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Ant fauna in megadiverse mountains: a checklist for the rocky grasslands

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Abstract

The rocky grasslands, environments locally known as *campo rupestre*, occur mainly along the Espinhaço Mountains and are considered local centers of biodiversity and endemism in Brazil. However, knowledge of ant species richness (Hymenoptera: Formicidae) in this kind of environment is still poor. Aiming at filling this gap, we compiled information from empirical studies and literature records. We found a total of 288 species of 53 genera and eight subfamilies recorded in rocky grasslands. Myrmicinae and Formicinae were the most representative subfamilies, with 53% and 18% of the total species richness, respectively. The genera with the largest number of species were *Pheidole* (41) and *Camponotus* (40). This large number of ant species recorded for the rocky grasslands surpasses those found in other studies conducted in several different places. Ant species richness decreased with altitude; most species occur below 800 m a.s.l. (171), and only a few species occur above1600 m a.s.l. (17). Some genera occur only at a specific altitude (e.g., *Azteca* and *Dolichoderus* at 800/900 m a.s.l.; *Leptogenys* and *Labidus* at 1400 m a.s.l.), which points out to the potential use of ants as biological indicators. Our results suggest that the rocky grasslands favor high ant diversity. The patterns of ant richness associated with the altitudinal gradient reinforce the idea of considering the rocky grasslands as priority areas for biological conservation. Moreover, we observed a lack of records on the occurrence of most ant species considered in the present study (93%), which shows that Brazilian myrmecologists need to invest more in taxonomy, management, and data sharing.

Introduction

The rocky grasslands, locally known as *campo rupestre*, are an ecosystem characterized by a montane, fire-prone vegetation mosaic, with rocky outcrops on quartzite, sandstone, or ironstone soils. They are inserted in a matrix of sandy and stony grasslands, and other vegetation types, such as Cerrado (Brazilian savanna), Atlantic Forest, and Caatinga (Giulietti & Pirani, 1997; Alves et al., 2014; Fernandes et al., 2014). Rocky grasslands occur mainly along the Espinhaço Mountains, a vast mountain range that has its southern limit in the state of Minas Gerais, southeastern Brazil, encompass important smaller ranges, such as Serra do Caraça and Serra do Cipó, and ends in Chapada Diamantina, state of Bahia, northeastern Brazil (Giulietti & Pirani, 1997). Rocky grasslands are also found in the mountains of central (e.g., Serra da Canastra) and southeastern Brazil (e.g., Serra da Mantiqueira), whose geology and flora resemble those of the Espinhaço Mountains (Giulietti & Pirani, 1997; Rapini et al., 2008; Vasconcelos, 2011). This complex geographic mosaic associated with a long evolutionary time turned this environment into a local biodiversity center, with high endemism (approximately one-third of its plant species are endemic) and several endangered species (Giulietti & Pirani 1997; Rapini et al., 2008).

Tropical grasslands have been under severe threat and are consistently overlooked by conservation policies (Parr et al., 2014). These ecosystems are subjected to several human pressures, such as mining, livestock raising, agriculture, road construction, tourism, and frequent fires (Barbosa et al., 2010; Fernandes et al., 2014). In addition to their large number of endangered species and human threats, montane ecosystems are also subjected to global changes (IPCC, 2013). Climatic models predict a catastrophic future in which, by the end of this century, the rocky grasslands may lose up to 95% of their current area (Fernandes et al., 2014). In this scenario, the development of effective conservation strategies is crucial. Fauna and flora inventories are of fundamental importance, as describing the biodiversity of rocky grasslands is the first step towards their conservation (Pearson, 1994).

Despite the information on the flora and fauna of rocky grasslands (Giulietti et al., 1987; Lessa et al., 2008; Rapini et al., 2008; Rodrigues et al., 2011), sampling in those environments has been heterogeneous and large areas remain unexplored (Madeira et al., 2008). In addition, most of the literature on the biodiversity of rocky grasslands focus on plants and vertebrates (Silveira et al., unpublished data). Therefore other groups, such as invertebrates, remain unknown. Some of the challenges to invertebrate conservation are a scarce and underfunded basic research, and the overlooking of invertebrates in most conservation policies (Cardoso et al., 2011).

Conversely, invertebrates dominate most terrestrial environments and deliver several ecosystem services (Cardoso et al., 2011). Among invertebrates, ants (Hymenoptera: Formicidae) represent one of the most important and abundant terrestrial groups (Hölldobler & Wilson, 1990). Well known for their functional roles, ants have been used as bioindicators due to their sensitivity to environmental and climate changes (Lach et al., 2010). Previous studies reported changes in ant diversity along altitudinal gradients (Fisher, 1996; Bharti & Sharma, 2013; Bishop et al., 2014). Altitudinal gradients are excellent to model species distribution, due to differences in abiotic conditions. However, as most literature records came from temperate mountains, the lack of information on tropical mountains makes it difficult to elaborate conservation plans.

What we know about ants from rocky grasslands comes from case studies on ant species associated with a particular plant or area (e.g., Guerra et al., 2011; Viana-Silva & Jacobi, 2012; Fagundes et al., 2013). However, a complete record that comprises the whole diversity and distribution of ants is still missing. In order to fill this gap of knowledge and support invertebrate conservation in the rocky grasslands, we need a more thorough biodiversity survey. In the present study, we compiled a checklist of ant species and their occurrence from original data and published information.

Material and Methods

Data sampling and database

We searched for studies carried out in areas of rocky grasslands that informed the geographic coordinates of their sampling sites and identified ants to the species. We compiled records from a total of eight datasets, most of which original and collected in Serra do Cipó (Lana, 2015). Seven other datasets were found through an online survey in the Web of Knowledge, other academic search engines such as Google Scholar, and Brazilian academic libraries. Among those sources is one unpublished dataset from Serra do Cipó (hereafter "Cipó") (Soares, 2003) and six published datasets from Cipó (n = 1), Serra do Rola Moça State Park (hereafter "Rola Moça") (n = 1), Itacolomi State Park (hereafter "Itacolomi") (n = 3), and Ibitipoca State Park (hereafter "Ibitipoca") (n = 1). All studied sites are located in the Espinhaço Mountains, except for Ibitipoca.

As we aimed at providing a broad inventory of the ant fauna, we used studies carried out with different sampling efforts and methods. Table 1 describes the samples collected from the literature, including information on sampling method, environment, and location. Details on species identification are given for each study.

Table 1. Sites where ants were sampled in the Brazilian rocky grasslands.

Sampling sites	Reference	Sampling method	Environment	Altitudinal Range (m)	Geographic coordinates provided in the study
Serra do Cipó region	Lana, 2015[1]	pitfalls, Winkler, beating and sweep net	cerrado ecotones, rocky grasslands	800 – 1400	19°21'36.2" S, 43°36'25.2" W 19°16'17.8" S, 43°36'18.1" W 19°15'50.6" S, 43°35'10.3" W 19°13'56.5" S, 43°34'34.8" W 19°17'43.0" S, 43°33'17.4" W 19°17'49.6" S, 43°35'28.2" W 19°16'59.3" S, 43°32'08.9" W
Itacolomi State Park region	Almeida et al., 2014*[2]	active capture	Rocky grasslands, *canga* outcrops	1200 – 1500	20°22'30" S, 43°32'30" W 20°27'55.4" S, 43°35'59" W 20°21'47" S, 43°30'10" W 20º22'27" S, 43º32'22" W
Itacolomi State Park	Fagundes et al., 2013*[3]	observations and active capture	Rocky grasslands	1400	20°26'26" S, 43°30'52" W
Serra do Rola Moça State Park	Viana-Silva & Jacobi, 2012*[4]	ground baits	*canga* outcrops	1400 – 1500	20°03'35.19" S, 44°00'41.9" W 20°03'33.57"S, 44°01'52.01" W
Itacolomi State Park	Rosumek, 2009*[5]	baits, observations and active capture	*canga* outcrops	1320 - 1400	20º26'18" S, 43º30'35" W
Serra do Cipó region	Soares, 2003*[6]	baited pitfalls	Rocky grasslands, Cerrado ecotone	800 - 1600	19º10'00" to 19º40'00" S, 43º30'00" to 43º 55'00" W
Serra do Cipó region	Araújo & Fernandes, 2003*[7]	baits and active capture	Rocky grasslands, Cerrado ecotone	800 – 1400	19º10'00" to 19º40'00" S, 43º30'00" to 43º55'00" W
Ibitipoca State Park	Sales et al., 2014*[8]	active capture	Rocky grasslands	1400	21º42'00" S, 43º53'00" W

*Studies found through an online survey; Superscript numbers provide reference for sources in the full list of species (Table 2).

In the original dataset (Lana, 2015) ants were sampled in seven sites during the Long Term Ecological Research of the Rocky Grasslands of Serra do Cipó (PELD-CRSC, in the Portuguese acronym). Those seven sites were chosen along an altitudinal gradient in Cipó, from 800 to 1,400 m a.s.l. In each site, three transects of 200 m were set up and five sampling points were established at 50 m from each other. In 2011 and 2012, ants were sampled quarterly, mainly with pitfalls traps, but also with beating, sweep nets, and Winkler traps. Ants were identified using a taxonomic key (Fernández, 2003), by comparison with specimens deposited in the Laboratório de Mirmecologia do Centro de Pesquisas do Cacau (CEPEC/CEPLAC), and by consulting specialists (Jacques H. C. Delabie). Nomenclature followed Bolton et al. (2005), with posterior improvements made available on the Online Catalog of the Ants of the World (AntCat).

We built a complete species checklist (Appendix) with information on several ant species organized by study, sampling locality, and altitude. As it was not possible to match the morphospecies hosted in different institutions and collections, we included in the analysis only one record for each morphospecies, regardless of its potential presence in more than one study, area, or altitude. Each morphospecies (e.g., *Pheidole* sp.1) probably represents more than one species, as the same nomenclature was established by different authors. However, excluding those records or trying to tell them apart could interfere with the estimation of the real diversity. Although we are aware of this taxonomic limitation, in face of the difficulty of assigning names to several Neotropical ant species (e.g., *Camponotus* and *Pheidole*) and the lack of current taxonomic revisions for many species-rich genera (e.g., *Brachymyrmex*, *Cyphomyrmex*, and *Solenopsis*) (Lach et al., 2010), this is the most parsimonious option for a study that aimed at estimating ant species diversity on a broad scale.

Study sites

The Espinhaço Mountains are 50-100 km wide and 1,200 km long, and encompass several mountains (up to approximately 2,000 m a.s.l.) (Giulietti & Pirani, 1997). Rocky grasslands occur mostly from 900 to 2,033 m a.s.l. In the basal part of the range, at altitudes between 800-1,000 m a.s.l., we found ecotones between savanna and rocky grassland. Trees and shrubs are the most common life forms at lower altitudes, but their predominance decreases with altitude, as the soil profile also changes, and they gradually give way to outcrops and grasslands (Giulietti & Pirani, 1997; Alves et al., 2014). Similarly, together with the altitudinal gradient there is also a climate gradient, in which the mountaintop is colder and moister than the base (Giulietti & Pirani, 1988).

Serra do Cipó is located in the southeastern part of the Espinhaço Mountains, state of Minas Gerais, southeastern Brazil (Fig 1). This region has a diversified mosaic of vegetations, which varies with soil type and altitude (from 800 to 1.600 m a.s.l.). This environment is covered by a low vegetation composed of shrubs and small trees and abundant grasses and sedges. There are also several watercourses, along which gallery evergreen forests grow (Giulietti et al., 1987).

Itacolomi State Park and Serra do Rola Moça State Park are characterized by rocky grasslands that grow on ironstone, locally known as *canga*. Both areas are located in the Iron Quadrangle of Minas Gerais, a 7,200 km^2 region in the southern part of the Espinhaço Mountains (Fig 1). The Iron Quadrangle is geologically dominated by ironstone and represents one of the world's main mineral provinces (Jacobi et al., 2011). Itacolomi comprises an altitudinal range varying from 700 to 1,772 m a.s.l. and a mosaic of rocky grasslands, *canga*, semi-deciduous montane forest, and associated vegetation types (Gastauer et al., 2012). Rola

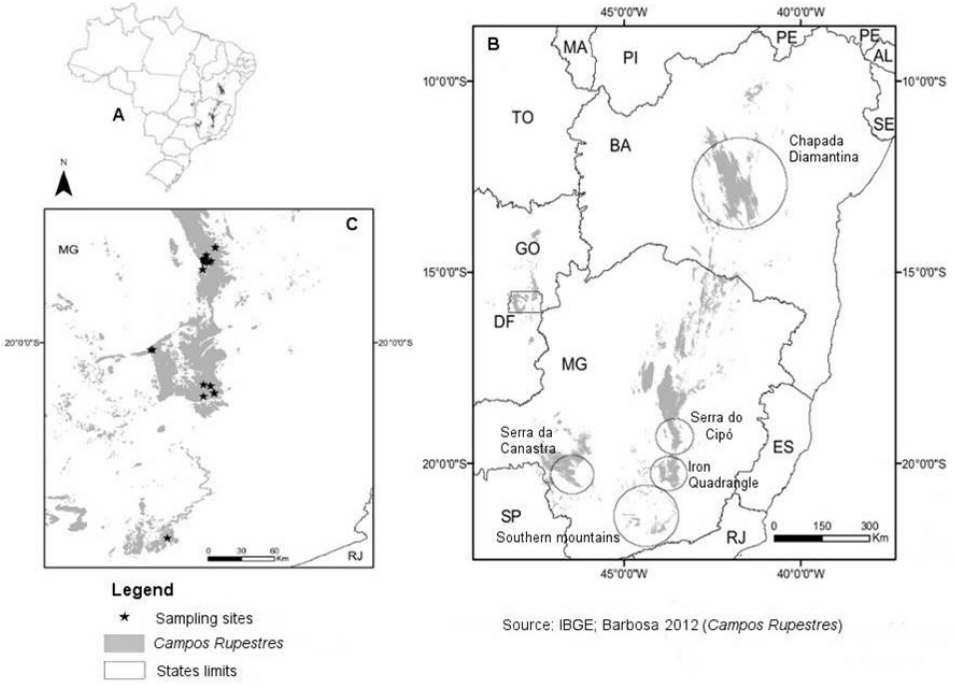

Fig 1. The location of rocky grasslands in Brazil (A). Rocky grasslands along the Espinhaço Mountains and other Brazilian mountain ranges (circumscribed) (B). Sampling sites in the southern part of the Espinhaço Mountains and the southern mountains of Minas Gerais (C).

Moça is located in an ecotone between the Cerrado and Atlantic Forest biomes, which comprises several vegetation types, such as Cerrado, semi-deciduous forest, riparian forest, and prominent rocky grasslands developing on *canga* on the mountaintops (1,200 –1,500 m a.s.l.) (Jacobi et al., 2008).

Ibitipoca State Park is a protected area located in Serra da Mantiqueira, southern Minas Gerais (Fig 1). This site is characterized by a vegetation type composed of grasses, herbs, and shrubs on outcrops of quartzite rocks associated with shallow soils and high sun incidence (Dias et al., 2002).

Results and Discussion

We recorded 288 ant species of 53 genera and eight subfamilies (Appendix). Myrmicinae was the most speciose subfamily, with 53% of the recorded species, followed by Formicinae (18%), Dolichoderinae (11%), Ponerinae (6%), and Ectatomminae (5%). The richest genus was *Pheidole* (41 species), followed by *Camponotus* (40), *Crematogaster* (22), *Dorymyrmex* (14), and *Solenopsis* (13). The largest number of ant species was found in Cipó (n = 265), followed by Itacolomi (48), Ibitipoca (20), and Rola Moça (14). Similarly, Cipó was the locality with the largest proportion of exclusive species (83%), which indicates that this site was the best sampled and the faunas of other sites are nested within it. The proportion of exclusive ant species in each site and ant species shared between at least two sites is shown in Fig 2.

Among the identified species, only *Camponotus crassus* (Mayr 1862) occurred in all sites. Only morphospecies of *Pheidole* exhibited similar distribution. Thus, *Camponotus* and *Pheidole* emerged as the most widespread genera currently recorded for rocky grasslands. The dominance of those genera is consistent with the patterns suggested for other Neotropical ants (Fernández & Sendoya, 2004) and similar ecosystems, such as open Cerrado (Ribas et al., 2003; Campos et al., 2011; Pacheco & Vasconcelos, 2012). Likewise, Myrmicinae and Formicinae were also the most prominent subfamilies in ant inventories conducted in different environments, such as Cerrado (Ribas et al., 2003; Campos et al., 2011), Amazon (Miranda et al., 2012), and Caatinga (Ulysséa & Brandão, 2013).

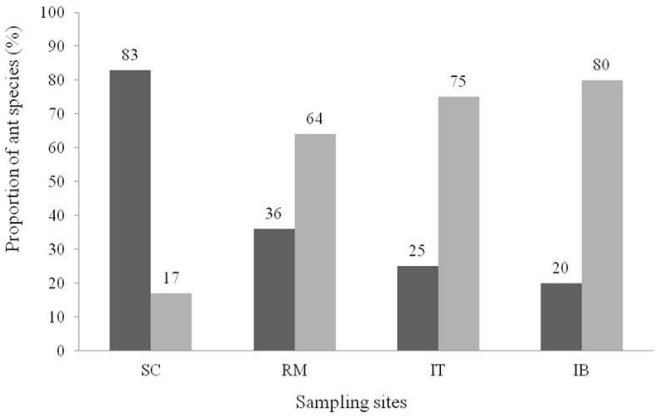

Fig 2. Proportion of ant species exclusive to each site and shared between at least two sites. Sampling site abbreviations: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Dark bars represent exclusive proportion and light bars correspond to the shared proportion of species.

The large number of ant species recorded for rocky grasslands (288) deserves attention, as other studies carried out in wider geographical ranges found a smaller or similar number. For example, checklists made for the Caatinga (Ulysséa & Brandão, 2013) and Amazon (Miranda et al., 2012) found 173 and 276 species, respectively. Although we did not find a comprehensive inventory for the Cerrado that could be used for comparison, studies carried out over large areas revealed about 150 species (Ribas et al., 2003; Campos et al., 2011; Pacheco & Vasconcelos, 2012). Actually, it is hard to compare number of species among studies or environments, as different studies used different sampling efforts and methods.

Nevertheless, by analyzing the map in Fig 1, we infer that the rocky grasslands have several sampling gaps (e.g., Chapada Diamantina, Serra da Canastra, northern and southern Minas Gerais). Considering this gap of knowledge, high endemism, and complex environmental mosaic found on those mountains, we expect ant diversity in the rocky grasslands to be even higher than observed in the present study (288). Moreover, the large number of unidentified species together with the inclusion of only one record per morphospecies point out to an underestimation of the number of ant species in the rocky grasslands.

We observed a decrease in ant richness along the altitudinal range (Appendix). The lowest altitudes, 800 and 900 m a.s.l., contributed with 171 and 127 ant species, respectively, whereas the highest altitude (1,600 m a.s.l.) had a smaller number of species (17). Only *Solenopis* occurred at all altitudes. Those findings corroborate the general diversity pattern of ants that live on mountains, in which the number of species decreases with altitude (Fisher, 1996; Brühl et al., 1999; Longino & Colwell, 2011; Bharti & Sharma, 2013). Nonetheless, very few studies have documented the altitudinal trends of ant biodiversity in Brazilian montane ecosystems (but see Araújo & Fernandes, 2003).

At 800 m a.s.l., there were 18 exclusive species, whereas at 1,400, 1,500, and 1,600 m a.s.l. there were 21, five, and two, respectively. We found some genera of dominant arboreal ants (*Azteca* and *Dolichoderus*) restricted to the mountain base (800/900 m a.s.l.), which indicates that altitude may restrict ant occurrences. Similarly, at 1,400 m a.s.l., we recorded some unique genera, such as specialized predators (*Leptogenys*) and legionary ants (*Labidus*) (Brandão et al., 2012). Those findings corroborate the potential of ants as bioindicators, especially of climate change. Similar patterns of restriction of functional groups to particular altitudes have already been observed for tropical (Brühl et al., 1999) and temperate regions (Bharti & Sharma, 2013). However, those findings may have been biased by the sampling effort used in each site. Ant responses to altitude, associated with the high richness found in a small geographic area, point to the importance of conserving the rocky grasslands. This conclusion is consistent with the strategies recommended for ant conservation, which state that efforts should be targeted to high biodiversity, high endemism, and extremely threatened areas (Alonso, 2010).

We also bring to light the need for investing in ant taxonomy, database management, and data sharing, which are essential tools for biodiversity conservation, though they are neglected in most Brazilian research institutions. Those gaps of knowledge became clear when we searched for information on ant species occurrence and distribution (only those with complete taxonomic identification) in online databases (Antwiki, AntWeb, CRIA speciesLink) and specialized catalogues (Kempf, 1972; Brandão, 1991). We noticed that most ant records (94%) neither were followed by a formal record for the rocky grasslands nor were hosted in databases (Appendix, symbol*). Approximately 5% of the records contained no information on geographic distribution and only 1% accounted this kind of information for the rocky grasslands. Therefore, myrmecology in Brazil needs to invest strongly in taxonomy and species inventories. Despite some recent advances, rocky grasslands still have many sampling gaps for ants, and, therefore, they need more efforts in conservation.

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Appendix. Occurrence and distribution of ant species along the altitudinal gradient, localities, and studies carried out in the Brazilian rocky grasslands. Sampling sites: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Numbers in columns indicate the literature sources described in Table 1.

TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Formicidae																															
Amblyoponinae																															
Prionopelta sp														x				x													
Dolichoderinae																															
Azteca sp		x	x			x																									
Dolichoderus diversus (Emery, 1894)*	x																														
Dolichoderus lutosus (Smith, 1858)*	x																														
Dorymyrmex brunneus (Forel, 1908)*	x			x			x			x														x							
Dorymyrmex goeldii (Forel, 1904)*	x						x			x				x				x						x							
Dorymyrmex jheringi (Forel, 1912)*								x																							
Dorymyrmex pyramicus (Roger, 1863)*	x			x			x			x				x				x													
Dorymyrmex sp										x																					
Dorymyrmex sp1								x			x				x				x												
Dorymyrmex sp2		x			x			x			x				x																
Dorymyrmex sp3															x				x												
Dorymyrmex sp4		x			x																										
Dorymyrmex sp5		x																													
Dorymyrmex sp6					x																										
Dorymyrmex sp7											x																				
Dorymyrmex sp8															x																
Dorymyrmex sp9																													x		
Forelius brasiliensis (Forel, 1908)*	x																														
Forelius maranhaoensis (Cuezzo, 2000)*	x						x			x								x													
Forelius sp		x			x										x																
Linepithema cerradense (Wild, 2007)*																					x										
Linepithema humile (Mayr, 1868)*	x									x				x				x						x	x						
Linepithema micans (Forel, 1908)†																							x								
Linepithema prox. *humile* sp															x																

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TÁXON	ALTITUDES (m)																																				
	800			900			1000			1100			1200				1300							1400							1500				1600		
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT			SC			RM	IT	SC			SC		
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6						
Dolichoderinae (Continuation)																																					
Linepithema sp1	x	x		x	x	x	x	x	x	x	x			x	x			x	x				x	x													
Linepithema sp2	x			x		x	x			x	x			x				x		x				x												
Linepithema sp3	x		x	x			x	x	x	x	x	x		x		x		x	x	x						x				x						
Linepithema sp4	x		x	x										x	x			x		x																
Linepithema sp5	x	x		x											x			x																			
Linepithema sp6															x				x					x	x					x			x			
Tapinoma sp1	x	x		x	x			x		x	x			x	x			x									x									
Tapinoma sp2		x		x	x			x			x				x																					
Dorylinae																																					
Labidus coecus (Latreille, 1802)*										x																											
Labidus praedator (Smith, 1858)*																							x														
Leptogenys prox. *linda* sp																								x													
Neivamyrmex diana (Forel, 1912)*																									x												
Neivamyrmex pseudops (Forel, 1909)*										x																											
Neivamyrmex sp1				x	x													x																		
Neivamyrmex sp2							x							x					x																		
Ectatomminae																																					
Ectatomma brunneum (Smith, 1858)*	x	x		x																																	
Ectatomma edentatum (Roger, 1863)*	x	x		x	x		x	x		x	x			x	x			x	x		x															
Ectatomma muticum (Mayr, 1870)*									x			x																									
Ectatomma opaciventre (Roger, 1861)*	x	x		x	x		x																														
Ectatomma permagnum (Forel, 1908)*	x				x													x																		
Ectatomma planidens (Borgmeier, 1939)*	x				x		x	x																													
Ectatomma sp1			x			x			x			x									x																
Ectatomma sp2			x			x						x				x																					
Ectatomma suzanae (Almeida, 1986)‡	x																	x																		
Ectatomma tuberculatum (Olivier, 1792)*	x	x		x	x																																

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Appendix. Occurrence and distribution of ant species along the altitudinal gradient, localities, and studies carried out in the Brazilian rocky grasslands. Sampling sites: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Numbers in columns indicate the literature sources described in Table 1 (Continuation).

TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Ectatomminae (Continuation)																															
Gnamptogenys sp1										x																					
Gnamptogenys striatula (Mayr, 1884)*										x																					
Gnamptogenys sulcata (Smith, 1858)*				x			x			x								x													
Formicinae																															
Brachymyrmex patagonicus (Mayr, 1868)*				x			x							x				x						x			x				
Brachymyrmex sp			x			x						x				x				x											
Brachymyrmex sp1	x	x		x	x		x	x		x	x			x	x			x	x					x					x		
Brachymyrmex sp2		x			x			x						x					x										x		x
Brachymyrmex sp3		x			x						x																				
Camponotus (Hypercolobopsis) sp1	x			x						x				x				x													
Camponotus (Hypercolobopsis) sp2	x																														
Camponotus (Hypercolobopsis) sp3										x								x													
Camponotus (Myrmaphaenus) sp1	x	x		x	x			x		x	x				x																
Camponotus (Myrmaphaenus) sp2	x			x				x		x	x			x	x									x					x		x
Camponotus (Myrmaphaenus) sp3	x	x		x	x		x	x		x	x			x										x							
Camponotus (Myrmaphaenus) sp4		x			x			x			x				x																
Camponotus (Myrmaphaenus) sp5								x			x				x																
Camponotus (Myrmaphaenus) sp6		x			x			x			x																				
Camponotus (Myrmaphaenus) sp7		x									x																				
Camponotus (Myrmaphaenus) sp8		x																													
Camponotus (Myrmaphaenus) sp9		x																													
Camponotus (Myrmaphaenus) sp10					x			x			x																				
Camponotus (Myrmaphaenus) sp11					x										x				x						x				x		
Camponotus (Tanaemyrmex) sp1		x		x						x																					
Camponotus (Tanaemyrmex) sp2	x	x			x		x	x			x			x	x																
Camponotus (Tanaemyrmex) sp3	x	x			x			x		x	x			x	x																x
Camponotus (Tanaemyrmex) sp4	x	x			x			x			x				x			x	x						x				x		

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Appendix. Occurrence and distribution of ant species along the altitudinal gradient, localities, and studies carried out in the Brazilian rocky grasslands. Sampling sites: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Numbers in columns indicate the literature sources described in Table 1 (Continuation).

TÁXON	ALTITUDES (m)																																				
	800			900			1000			1100			1200				1300				1400								1500				1600					
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC			SC				
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6					
Formicinae (Continuation)																																				
Camponotus (Tanaemyrmex) sp5																			x																	
Camponotus atriceps (Smith, 1858)*		x																																		
Camponotus blandus (Smith, 1858)*	x			x			x							x				x						x												
Camponotus cingulatus (Mayr, 1862)*	x																																			
Camponotus crassus (Mayr, 1862)*		x	x		x	x		x	x		x	x			x	x			x	x	x	x	x			x	x			x						
Camponotus fastigatus (Roger, 1863)*	x									x													x													
Camponotus genatus (Santschi, 1922)*																					x						x									
Camponotus leydigi (Forel, 1886)*	x			x	x																															
Camponotus melanoticus (Emery, 1894)*	x			x			x			x				x				x						x												
Camponotus novogranadensis (Mayr, 1870)*	x			x			x			x				x				x				x		x												
Camponotus punctulatus (Mayr, 1867)*		x						x			x																			x						
Camponotus renggeri (Emery, 1894)*	x	x		x	x		x	x		x				x	x			x			x			x												
Camponotus rufipes (Fabricius, 1775)*	x	x	x	x			x	x		x	x			x	x	x		x				x	x	x			x			x						
Camponotus senex (Smith, 1858)*	x			x			x			x				x				x				x		x												
Camponotus sericeiventris (Guérin-Méneville, 1838)*			x			x																														
Camponotus sp1										x												x														
Camponotus sp2														x								x	x													
Camponotus sp3	x		x			x			x			x				x				x			x			x										
Camponotus sp4	x															x				x			x			x										
Camponotus sp5	x		x			x										x				x			x													
Camponotus sp6																				x																
Camponotus vittatus (Forel, 1904)‡	x									x				x				x																		
Myrmelachista nodigera (Mayr, 1887)*													x				x											x								
Myrmelachista sp													x															x								
Myrmelachista sp1		x								x								x			x			x												
Myrmelachista sp2										x																				x		x				
Myrmelachista sp3										x								x						x												
Nylanderia sp	x																																			
Paratrechina sp					x			x			x																									

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TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Myrmicinae																															
Acromyrmex balzani (Emery, 1890)*	x	x			x			x							x			x											x		
Acromyrmex crassispinus (Forel, 1909)*	x			x																											
Acromyrmex fracticornis (Forel, 1909)*				x																											
Acromyrmex sp1	x	x			x													x							x				x		
Acromyrmex sp2	x	x		x				x			x				x									x							
Acromyrmex sp3	x			x	x																				x				x		
Acromyrmex sp4																								x							
Acromyrmex subterraneus subterraneus (Forel, 1893)*	x			x			x							x				x													
Apterostigma (gr.Pillosum) sp1	x									x								x													
Apterostigma sp1		x			x																										
Apterostigma sp2					x																										
Atta sexdens (Linnaeus, 1758)*											x				x				x												
Atta sexdens rubropilosa (Forel, 1908)*	x			x																											
Octostruma iheringi (Emery, 1888)‡	x																														
Carebara sp	x	x	x	x		x																									
Cephalotes atratus (Linnaeus, 1758)*																											x				
Cephalotes maculatus (Smith, 1876)*	x	x																x													
Cephalotes minutus (Fabricius, 1804)*	x													x							x										
Cephalotes pavonii (Latreille, 1809)*	x																														
Cephalotes prox. *pallidoides* sp	x	x	x	x		x	x	x	x	x	x	x		x		x		x		x	x	x				x					
Cephalotes pusillus (Klug, 1824)*	x	x	x																				x								
Cephalotes sp1		x			x			x															x								
Cephalotes sp2					x																										
Cephalotes sp3	x						x							x																	
Crematogaster acuta (Fabricius, 1804)*	x			x			x			x				x				x													
Crematogaster arcuata (Forel, 1899)*																								x							
Crematogaster brasiliensis (Mayr, 1878)*													x				x											x			

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TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Myrmicinae (Continuation)																															
Crematogaster complex. *crinosa* sp1													x																		
Crematogaster complex. *crinosa* sp2																											x				
Crematogaster erecta (Mayr, 1866)*													x				x														
Crematogaster goeldii (Forel, 1903)*																											x				
Crematogaster moelleri (Forel, 1912)*	x			x			x																								
Crematogaster prox. *erecta* sp1	x						x			x																					
Crematogaster prox. *obscurata* sp1																					x										
Crematogaster sericea (Forel, 1912)*																						x									
Crematogaster sp	x		x			x			x		x	x											x								
Crematogaster sp1	x						x	x			x				x								x								
Crematogaster sp2					x										x									x							
Crematogaster sp3															x																
Crematogaster sp4															x																
Crematogaster sp5		x			x						x																				
Crematogaster sp6		x																													
Crematogaster sp7								x											x												
Crematogaster sp8																			x												
Crematogaster sp9																			x										x		
Crematogaster sp10	x						x																								
Cyphomyrmex (gr.Rimosus) sp1	x						x			x				x				x						x							
Cyphomyrmex (gr.Rimosus) sp2	x													x																	
Cyphomyrmex (gr.Strigatus) sp1														x				x													
Cyphomyrmex (gr.Strigatus) sp2																		x													
Cyphomyrmex (gr.Strigatus) sp3	x			x						x				x				x													
Cyphomyrmex lectus (Forel, 1911)*															x																
Cyphomyrmex peltatus (Kempf, 1966)*															x																
Cyphomyrmex sp1																									x						

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TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Myrmicinae (Continuation)																															
Cyphomyrmex sp2		x						x											x						x				x		
Cyphomyrmex transversus (Emery, 1894)*										x								x						x							
Hylomyrma balzani (Emery, 1894)*																									x				x		x
Hylomyrma sp				x														x													
Kalathomyrmex emeryi (Forel, 1907)*												x				x															
Leptothorax sp1			x						x			x				x															
Leptothorax sp2																x				x						x					
Leptothorax sp3														x																	
Megalomyrmex sp											x								x												x
Monomorium pharaonis (Linnaeus, 1758)*														x																	
Mycetarotes sp								x							x																
Mycetophylax emeryi (Forel, 1907)*	x			x			x			x				x	x																
Mycocepurus goeldii (Forel, 1893)*		x			x			x																							
Mycocepurus smithi (Forel, 1893)*	x	x																													
Myrmicocrypta sp																	x														
Nesomyrmex prox. *echinatinodis* (Forel, 1886)													x																		
Nesomyrmex spininodis (Mayr, 1887)*		x						x																							
*Ochetomyrmex semipolitus (*Mayr, 1878)*	x						x							x				x													
Ochetomyrmex sp																		x													
Oxyepoecus prox. *bruschi* sp1																		x						x							
Oxyepoecus prox. *bruschi* sp2										x								x						x							
Oxyepoecus sp1										x								x	x						x				x		x
Oxyepoecus sp2																													x		
Oxyepoecus sp3																													x		
Pheidole gertrudae (Forel, 1886)*	x			x			x			x																					
Pheidole obscurithorax (Naves, 1985)*																					x						x				
Pheidole oxyops (Forel, 1908)*	x		x	x			x			x				x				x						x							

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Appendix. Occurrence and distribution of ant species along the altitudinal gradient, localities, and studies carried out in the Brazilian rocky grasslands. Sampling sites: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Numbers in columns indicate the literature sources described in Table 1 (Continuation).

TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Myrmicinae (Continuation)																															
Pheidole radoszkowskii (Mayr, 1884)*																					x										
Pheidole sp																						x									
Pheidole sp1	x	x	x		x			x	x		x				x	x		x	x		x		x	x			x		x		
Pheidole sp2	x	x	x	x			x	x	x		x					x		x		x	x		x	x					x		
Pheidole sp3	x	x	x		x	x		x	x		x	x			x	x				x	x		x								
Pheidole sp4		x				x		x		x	x					x		x	x		x		x	x							
Pheidole sp5	x	x	x	x	x	x		x			x				x				x				x		x				x		
Pheidole sp6	x	x	x	x	x	x		x			x												x								
Pheidole sp7	x	x		x										x									x								
Pheidole sp8	x	x		x														x					x								
Pheidole sp9	x			x			x			x				x				x	x				x	x	x				x		
Pheidole sp10	x	x	x	x		x		x	x	x		x				x				x			x			x					
Pheidole sp11	x	x		x			x			x				x				x					x								
Pheidole sp12	x	x		x				x		x				x				x	x												
Pheidole sp13	x	x		x										x				x						x							
Pheidole sp14	x														x			x	x										x		
Pheidole sp15	x	x						x		x				x				x													
Pheidole sp16	x	x		x										x										x							
Pheidole sp17	x	x			x													x													
Pheidole sp18	x	x						x										x													
Pheidole sp19	x	x					x	x			x			x	x				x												
Pheidole sp20	x			x	x		x	x																							
Pheidole sp21	x				x					x																					
Pheidole sp22	x				x																										
Pheidole sp23	x							x																							
Pheidole sp24	x							x																							
Pheidole sp25	x							x						x	x																

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Appendix. Occurrence and distribution of ant species along the altitudinal gradient, localities, and studies carried out in the Brazilian rocky grasslands. Sampling sites: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Numbers in columns indicate the literature sources described in Table 1 (Continuation).

TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Myrmicinae (Continuation)																															
Pheidole sp26								x			x													x					x		
Pheidole sp27										x	x																				
Pheidole sp28	x														x				x						x				x		x
Pheidole sp29	x																		x												
Pheidole sp30	x																		x						x				x		
Pheidole sp31							x												x												
Pheidole sp32	x																								x						
Pheidole sp33																									x				x		
Pheidole sp34																													x		
Pheidole sp35		x			x																										
Pheidole sp36								x											x												
Pogonomyrmex abdominalis (Santschi, 1929)*		x			x			x			x																		x		
Pogonomyrmex naegelii (Emery, 1878)*	x			x			x			x				x				x									x				
Pogonomyrmex sp1												x																			
Procryptocerus sp																	x														
Sericomyrmex sp	x	x						x		x								x													
Solenopsis (Diplorhoptrum) sp																				x						x				x	
Solenopsis bondari (Santschi, 1925)‡			x			x			x			x								x											
Solenopsis globularia (Smith, 1858)*	x			x			x	x		x				x				x													
Solenopsis saevissima (Smith, 1855)*			x			x		x	x		x	x			x				x	x				x		x			x		
Solenopsis sp1	x			x			x			x	x			x				x	x		x		x	x	x				x		x
Solenopsis sp2	x	x		x	x		x	x		x	x			x				x					x								
Solenopsis sp3	x	x		x	x		x	x		x				x				x					x						x		
Solenopsis sp4					x						x							x					x	x							
Solenopsis sp5	x			x			x	x		x				x				x	x												
Solenopsis sp6				x			x			x								x	x					x							
Solenopsis sp7																									x						

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Appendix. Occurrence and distribution of ant species along the altitudinal gradient, localities, and studies carried out in the Brazilian rocky grasslands. Sampling sites: Serra do Cipó (SC), Itacolomi State Park (IT), Ibitipoca State Park (IB), and Serra do Rola Moça State Park (RM). Numbers in columns indicate the literature sources described in Table 1 (Continuation).

TÁXON	ALTITUDES (m)																															
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Myrmicinae (Continuation)																															
Solenopsis sp8																													x		
Solenopsis sp9																													x		x
Strumigenys crassicornis (Mayr, 1887)*	x																														
Strumigenys eggersi (Emery, 1890)*														x																	
Strumigenys elongata (Emery, 1890)*														x																	
Strumigenys louisianae (Roger, 1863)*																								x							
Strumigenys schulzi (Emery, 1894)*	x																	x													
Strumigenys sp																															x
Trachymyrmex sp1	x			x				x		x	x			x	x			x	x					x	x						
Trachymyrmex sp2	x	x			x			x										x	x						x				x		x
Trachymyrmex sp3	x	x																x													
Trachymyrmex sp4	x			x				x							x																
Trachymyrmex sp5																		x													
Trachymyrmex sp6	x																														
Trachymyrmex sp7										x								x						x							
Trachymyrmex sp8	x			x										x				x													
Trachymyrmex sp9	x			x						x																					
Tranopelta gilva (Mayr, 1866)*	x			x						x																					
Wasmannia auropunctata (Roger, 1863)*	x	x		x	x			x		x				x				x					x	x			x				
Wasmannia sp																															x
Ponerinae																															
Anochetus diegensis (Forel, 1912)*								x																							
Anochetus inermis (André, 1889)*	x			x						x																					
Hypoponera sp								x																	x						
Hypoponera sp1	x						x			x				x				x						x							
Hypoponera sp2	x			x			x			x				x																	
Neoponera bucki (Borgmeier, 1927)‡																													x		x

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TÁXON	ALTITUDES (m)																														
	800			900			1000			1100			1200				1300				1400							1500			1600
	SC			SC			SC			SC			IT	SC			IT	SC			IB	IT		SC			RM	IT	SC		SC
	1	6	7	1	6	7	1	7	7	1	6	7	2	1	7	8	2	1	6	7	8	3	5	1	6	7	4	2	6	7	6
Ponerinae (Continuation)																															
Neoponera villosa (Fabricius, 1804)*	x						x																	x							
Odontomachus bauri (Emery, 1892)*					x														x												
Odontomachus brunneus (Patton, 1894)*	x				x																										
Odontomachus chelifer (Latreille, 1802)*	x		x			x																									
Odontomachus haematodus (Linnaeus, 1758)*																											x				
Odontomachus insularis (Guérin-Méneville, 1844)*	x																														
Odontomachus meinerti (Forel, 1905)*				x																											
Odontomachus sp1																					x										
Pachycondyla sp1	x		x			x																									
Pachycondyla sp2	x													x																	
Pachycondyla striata (Smith, 1858)*	x									x									x		x			x	x				x		x
Ponera sp1									x																						
Pseudomyrmicinae																															
Pseudomyrmex (gr. Pallidus) sp2																											x				
Pseudomyrmex (gr.Pallidus) sp	x			x						x				x				x				x		x							
Pseudomyrmex cf. *flavidulus*		x						x																							
Pseudomyrmex elongatus (Mayr, 1870)*		x																													
Pseudomyrmex gracilis (Fabricius, 1804)*	x	x					x	x														x									
Pseudomyrmex pupa (Forel, 1911)*					x																										
Pseudomyrmex sp1						x			x			x				x					x		x								
Pseudomyrmex sp2			x			x			x			x				x				x			x								
Pseudomyrmex termitarius (Smith, 1855)*	x	x		x	x		x	x		x	x			x	x			x						x							
Total number of species per altitude		**171**			**127**			**111**			**116**			**117**				**121**						**112**					**45**		**17**

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