphigiaceae (10), and Rubiaceae (10). The high representivities of these families were likewise observed in other studies of rocky outcrop cerrado sites in Brazil (Manoel 1999, Amaral et al. 2006, Moura et al. 2007, Pinto et al. 2009), as well as in cerrado areas sensu stricto (Marimon et al. 1998, Felfili et al. 2002, Assunção & Felfili 2004), and it could be seen that the rocky field and typical cerrado areas of Goiás State do not differ greatly in terms of their most representative families. Nonetheless, Marcgraviaceae and Velloziaceae, two well-represented families in rocky outcrop cerrados in terms of their numbers of species, densities of individuals, and geographical distribution (table 2), are generally poorly represented in areas of deep soils of cerrado (Ratter et al. 2000, 2003, Bridgewater et al. 2004), thus defining certain floristic differences between typical and rocky outcrop cerrados in the state.

Goodland (1979) considered the family Fabaceae to be one of the most important plant groups in the Cerrado biome. Vochysiaceae was also one of the best represented families in the present study, and its species (e.g. *Qualea grandiflora*, *Q. parviflora*, *Q. multiflora*, *Vochysia thyrsoidea* and *V. elliptica*) are known to accumulate aluminum (Haridasan 2000). According to this same author, the families Melastomataceae (e.g. *Miconia ferruginata* and *M. pohliana*); Rubiaceae (*Palicourea rigida*) also accumulate this metal. It is important to note that all the species cited above and identified as aluminum accumulators were encountered in the present study.

The floras of the rocky outcrop cerrado areas analyzed were largely composed of species known from cerrado sensu stricto (cerrado) formations growing on deep soils (74.40%) and forest species (21.50%). Nine species (4.10%) considered specialist to specific habitats (sensu Rabinowitz 1981) of rocky outcrop cerrado and that are restricted to rupestre environments were recorded: *Clusia weddelliana*, *Schwartzia adamantium*, *Mimosa setosissima*, *Tibouchina papyrus*, *Wunderlichia mirabilis*, *W. cruelsiana*, *Hyptis pachyphylla* (Ratter et al. 2000, Ribeiro & Walter 2008, Pinto et al. 2009), *Vellozia variabilis* (Silva et al. 2001), and *Vellozia tubiflora* (Munhoz & Proença 1998). *Tibouchina papyru*s is important because its distribution is restricted to Goiás State, occurring principally in Serra dos Pirineus, Serra Dourada, and Chapada dos Veadeiros (Munhoz & Proença 1998). In spite of the fact that only a small number of specialist species restricted to specific habitats were encountered in the rocky outcrop cerrado areas studied here, a number of them (*Wunderlichia cruelsiana*, *Schwartzia adamantium*, *Hyptis pachyphylla*, *Vellozia variabilis* and *V. tubiflora*) were cited as being important in determining the structure of rocky outcrop cerrado sites in Caldas Novas-GO (Lima et al. 2010) and in Alto Paraíso de Goiás-GO (Lenza et al. 2011).

Of the 38 species cited by Ratter et al. (2003) as being widely distributed throughout the Cerrado biome, 37 were encountered in areas of rocky outcrop cerrado in Goiás State (table 2). According to Lima et al. (2010), these species can serve as sources of diaspores for cerrado sensu stricto areas on deep soils and can contribute to the recuperation of altered areas of that biome. Twenty-six species (11.87% of the total) were considered of limited regional abundance in the 10 areas of rocky outcrop cerrado surveyed by us in Goiás State (table 2). A species was considered of limited regional abundance in the present study if only one individual was encountered in only one of the areas inventoried. Among all the species recorded in rocky outcrop cerrado areas in Goiás State, nine (4.10%) were recorded in less than three (< 10%) of the 376 areas of Cerrado studied by Ratter et al. (2003) throughout Brazil. Among these species, only two (*Erythroxylum anguifugum* and *Miconia pepericarpa*) were found among the species considered to be of limited regional abundance in the present study, reinforcing the importance of rocky outcrop cerrado sites in the preservation of species demonstrating low general abundance as well as those that are specialists in specific habitats.

The floristic similarities of the 10 survey areas as calculated by the Sørensen index varied from 0.18 to 0.71 (table 3). Values > 0.50 (indicating high similarities between areas) (Kent & Coker 1992), were observed in 42.3% of the comparisons. Additionally, many of the values were between 0.45 and 0.50 (table 3), and therefore near the level of high similarity. Based on these results, it is possible to infer that there was considerable floristic similarity between the areas surveyed. On the other hand, all of the values generated by the Czekanowski index were low (< 0.50), except between Jaraguá and Mara Rosa areas (table 3) – indicating that in spite of the apparent similarities in the species compositions among the different areas, differences in relative densities that gave them unique structural characteristics. In their studies of Cerrado areas (sensu stricto) in Chapada Pratinha, Chapada dos Veadeiros and São Francisco, Felfili et al. (2004) noted that species densities were one of the most important factors in differentiating between the different areas. According to those authors, this parameter must be taken into consideration when considering strategies designed to protect populations of native woody Cerrado species.

Table 3. Sørensen and Czekanowski floristic similarity indices, calculated based on the tree-shrub vegetation ($DB_{30} \geq 5$ cm) surveyed in 10 areas of rocky outcrop cerrado (ten 20 × 50 m plots) in Goiás State, Brazil. (A1 = Alto Paraíso de Goiás; A2 = Caldas Novas; A3 = Cavalcante; A4 = Cristalina; A5 = Jaraguá; A6 = Mara Rosa; A7 = Nazário; A8 = Piranhas; A9 = Pirenópolis; A10 = Mineiros). Values indicated in bold type indicate high levels of floristic similarity between the areas.

		Czekanowski									
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Sørensen	A1	1	0.07	0.15	0.17	0.11	0.08	0.10	0.06	0.19	0.11
	A2	0.32	1	0.21	0.40	0.35	0.29	0.40	0.25	0.21	0.17
	A3	0.48	0.47	1	0.28	0.35	0.47	0.29	0.22	0.20	0.19
	A4	0.45	**0.61**	0.49	1	0.29	0.32	0.30	0.14	0.39	0.22
	A5	0.36	**0.64**	**0.57**	**0.59**	1	**0.50**	0.47	0.27	0.19	0.28
	A6	0.30	**0.56**	**0.51**	**0.52**	**0.71**	1	0.40	0.30	0.23	0.30
	A7	0.28	**0.58**	**0.50**	**0.53**	**0.71**	**0.67**	1	0.37	0.21	0.23
	A8	0.18	0.37	0.32	0.26	0.40	0.44	0.40	1	0.11	0.19
	A9	0.45	0.45	0.42	**0.58**	**0.52**	0.48	0.47	0.29	1	0.16
	A10	0.32	**0.52**	0.47	**0.51**	**0.52**	**0.56**	0.45	0.31	0.38	1

The greatest similarity values in the present study were seen between Jaraguá and Mara Rosa according to both indices, and between Jaraguá and Nazário by the Sørensen index. On the other hand, the areas of Alto Paraíso de Goiás and Piranhas showed the greatest mutual differences, and were not found in the similar to any of the other survey areas as judged by either of the indices used here. Considered together, the results of the floristic similarity analyses did not reveal any relationships between the regions or with the geographical distances between the 10 sites analyzed. These results corroborated with those reported by Felfili et al. (2004), which indicated that local environmental conditions largely determine floristic similarities of cerrado (sensu stricto) areas, independent of their geographical proximity.

Similarly, the groups formed by Two-Way Indicator Species Analysis (TWINSPAN) (figure 2) (e.g. Alto Paraíso de Goiás and Pirenópolis; Cristalina and Mineiros; Caldas Novas, Jaraguá, Mara Rosa and Nazário) did not correspond to any defined geographical area, while the areas separated by the analyses were geographically close, or even belonged to the same geographical region (e.g. Alto Paraíso de Goiás and Cavalcante). As such, the results generated by TWINSPAN likewise indicated the lack of regional influences (or of the geographical distances between the areas) on their species distributions. In general, the differences in population sizes were responsible for forming these groups as the species compositions were generally homogeneous among the different areas.

The results of the Mantel test ($r = 0.32$, $P = 0.05$) likewise indicated the lack of any relationships between geographical distances separating them and the floristic similarity values of the areas. In this case, the similarities of the environmental parameters were more important in the analyses than the geographical distances between the areas, as was also observed by Conceição et al. (2007) in four areas of open rocky field vegetation in the Chapada Diamantina (Bahia State). These authors observed that the closest sites were not the most floristically similar, indicating that other factors more relevant than distance were involved in determining species compositions.

Felfili et al. (2004) compared a number of cerrado sites growing on deep soils in the Chapada Pratinha, Chapada dos Veadeiros, and Espigão Mestre do São Francisco physiographic units, and encountered high floristic similarities between them. However, when some of the sites within these units were compared with the Alto Paraíso de Goiás and Chapada dos Veadeiros sites, only low similarities were found – leading the authors to believe that the Chapada dos Veadeiros region is physiographically highly heterogeneous, and that this heterogeneity is accentuated by the presence of superficial limestone and sandstone rock formations and an irregular landscape. Additionally, Chapada dos Veadeiros is considered a center of species endemism for the Cerrado biome (Simon & Proença 2000). These factors probably influenced the finding that there were 16 species exclusive to the Alto Paraíso de Goiás and Piranhas sites (both of which were examined in the present study). It is important to point out that the region near Piranhas has many granitic outcrops, which may have favored the establishment of these exclusive species. A number of authors have commented on the possibility that differences in environment conditions (such as edaphic and landscape qualities) could explain the low similarities seen between different areas (Felfili & Felfili 2001, Felfili & Silva Júnior 2005).

The peripheral geographical localization of the Alto Paraíso and Piranhas areas, together with their floristic similarities and their large numbers of exclusive species, make these areas important potential sites for the conservation of the woody rocky outcrop cerrados flora in Goiás State. According to Felfili (2007), the

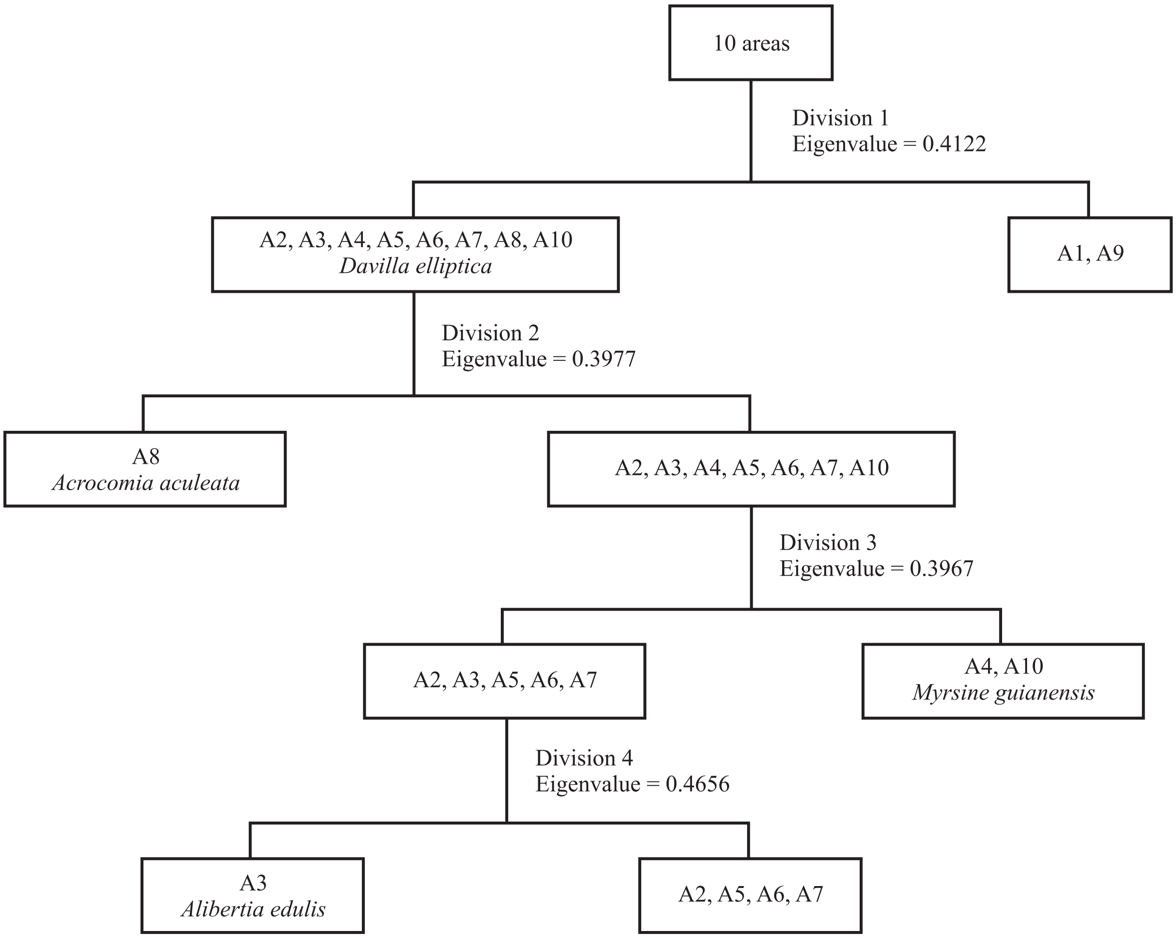

Figure 2. Dendrogram generated by divisive classification (TWINSPAN) of 10 areas of rocky outcrop cerrado surveyed in Goiás State, Brazil. (A1 = Alto Paraíso de Goiás; A2 = Caldas Novas; A3 = Cavalcante; A4 = Cristalina; A5 = Jaraguá; A6 = Mara Rosa; A7 = Nazário; A8 = Piranhas; A9 = Pirenópolis; A10 = Mineiros).

only conservation area in the region (the Chapada dos Veadeiros National Park) is not in itself sufficient to preserve the elevated richness and floristic heterogeneity found in the region. As such, we suggest the creation of new conservation areas in these two regions, especially in sites that have distinct edaphic conditions not represented in other established conservation sites.

The results of the present study indicate that the rocky outcrop cerrado vegetation of Goiás State has high floristic richness. Most of the species identified can also be found in cerrado sensu stricto sites on deep soils, and some of them are seen in forest environments, and small numbers of specialist species that inhabit specific and limited habitats. The combination of high richness, floristic uniqueness, and the small disturbance indices of rocky outcrop cerrados sites in Goiás State make them strategically valuable for the conservation of the woody vegetation of cerrado formations in the Cerrado biome.

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