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Patterns of richness and distribution of Cactaceae in the Serra da Mantiqueira, Southeast Brazil, and implications for its conservation[1]

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ABSTRACT

This study aimed to analyze patterns of richness and distribution of Cactaceae in the Serra da Mantiqueira (SM), a mountain range located in Southeast Brazil, and assess its conservation status. We compiled distribution data from the literature and 16 herbaria and plotted it on a map divided into grid squares of 0.5°. Richness, collection effort and similarity among grid squares were analyzed for the 33 taxa recorded in SM (five of which are endemic). Maciço do Itatiaia (in southern SM), Serra do Brigadeiro and Serra do Caparaó (in northern SM) are the richest areas. Collection effort and richness were correlated (R^2=0.75). Similarity analysis revealed five clusters, one of which is composed of high elevation areas with a vegetation mosaic; the remaining clusters lack biogeographic significance, and are mainly composed of widely distributed species. Ten species had no records in any state or national conservation unit of integral protection, at least two of which are threatened with extinction. Species of Cactaceae deserve attention because several taxa are threatened and/or endemic, and because the majority of SM is environmentally degraded. These findings highlight the need for urgent conservation actions for the local biodiversity os SM.

Keywords: Atlantic Forest, *campo de altitude*, conservation, distribution patterns, species richness

Introduction

Tropical mountains harbor significant biological diversity (Mutke & Barthlott 2005; Körner *et al*. 2016), largely due to the isolation and heterogeneity of habitats and an environmental gradient that often results in high beta diversity (Whittaker *et al*. 2001; Muenchow *et al*. 2018) and endemism (Barthlott *et al*. 2005). This is particularly true for the floristic component (Martinelli 2007; Körner *et al*. 2016). Distribution patterns are the subject of biogeography and macroecology, and their explanations are quite diverse (Villalobos & Rangel 2014). Isolation is one of the drivers responsible for the distribution patterns of several taxa in mountains (Körner *et al*. 2016); however, to investigate such phenomena surveys need to be performed in several areas in order to fill knowledge gaps about species composition. This is true at different scales, such as for Brazil as a whole (Sousa-Baena *et al*. 2013), for Atlantic phytogeographic domain (Werneck *et al*. 2011) and for Brazilian mountains (Martinelli 2007).

Serra da Mantiqueira (SM) is a Brazilian mountain range comprising several vegetation physiognomies in the states of Espírito Santo, Minas Gerais, Rio de Janeiro, and São Paulo. It is composed of two main plateaus referred to as the Northern Plateau and the Southern Plateau (Machado-Filho *et al*. 1983). The area is of special biological importance and is considered a priority for the conservation of springs and endemic species (Drummond *et al*. 2005; Pelissari & Romaniuc-Neto 2013; Saout *et al*. 2013). Given the lack of

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floristic knowledge and the conservation priority for SM, additional botanical collections are needed (Stehmann & Sobral 2009).

Serra da Mantiqueira has been highly damaged throughout its historical occupation with much of its original vegetation being replaced by forestry or agricultural crops (Mendes Júnior *et al*. 1991; Pelissari & Romaniuc-Neto 2013). Burning, deforestation, cultivation on steep slopes and extensive pastures of low productivity are examples of the activities that have shaped Serra da Mantiqueira over the last two centuries (Mendes Júnior *et al*. 1991). Nonetheless, there are some conservation units in the region, with the main ones being the Itatiaia and Caparaó national parks and Ibitipoca, Serra do Brigadeiro, Serra do Papagaio, Pedra Selada and Campos do Jordão state parks (Gonzaga & Menini Neto 2017).

Cactaceae comprises 124 genera and about 1438 species, and is almost exclusively distributed in tropical and subtropical America from Canada to Patagonia; *Rhipsalis baccifera* is the only species that occurs in Africa, Madagascar and Sri Lanka (Hunt *et al*. 2006). The main centers of diversity and endemism for the family are in Mexico, the Southwest United States, the central region of the Andes — mainly Peru and Bolivia — and eastern Brazil, where it occurs in several types of habitats (Taylor & Zappi 2004).

Species of Cactaceae are highly affected by anthropic disturbances, which cause rapid habitat destruction that especially affects narrowly distributed endemic taxa. Thirty-one percent of the species of Cactaceae are considered threatened, which reflects the high anthropogenic pressure put on biodiversity in arid lands (Goettsch *et al*. 2015). There are 39 genera of Cactaceae in Brazil, of which 14 are endemic, encompassing 261 species and 92 subspecies (BFG 2015). They occur in all states and phytogeographic domains of the country, but especially in the Caatinga, Cerrado and Atlantic Forest (Taylor & Zappi 2004). There are 11 genera and 33 subgeneric taxa of Cactaceae in SM, five of which are endemic and several that are narrowly distributed and threatened due to anthropogenic pressures (Gonzaga 2016). Two of these taxa are cited among the rare plants of Brazil (Machado 2009), while 11 are considered to be in some category of threat (Goettsch *et al*. 2015).

Taylor & Zappi (2004) provided descriptions and comments on the geographic distribution and conservation of taxa of Cactaceae for eastern Brazil, while other studies have focused specifically on Serra da Mantiqueira, such as those by Gonzaga *et al*. (2014a; b; 2015; 2016a; b; 2017), which provided additional knowledge about the distribution of several taxa. Nonetheless, a thorough study dealing with the distribution and conservation of Cactaceae in Serra da Mantiqueira is yet to be realized, even though knowledge of the distribution of organisms is very important for implementing conservation efforts.

Taking this into consideration, the present study seeks to answer the following questions: 1) How are taxa of Cactaceae geographically and altitudinally distributed in Serra da Mantiqueira? 2) What are the most taxonomic rich areas of SM? 3) Are taxonomic richness and collection effort of Cactaceae correlated in SM? 4) Are there any relationships between the regions of SM and the flora of Cactaceae? 5) What are the knowledge gaps in need of being filled for Cactaceae in SM? 6) Which taxa of Cactaceae are protected by comprehensive protection conservation units in SM, and are these taxa listed as threatened with extinction on red lists?

Materials and methods

Study area

Different proposals exist for delimiting SM (Mello & Mello 1909; Várzea 1942; CETEC 1983; Machado-Filho *et al*. 1983), of which the most recent is followed herein. Machado-Filho *et al*. (1983) indicated the existence of two main plateaus that encompass an extension of approximately 500 km: the Northern Plateau and the Southern Plateau (Fig. 1A). The Northern Plateau is composed of the staggered steppes of southern Espírito Santo State, the Maciço of Caparaó, the Serra do Brigadeiro and the Zona da Mata range of the state of Minas Gerais. The Southern Plateau comprises the geomorphological units of the Campos do Jordão and Itatiaia plateaus and is bordered to the north by the high plateau regions of the upper Rio Grande (state of Minas Gerais), to the east by the south-central plateau of Minas Gerais, to the south by the Paraíba do Sul Valley (state of Rio de Janeiro), and to the west by the Amparo plateau (state of São Paulo).

Data collection

Data on the geographical distribution of Cactaceae in SM were obtained from the literature along with observations of natural populations and analysis of specimens deposited in Brazilian herbaria: BHCB, CESJ, ESALQ*, FCAB, GUA, HB, HUEMG, MBML, R, RB, RBR, SP, SPF, UEC, VIC, and VIES (acronyms according to Thiers 2018). These herbaria were visited or data were obtained from available records in speciesLink (www.splink.org.br; highlighted with an asterisk). Records presented by Gonzaga (2016) with questionable provenance data or referring to cultivated plants [*Brasiliopuntia brasiliensis* (Willd.) A. Berger; *Hylocereus undatus* (Haw.) Britton & Rose; *Opuntia ficus-indica* (L.) Mill.; and *Schlumbergera truncata* (Haw.) Moran] were not considered. Records lacking coordinates were georeferenced when possible using the "GeoLoc" tool available in the "*Centro de Referência em Informação Ambiental*" site (*CRIA*) (http://splink.cria.org.br/geoloc?criaLANG=pt) or Google Earth (https://www.google.com/earth/).

Spatial analyses

To evaluate the existence of distribution patterns for Cactaceae in SM, records were plotted on the Americas Base Map (Bletter *et al*. 2004) with a graticule of 0.5° x 0.5°. The Serra da Mantiqueira shapefile was created by the geoprocessing team of the Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, according to the delimitation of Machado-Filho *et al*. (1983). Richness considered the presence of species of Cactaceae in each grid square while collection effort represented the total number of Cactaceae records in each grid square. A regression analysis was performed to evaluate any correlation between richness and collection effort. The elevation of each record was extracted and the distribution of species of Cactaceae was evaluated along the elevation gradient using 14 elevation belts of 200m. These analyses were conducted using DIVA-GIS v.7.5 free access software (http://www.diva-gis.org/).

Similarity analysis

Similarity analysis was performed between grid squares with occurring taxa (Tab. 1) using the UPGMA algorithm (Unweighted Pair-Group Method using Arithmetic Averages), and Jaccard index to verify relationships between

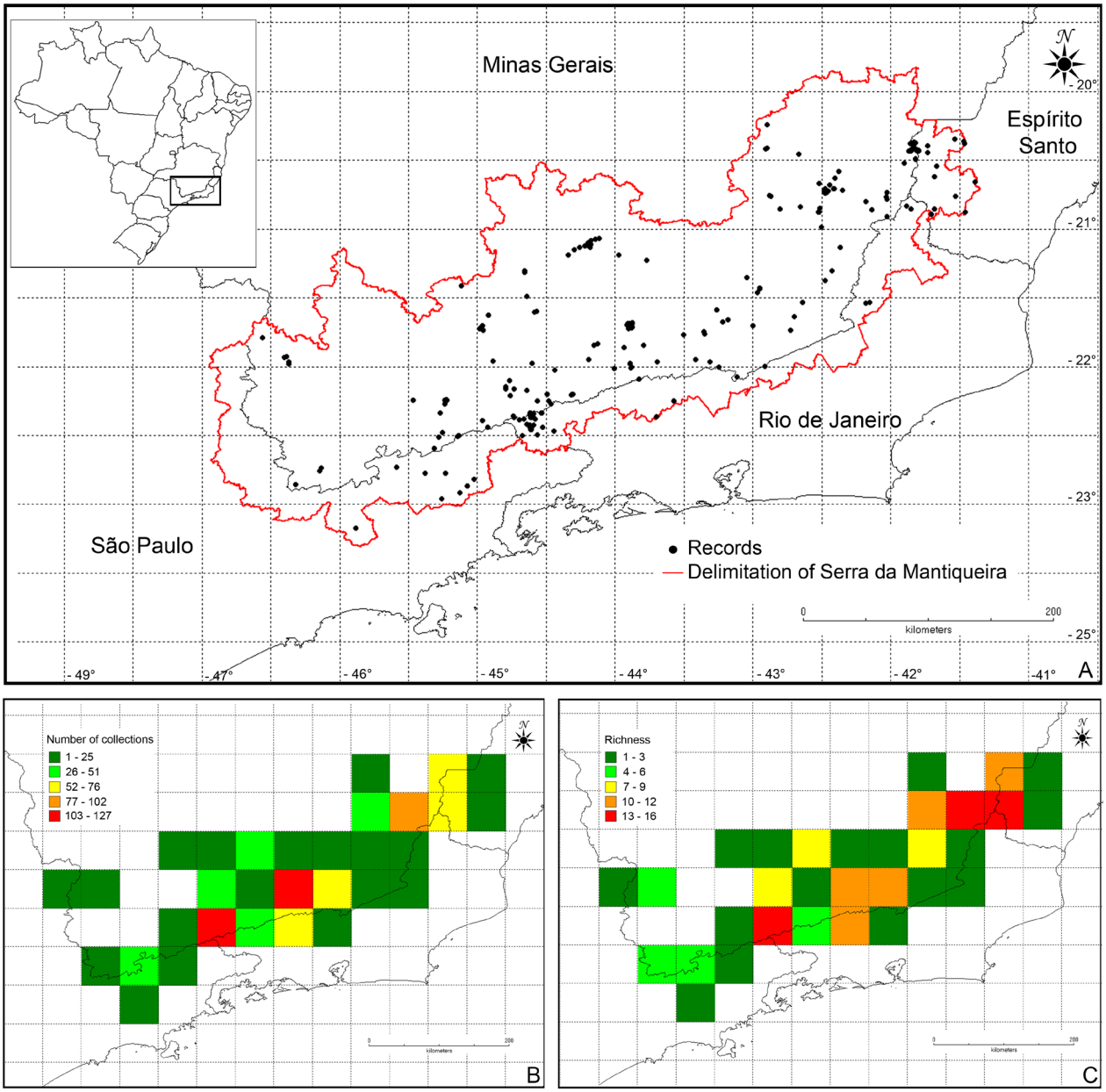

Figure 1. **A.** Records of Cactaceae in Serra da Mantiqueira; **B.** Collection effort of Cactaceae in Serra da Mantiqueira; **C.** Species richness of Cactaceae in Serra da Mantiqueira. Grid squares: 0.5°.

the SM regions (Fig. 1). A similarity dendrogram was created from a presence (1)/absence (0) matrix, and the cophenetic coefficient calculated, using PAST v.3 free access software (Hammer *et al.* 2001).

Conservation

To determine which taxa are protected and if a reevaluation of extinction risk is needed, especially for SM endemics, records were overlaid with national and state comprehensive protection conservation units and the taxa compared with red lists obtained from MMA (2014) and Goettsch *et al*. (2015). The shapefiles for the conservation units were obtained at http://www.mma.gov.br.

Results

Distribution, elevation gradient, richness and collection effort

Grid squares with records of the presence of Cactaceae had from one (especially in the northwestern border of SM at the ecotone between Atlantic Forest and Cerrado) to 16 (in the Maciço do Itatiaia region) taxa. In general, there were few areas with many taxa, and many areas with few taxa (Fig. 1).

We found three distribution patterns for taxa of Cactaceae in SM: I) taxa widely distributed in SM (found in both plateaus), *Cereus fernambucensis* subsp. *sericifer*,

Table 1. Red list category, grids and occurrences in Conservation Units in Serra da Mantiqueira.

Taxa	Red List Category		Grids	Occurrence in Conservation Units of Integral Protection								
	MMA (2014)	Goettsch *et al.* (2015)		PNC (MG/ES)	PNI (MG/RJ)	PEIB (MG)	PESB (MG)	PESNM (MG)	PESP (MG)	RSJ (MG)	PEPS (RJ)	PECJ (SP)
Arthrocereus melanurus subsp. *magnus* N.P.Taylor & Zappi *	EN	LC	3	-	-	+	-	+	-	-	-	-
A. melanurus Diers *et al.* subsp. *melanurus*	EN	VU	4	-	-	-	-	-	-	+	-	-
Cereus fernambucensis subsp. *sericifer* (Ritter) N.P.Taylor & Zappi	LC	LC	3	-	-	-	-	-	-	-	-	-
Coleocephalocereus fluminensis (Miq.) Backeb.	LC	LC	4	-	-	-	-	-	-	-	-	-
Epiphyllum phyllanthus (L.) Haw.	LC	LC	9	-	-	-	-	-	-	-	-	-
Hatiora herminiae (Porto & Castell.) Backeb. ex Barthlott *	LC	EN	2	-	-	-	-	-	-	-	-	+
Hatiora salicornioides (Haw.) Britton & Rose	LC	LC	16	+	+	+	+	+	-	+	-	+
Hylocereus setaceus (Salm-Dyck) R.Bauer	LC	LC	9	-	-	-	-	-	-	-	-	-
Lepismium cruciforme (Vell.) Miq.	LC	LC	9	+	-	+	+	-	-	-	-	-
L. houlletianum (Lem.) Barthlott	LC	LC	9	+	+	+	-	+	-	+	-	-
L. lumbricoides (Lem.) Barthlott	LC	LC	1	-	-	-	-	-	-	-	-	-
L. warmingianum (K.Schum.) Barthlott	LC	LC	1	-	-	-	-	-	-	-	-	-
Opuntia monacantha Haw.	LC	LC	4	-	-	-	-	+	-	-	-	-
Pereskia aculeata Mill.	LC	LC	5	-	+	-	+	-	-	-	-	-
P. grandifolia Haw.	LC	LC	3	-	-	-	-	-	-	-	-	-
Rhipsalis agudoensis N.P.Taylor	LC	DD	1	-	+	-	-	-	-	-	-	-
R. campos-portoana Loefgr.	LC	LC	1	-	+	-	-	-	-	-	-	-
R. clavata F.A.C.Weber	LC	NT	3	+	-	-	+	-	-	-	-	-
R. crispata (Haw.) Pfeiff.	LC	EN	1	-	-	-	-	-	-	-	-	-
R. elliptica G.Lindb. ex K.Schum.	LC	LC	8	+	+	+	+	+	-	-	+	-
R. floccosa subsp. *pulvinigera* (G.Lindb.) Barthlott & N.P.Taylor	LC	LC	16	+	+	+	+	+	+	+	-	+
R. juengeri Barthlott & N.P.Taylor	LC	LC	7	+	+	+	+	+	-	-	-	-
R. lindbergiana K.Schum.	LC	LC	18	+	-	-	-	+	-	-	+	-
R. neves-armondii K.Schum.	LC	LC	1	-	+	-	-	-	-	-	-	-
R. oblonga Loefgr.	LC	VU	1	-	-	-	-	-	-	-	-	-
R. pachyptera Pfeiff.	LC	LC	1	-	-	-	-	-	-	-	-	-
R. pilocarpa Loefgr.	LC	VU	3	+	+	-	-	+	-	-	-	-
R. pulchra Loefgr.	LC	LC	6	+	+	+	+	-	+	-	+	+
R. teres (Vell.) Steud.	LC	LC	5	+	-	-	-	-	-	-	-	-
Schlumbergera kautskyi (Horobin & McMillan) N.P.Taylor	EN	EN	3	+	-	-	+	-	-	-	-	-
S. lutea Calvente & Zappi subsp. *lutea* *	LC	EN	1	-	+	-	-	-	-	-	-	-
S. microsphaerica (K.Schum.) Hoevel *	VU	VU	3	-	+	-	-	-	-	-	-	-
S. opuntioides (Loefgr. & Dusén) D.R.Hunt *	VU	VU	5	-	+	+	-	-	+	-	-	+

Red List Category: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient. Grids: number of grids with occurrence of the species. PNC: Parque Nacional do Caparaó; PNI: Parque Nacional do Itatiaia; PEIB: Parque Estadual do Ibitipoca; PESB: Parque Estadual da Serra do Brigadeiro; PESNM: Parque Estadual da Serra da Negra da Mantiqueira; PESP: Parque Estadual da Serra do Papagaio; RSJ: Refúgio de Vida Silvestre Libélulas da Serra de São José; PEPS: Parque Estadual da Pedra Selada; PECJ: Parque Estadual de Campos do Jordão. States: ES – Espírito Santo; MG – Minas Gerais; RJ – Rio de Janeiro; SP – São Paulo. * Endemic to Serra da Mantiqueira.

Coleocephalocereus fluminensis, *Epiphyllum phyllanthus*, *Hatiora salicornioides*, *Hylocereus setaceus*, *L. cruciforme*, *L. houlletianum*, *P. aculeata*, *P. grandifolia*, *R. elliptica*, *R. floccosa* subsp. *pulvinigera*, *R. juengeri*, *R. lindbergiana*, *R. pilocarpa*, *R. pulchra*, *R. teres*, *S. microsphaerica*, *S. opuntioides*; II) taxa restricted to the Northern Plateau, *O. monacantha*, *R. clavata*, *R. crispata*, *R. oblonga*, *R. pachyptera*, and *S. kautskyi*; III) taxa restricted to the Southern Plateau, *A. melanurus* subsp. *magnus*, *A. melanurus* subsp. *melanurus*, *Hatiora herminiae*, *L. lumbricoides*, *L. warmingianum*, *R. agudoensis*, *R. campos-portoana*, *R. neves-armondii*, *S. lutea* subsp. *lutea* (Tab. 1).

Arthrocereus melanurus subsp. *magnus*, *Hatiora herminiae*, *Schlumbergera lutea* subsp. *lutea*, *S. microsphaerica* and *S. opuntioides* had the narrowest distributions, being endemic to SM. *Schlumbergera lutea* subsp. *lutea* is only known from its type locality (grid square 24) in Maciço do Itatiaia/Mauá, and has not been collected since its discovery. *Rhipsalis agudoensis* is known from two records in SM — one in Parque Nacional do Itatiaia and one from the district of Penedo — both in the municipality of Itatiaia, state of Rio de Janeiro, and thus its distribution is limited to grid square 24. *Lepismium lumbricoides*, *L. warmingianum*, *Rhipsalis campos-portoana*, *R. crispata*, *R. neves-armondii*, *R. oblonga* and *R. pachyptera* are widely distributed throughout the Atlantic Forest, but are known from only one collection site each in SM.

The occurrence of taxa is more common between 600 and 1200 m (12 taxa). *Lepismium cruciforme* and *R. lindbergiana* are the only taxa that occur in the 0–200 m elevation range. Some species occur at specific elevations, as is the case of *Schlumbergera lutea* subsp. *lutea* (401–600 m), *Rhipsalis crispata*, *R. oblonga*, *R. pachyptera* (601–800 m), *R. neves-armondii* (801–1000 m) and *R. clavata* (1201–1600 m). *Rhipsalis pulchra*, *S. microsphaerica* and *S. opuntioides* reach elevations above 2000 m, while *S. microsphaerica* is the only species to reach the range of 2600–2800 m (Tab. S1 in supplementary material).

The richest regions are represented by grid squares 5, 6 and 24 (Fig. 1), with 13, 14, and 16 taxa, respectively. The first two of these grids represent an area bridging Parque Estadual da Serra do Brigadeiro and Parque Nacional do Caparaó at the border of the states of Minas Gerais and Espírito Santo. The last refers to the region of Maciço de Itatiaia at the border of states of Minas Gerais and Rio de Janeiro. Richness and collection effort were found to be positively correlated ($R^2 = 0.75$, $F = 88.1$, $df = 29$) (Fig. 1).

Similarity

The similarity analysis of grid squares resulted in the dendrogram of Figure 2. The cophenetic coefficient was 0.84, indicating a good fit between the presence/absence matrix and the obtained dendrogram. The dendrogram splits the grids into two groups — one composed of clusters A, B, C, and D, and one composed of cluster E. The clearest distribution pattern observed is that of cluster A, which was formed by the grid squares 2, 4, 5, 6, 13, 19, and 24, thus grouping high elevation areas together. The vegetation of this cluster is composed of a mosaic of forests (mainly rainforest) and field formations (*campos rupestres* and *campos de altitude*). All grids of cluster A share the occurrence of *Rhipsalis elliptica* and *R. lindbergiana*, which are commonly found taxa in SM. The cluster also contains the occurrence of endemic taxa to SM: *Schlumbergera microsphaerica* (grid squares 6 and 24), *S. opuntioides* (grid squares 19 and 24), *S. lutea* subsp. *lutea* (grid square 24) and *Arthrocereus melanurus* subsp. *magnus* (grid square 19). The other clusters (B, C, D, and E) are generally composed of geographically unrelated grid squares and mainly share supertramp species (which, consequently, have broad distributions) and/or possess a reduced number of taxa (*e.g.*, grids 1, 7, 8, 12, 15 and 18 have only one taxon each), and thus do not represent a clear distribution pattern. In spite of the lack of a clear distribution pattern, it is interesting to notice the occurrence of some narrowly-distributed species, such as *Hatiora herminiae* restricted to grids 28 and 29, *Lepismium lumbricoides* to grid 28, *L. warmingianum* to grid 16, *Rhipsalis crispata* to grid 20 and *R. oblonga* to grid 26.

Conservation

Twenty-three species have at least one record within at least one of the nine state and national parks considered (Tab. 1). Among the remaining 10 species not recorded inside a CU, *Rhipsalis crispata* and *Rhipsalis oblonga* are considered threatened with extinction and are known from only one site in SM — a private area in the municipality of Chácara, Minas Gerais. Some areas represent collection gaps for Cactaceae in SM, especially in the southern region of the state of Minas Gerais where several areas have only a few records (Fig. 1).

Discussion

The taxa of Cactaceae recorded in SM possess different global patterns of geographical distribution. Some species possess broad distributions throughout South America and are also widely distributed throughout SM, such as *E. phyllanthus* (common in urban and disturbed areas), *Hylocereus setaceus*, *O. monacantha* and *P. aculeata*. The majority of taxa are endemic to the Atlantic forest domain (Taylor & Zappi 2004; BFG 2015), but can be broadly distributed within SM (*Cereus fernambucensis* subsp. *sericifer*, *Coleocephalocereus fluminensis*, *L. cruciforme*, *L. houlletianum*, *R. elliptica*, *R. juengeri*, *R. pilocarpa*, *R. pulchra*, *R. teres*, *S. microsphaerica* and *S. opuntioides*) or restricted to one of the plateaus (*A. melanurus* subsp. *magnus*, *Hatiora herminiae*, *L. lumbricoides*, *L. warmingianum*, *R. agudoensis*, *R. campos-portoana*, *R. clavata*, *R. crispata*, *R. neves-armondii*, *R. oblonga*, *R. pachyptera*, *S. kautskyi* and *S. lutea* subsp. *lutea*). Two of

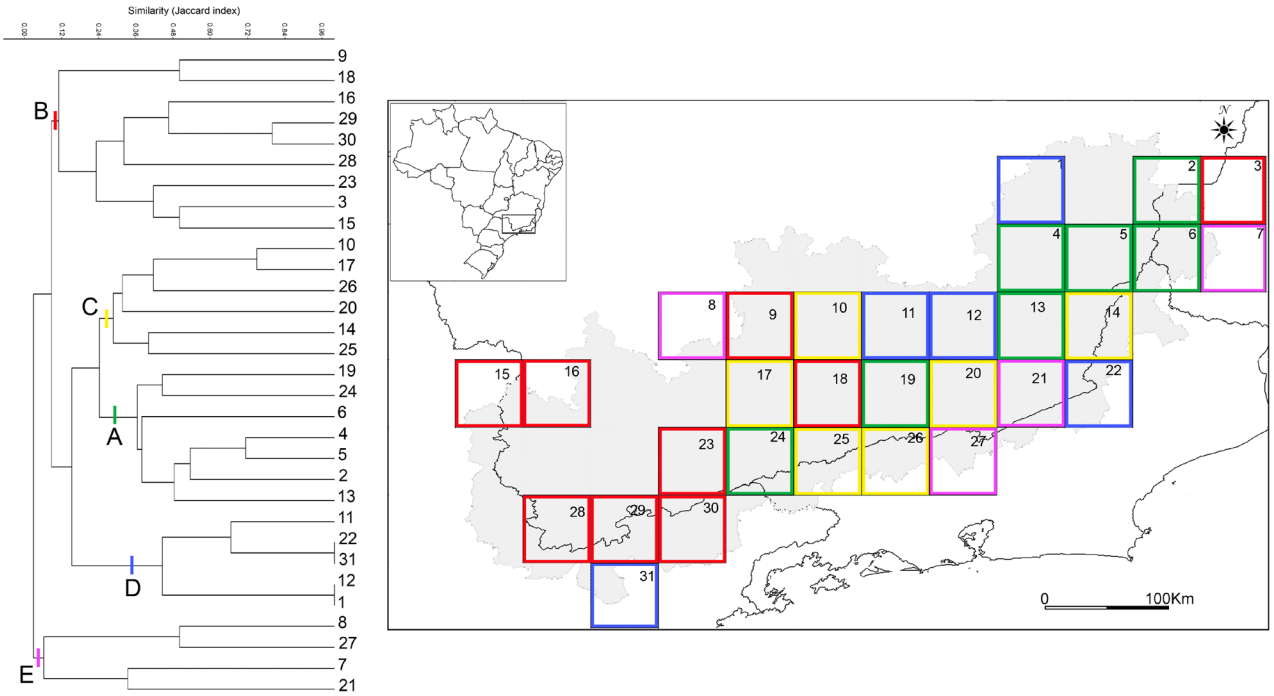

Figure 2. Dendrogram resulting from similarity analysis between grid squares (UPGMA and Jaccard index). Grid squares: 0.5°.

these taxa are restricted to the subtropical region of the South America (i.e., the Southern Cone) — *L. lumbricoides* and *L. warmingianum* (Hunt *et al.* 2006) — both of which are known from one collection in SM (Gonzaga 2016).

The richest areas of SM for Cactaceae were grid squares 5, 6 and 24, which are also areas with several research and educational institutions and thus more thoroughly surveyed. As a result, there is a high correlation between richness and collection effort (~75 %), which is the so-called 'museum effect', as has been previously cited in other similar studies (*e.g.*, Madeira *et al.* 2008; Werneck *et al.* 2011; Sousa-Baena *et al.* 2013). Grid squares 5 and 6 are part of Northern Plateau of SM, which comprises the regions of Serra do Brigadeiro and Maciço do Caparaó, which are the highest areas of SM. These two areas have been previously studied by researchers from the Universidade Estadual de Minas Gerais (Carangola campus), Universidade Federal de Juiz de Fora, Universidade Federal de Viçosa, and Escola Superior de Agricultura Luiz de Queiroz (Caiafa & Silva 2005; Soares *et al.* 2006; Tinti *et al.* 2015). Maciço do Itatiaia (Southern Plateau of SM) lies in grid square 24, and has been studied by the Instituto de Pesquisas Jardim Botânico do Rio de Janeiro for many decades (Brade 1956; Gonzaga *et al.* 2017). Other areas of southern Minas Gerais have also been studied previously (França & Stehmann 2004; Meireles *et al.* 2008; 2014; Ferreira & Forzza 2009; Furtado & Menini Neto 2015; 2016; Santiago *et al.* 2018).

Despite the aforementioned studies, Stehmann & Sobral (2009) emphasize that it is important that more surveys be performed in SM, as recent new records for Cactaceae reinforce — *Lepismium lumbricoides* (Gonzaga *et al.* 2016b), *Rhipsalis agudoensis* (Gonzaga *et al.* 2016a), *R. crispata* (unpublished data), and *R. oblonga* (Gonzaga *et al.* 2015). This is especially true for less studied areas, as evidenced by the lack or scarcity of records for Cactaceae in grid squares of the Southern Plateau of SM.

Data gathered from specific field expeditions (Gonzaga 2016) and from the online database SpeciesLink, enhanced the number of taxa for areas of SM for which surveys have already been published, such as Parque Estadual do Ibitipoca and Parque Estadual da Serra Negra da Mantiqueira (from seven to nine spp. in both areas) (Forzza *et al.* 2013; Salimena *et al.* 2013; Gonzaga *et al.* 2014a; b); Parque Estadual da Serra do Brigadeiro (from four to nine spp.) (Leoni & Tinte 2004); Parque Nacional do Itatiaia (from seven to 14 spp.) (Brade 1956; Gonzaga *et al.* 2017); and Parque Nacional do Caparaó (from three to 12 spp.) (Brade 1942; Leoni 1997). These results emphasize the importance of more specific and thorough studies of botanical groups, even in areas that have already had their flora surveyed.

As mentioned previously for Cactaceae, the Northern Plateau of SM was also found to be relevant for Bromeliaceae in Minas Gerais (Versieux & Wendt 2007), especially the grid square comprising areas of Serra do Brigadeiro and Serra do Caparaó, which further demonstrates the floristic significance of this region. These authors emphasize that the higher elevation and the occurrence of cloud forest supports great epiphytic species richness and abundance. Thus, areas of high elevation and the isolation of SM seem to be responsible for the notable richness and endemism

of different botanical families, however, the scarcity of information about the distribution of plants in relation to elevation in the Atlantic Forest hinders a better evaluation of distributional patterns (Silva *et al*. 2016).

The similarity analysis of grid squares resulted in five clusters. Cluster A comprises the richest regions in SM, with a high number of shared taxa (*e.g. Rhipsalis agudoensis*, *R. campos-portoana*, *R. clavata*, *R. neves-armondii*, *R. pachyptera*, *Schlumbergera kautskyi* and *S. microsphaerica*). It also possesses areas of high elevation and a mosaic of phytophysiognomies composed of both fields (*campos rupestres* and *campos de altitude*) and forests (mainly rainforests). These phytophysiognomies are especially well-represented in Ibitipoca and Brigadeiro state parks and Caparaó and Itatiaia national parks, whose floristic relationships have already been highlighted by Abreu *et al*. (2011), Rezende *et al*. (2013), Salimena *et al*. (2013) and Alves & Menini Neto (2014), and corroborate the results of Versieux & Wendt (2007) for Bromeliaceae. In general, the remaining clusters did not exhibit a clear distribution pattern, with the grid squares being grouped together mainly due to the presence of widely-distributed generalist taxa, which are also adapted to disturbed environments — the so-called 'supertramp' species (*e.g. Epiphyllum phyllanthus*, *Hylocereus setaceus, Pereskia grandifolia* and *Rhipsalis lindbergiana*) (BFG 2015). Thus, clusters B, C, D and E are primarily composed of border areas of SM or by grid squares that mainly share generalist species. Collections in areas with knowledge gaps can shed some light on the relationships between areas and the distribution patterns of taxa.

From a conservation standpoint, recent records of two endangered species — *R. crispata* and *R. oblonga* (Goettsch *et al*. 2015) — in SM is noteworthy, both of which were in private areas outside of conservation units. Calvente *et al*. (2005) and Versieux & Wendt (2007) emphasize the need for studies in private areas in order to fully assess conservation needs and to provide information for maintaining remnants and species outside of conservation units. Collection efforts, therefore, should be concentrated in areas of SM that lack knowledge of Cactaceae, especially in southern Minas Gerais, to document conserved areas outside conservation units and to better understand the flora.

Three of the five taxa endemic to SM — *A. melanurus* subsp. *magnus*, *H. herminiae*, and *S. lutea* subsp. *lutea* — are listed under different categories of red lists (MMA 2014; Goettsch *et al*. 2015). However, it is worth mentioning that Goettsch *et al*. (2015) did not consider infraspecific taxa, and thus evaluated *A. melanurus* subsp. *magnus* and *S. lutea* subsp. *lutea* together with other subspecies (*A. melanurus* subsp. *melanurus*, *A. melanurus* subsp. *odorus* and *S. lutea* subsp. *Bradei*), resulting in wider distributions with more records. MMA (2014) considered the three subspecies of *A. melanurus* as endangered, which is corroborated by the present study. Despite field efforts to collect *S. lutea* subsp. *lutea* (Gonzaga 2016), there has been no success, and thus we propose that it be considered 'data deficient', since the type specimen, collected 85 years ago, is the only known record. *Hatiora herminiae* was previously described as an epiphyte from the plateau of Campos do Jordão (state of São Paulo), but after it was found as rupicolous in Monte Verde (state of Minas Gerais), (both in the Southern Plateau of SM), it was considered 'least concern' by MMA (2014) and 'endangered' by Goettsch *et al*. (2015), with the latter being the most adequate classification.

Rhipsalis agudoensis is also noteworthy. This taxon was categorized as 'data deficient' by Goettsch *et al*. (2015), but later revised as 'endangered' by Gonzaga *et al*. (2016a) based on two records in Maciço do Itatiaia, state of Rio de Janeiro (Southern Plateau of SM). The occurrence of this taxon was later extended to Bananal (state of São Paulo), Sossego do Imbé and Três Rios (state of Rio de Janeiro), and outside the limits of the SM (Taylor & Hofacker 2017) based on field observations, although no vouchers were indicated.

The gaps of distributional knowledge of Cactaceae found herein represent areas where future effort should be focused to further contribute to the knowledge of the flora of SM and Brazil. Such effort would also provide important support to studies of distribution patterns and conservation of both species of Cactaceae and SM. Some endemic species must be carefully reevaluated for future red lists of Brazilian flora, especially considering that the rapid rate of degradation of SM — caused by crops, cattle livestock, burning, real-estate speculation, disordered tourism — can lead to their extinction.

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