

## Life-form spectra of quartzite and itabirite rocky outcrop sites, Minas Gerais, Brazil

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**Abstract:** Vascular species and their respective life-forms and coverage were recorded in a Brazilian quartzite and itabirite rocky outcrop site at *Serra de Ouro Preto*, producing the floristic, frequency and vegetational spectra. Three habitats in both lithologies were defined by geomorphology as: 1) Sloped areas near the mountain summit, with grasslands; 2) Plateaus in the middle of the slope, with grasslands; and 3) Lower and/or concave parts of the slopes, with woody savannas. The life-forms followed Raunkiaer's System. We aimed to answer the following questions: Do quartzite and itabirite rocky outcrops have different biological spectra? Are the biological spectra different in the geomorphologic habitats? Do the floristic, vegetational and frequency spectra differ from one another? What spectrum stacks up to a rocky outcrop physiognomy description? The results portrayed that: a) the most represented life-forms were the phanerophytes and hemicryptophytes; b) the floristic and frequency spectra did not differ from each other, but both differed from the vegetational one; c) all the floristic spectra were similar, but there were significant differences in the frequency and vegetational spectra among the lithology and geomorphology habitats; d) higher phanerophyte and lesser hemicryptophyte coverages were found in the itabirite areas and also in the lower or concave parts of the slopes of both lithologies; and e) the vegetational spectrum was more efficient for the studied rocky outcrop comparison. Relationships between the environmental aspects and life-form spectra are discussed. This study will help advance the development of restoration projects for these areas by adding knowledge of their flora composition, structure and function.

**Keywords:** *biological spectrum, ferruginous rocky outcrops, Quadrilátero Ferrífero, Raunkiaer.*

MESSIAS, M.C.T.B., LEITE, M.G.P., MEIRA-NETO, J.A.A., KOZOVITS, A.R. **Formas de vida em campos rupestres sobre quartzito e itabirito, em Minas Gerais, Brasil.** *Biota Neotrop.* 11(2): <http://www.biotaneotropica.org.br/v11n2/pt/abstract?article+bn01311022011>

**Resumo:** Realizou-se um levantamento das espécies vasculares e suas respectivas formas de vida e coberturas, em campos rupestres na Serra de Ouro Preto, sobre quartzito e itabirito, para construção dos espectros florísticos, de frequência e vegetacional. Em cada litologia foram delimitados, pela geomorfologia, três tipos de habitats: 1) Áreas inclinadas, nos topos das montanhas, com campos limpos; 2) Platôs, na parte mediana das encostas, com campos limpos e 3) Partes mais baixas ou côncavas das encostas, com campos sujos. As formas de vida seguiram o sistema de Raunkiaer. Averiguaram-se as seguintes questões: Campos rupestres sobre itabirito e quartzito possuem diferentes espectros biológicos? Os habitats estratificados pela geomorfologia diferem quanto aos espectros biológicos? Os espectros florísticos, de frequência e vegetacional diferem entre si? Qual espectro se destaca como descritor da fisionomia de campos rupestres? Os resultados evidenciaram que: a) fanerófitas e hemicriptófitas são as formas de vida predominantes; b) os espectros florísticos e de frequência não diferiram entre si e ambos foram estatisticamente diferentes do espectro vegetacional; c) os habitats estratificados pela litologia e geomorfologia apresentaram espectros florísticos similares, mas os espectros de frequência e vegetação mostraram diferenças significativas; d) maior cobertura de fanerófitas e menor cobertura de hemicriptófitas foram encontradas nas áreas sobre itabirito, assim como nas partes mais baixas ou côncavas das encostas, em ambas litologias; e e) o espectro vegetacional mostrou-se mais eficiente para comparação dos habitats. Aspectos do ambiente relacionados com a distribuição de formas de vida são discutidos. Este estudo subsidia programas de restauração ambiental, ampliando o conhecimento da vegetação de campos rupestres.

**Palavras-chave:** *espectro biológico, campos ferruginosos, Quadrilátero Ferrífero, Raunkiaer.*

## Introduction

*Campos Rupestres* are also known as montane savannas, a kind of Brazilian rocky outcrop, that mainly occurs in the Espinhaço Range (*Cadeia do Espinhaço*), which extends northward from the State of Minas Gerais, to the State of Bahia, between 20° 35' S and 11° 11' S (Meguro et al. 1994). They are located in contact zones between the Cerrado (the main Neotropical savanna) and the Atlantic Forest (southern Espinhaço), as well as in transition zones of the Caatinga, the Cerrado and the Atlantic Forest (central and northern Espinhaço), important terrestrial hotspots. They harbor a great biodiversity and many endemic and threatened species (Giulietti & Pirani 1988). The dominant vegetation is herbaceous and presents a mosaic of shrubs and subshrubs growing in a wide variety of substrates, including rocks and recently-decomposed stony, sandy or colluvial soils. The most common type of rock in this region is quartzite (Benites et al. 2007). According to Harley & Simmons (1986), “campos rupestres” is the expression that defines the vegetation growing on quartzite-sandstone substrate, although this terminology is used to refer to Brazilian vegetation found on other kinds of rocky substrate such as granitic-gneiss (e.g. Queiroz et al. 1996) or itabirite (e.g. Jacobi & Carmo 2008, Mourão & Stehmann 2007, Viana & Lombardi 2007). In the *Quadrilátero Ferrífero*, Southeastern Brazil, rocky outcrops occur frequently in areas with quartzite rocks, interspersed with itabirite, metasandstone, phyllite, schist and gneiss. Itabirite is frequently covered with a layer of duricrusts, formed by the rock's lateritic chemical weathering, known as *cangas* (Rosière & Chemale Junior 2000).

Rocky outcrop plant communities are basically controlled by edaphic conditions, and often represent islands of xeric communities rising in a matrix of mesophytic vegetation (Porembski et al. 1994, 1998). Species show adaptation to over-heating or drought, such as: trichomes or persistent leaf sheaths for isolation and water uptake and accumulation, succulence, sclerophylly and desiccation tolerance, in the so-called resurrection plants (Gaff 1977, 1987, Porembski & Barthlott 2000). The vegetation of ironstone outcrops also exhibits adaptations to living in a substrate rich in heavy metals like Iron, Manganese, Copper, Lead and others (Vincent & Meguro 2008). Little is known about the communities in iron-rich rocks compared to other kinds of rocky outcrops (Jacobi et al. 2007, Jacobi & Carmo 2008, Mourão & Stehmann 2007, Silva 1991, Viana & Lombardi 2007, Vincent 2004, Vincent & Meguro 2008). In Brazil, plant communities in itabirite rocks occur in two main areas: *Serra dos Carajás*, in the Amazon region and *Quadrilátero Ferrífero* in the Southeast. These areas are threatened mainly by the high intensity of open pit mining.

According to Cain (1950), life-form studies are almost as important as the floristic composition in vegetation description. Plants can be categorized into different life-form classes depending on their similarities in structure and function (Mueller-Dombois & Ellenberg 1974, Harrison et al. 2010). A life-form is characterized by the plant's adaptations to specific ecological conditions (Mera et al. 1999). Raunkiaer (1934) suggested a system for the classification of the life-forms of plants based on the position and degree of protection of the renewing buds, which are responsible for the renewal of the plant's aerial body on arrival of the season favorable to growth. In Raunkiaer's (1934) system, the harsher the unfavorable season is, the more protected the renewing buds are. This author stated five major classes, ordered according to increased protection of the renewing buds: phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes. The original classification of Raunkiaer was changed by Mueller-Dombois and Ellenberg (1974), among others, to add plant features in the favorable season. Raunkiaer's system was strongly criticized (Sarmiento & Monasterio 1983), but is still

considered, in several ways, the most fundamental explanation for why certain combinations of plant species co-occur in a given habitat (Begon et al. 1996, Lomolino et al. 2005).

A floristic spectrum is created with a species list, where every species has the same weight. However, the usefulness of life-form spectra, for ecological investigations, seems to depend largely on some means of evaluating the species composing the flora of the communities (Cain 1950). The weighting of the species could be accomplished by the use of any quantitative data concerning the species, such as number of individuals, frequency or coverage. When the number of individuals of each life-form is counted, instead of species, each class can be weighted by its abundance, resulting in the vegetation's biological spectrum. This feature describes the vegetation rather than the flora, and allows comparisons to other spectra similarly constructed for other sites. However, Raunkiaer (1934) asserted that counting plant individuals in a survey is complicated, because sometimes it is difficult to distinguish what an individual is. For this reason, this author proposed a frequency spectrum, using the number of sampling units in which the species is present to weight the species.

In a Brazilian granitic rocky outcrop, Caiafa & Silva (2005) found that the floristic spectra were different in the different habitats, where the grasslands had a higher percentage of hemicryptophytes followed by chamaephytes; and the scrub boundaries are more phanerophytic. Conceição & Giulietti (2002), Conceição & Pirani (2005) and Conceição et al. (2007a, b), working in quartzite-sandstone rocky outcrop areas, described these communities as having a high percentage of hemicryptophytes and a lack of therophytes. Little is known about life form spectra in ferruginous rocky outcrops (Jacobi et al. 2007).

There are few quantitative studies in ferruginous rocky outcrops in relation to quartzitic and granitic ones; known only are those of Jacobi et al. (2007), Jacobi & Carmo (2008), Vincent (2004) and Vincent & Meguro (2008). The accomplishment of ecological studies in Brazilian rock outcrops is important to improve the knowledge of Brazilian phytogeography by understanding the adaptation of plants to the environment and how they contribute to vegetational structure and physiognomy. Since the ferruginous rocky outcrops are highly threatened by mining activities, the ecological knowledge of this environment will also help advance the development of restoration projects for these areas.

The aim of this study was to answer the following questions: Do the floristic, vegetational and frequency spectra differ from quartzite to itabirite areas? Are the biological spectra different in the different geomorphologic habitats? What classes characterize these rocky outcrop life-form spectra? Do the floristic, vegetational and frequency spectra differ from one another? What aspects of the environment might be related with the distributions of life-form? What spectrum stacks up to a rocky outcrop physiognomy description?

## Material and Methods

### 1. Study sites

This study was carried out in the Municipalities of Ouro Preto and Mariana, Minas Gerais State, southeastern Brazil, at about 20° 10' S and 43° 30' W, 890 to 1250 meters above sea level. This area belongs to Samarco Mineração S.A. and is part of the *Serra de Ouro Preto*, South of *Espinhaço* Range. The climate according to Köppen is Cwb, i.e. mesothermic, with a rainy summer concentrated during November-March and a dry winter (Nimer 1989). The annual mean rainfall is 1250 mm and the annual mean temperature is around 20 °C. Two *campos rupestres* areas, 12 km apart, with different

kinds of rock (itabirite and quartzite), were selected to set the plots. The rocky outcrops in each lithology were stratified in three habitats by geomorphology as: 1) Sloped areas with bare rocks, near the mountain summit, with grasslands (*campos limpos*); 2) Plateaus, in the middle of the slope, with no more than 10% slope inclination, with grasslands; 3) Lower and/or concave parts of the slopes, in valleys or depressions, with woody savannas (*campos sujos*). Altogether six habitats were studied, determined by the two lithologies and three different geomorphologies. The grasslands in the sloped areas, established on itabirite (ISG), showed bare rocks with typical banded iron formation feature. The grasslands on the plateaus (IPG) had duricrusts formed by the lateritic chemical weathering of itabirite, known locally as *cangas couraçadas*. The woody savannas on itabirite (IWS) also had *cangas* partially covered by colluvial soil. On the other hand, the sloped grassland areas on quartzite (QSG) had a great amount of smooth bare rocks, and either shallow soil occupying the gaps between them, or forming small pools in their depressions. The grassland plateaus in the quartzitic areas (QPG) were comprised of a sandy, shallow and continuous soil with almost no bare rocks. The soil in this habitat showed poor drainage in the rainy season. The woody savannas on quartzite (QWS) presented sandy and colluvial soil with occasional bare rocks.

## 2. Methods

The survey was carried out from September/2007 to February/2009 by weekly field trips. In each lithology, thirty 10 × 10 m plots, ten in each geomorphological habitat, were defined. All the vascular species were collected, identified and classified into life-forms according to Raunkiaer's System (Raunkiaer 1934). The cover area (%) of each species was estimated as a measure of dominance (Mueller-Dombois & Ellenberg 1974), by the vertical projection of the aerial parts of each species as a percentage of the total area of the plot (Westhoff & Maarel 1978). The cover area estimation was assessed similar to the Braun-Blanquet method (Mueller-Dombois & Ellenberg 1974). The difference was that the cover area was evaluated as a continuous variable instead of using the categorical values of the Braun-Blanquet Cover-abundance Scale. After all species were recorded, the cover-abundance rating of each species was assigned from a point that had the best overview of the plot's entire plant assemblage. All the collected specimens were herborized and deposited in the Herbarium "Professor José Badini" (OUPR) of the Universidade Federal de Ouro Preto and grouped according to the Angiosperm Phylogeny Group (2009).

The data of each species life-form were used to construct the floristic, frequency and vegetational spectra (Raunkiaer 1934). Only Raunkiaer's major classes (phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes) were considered in this analysis. The lianas and epiphytes were included in the phanerophyte class, while the geophytes and saprophytes were put in the cryptophyte class, as originally proposed by Raunkiaer (1934). In the frequency spectrum, each species was weighted by the number of plots in which it appeared, whereas in the vegetational spectrum, each life-form was weighted by its coverage (Mueller-Dombois & Ellenberg 1974). In the construction of the biological spectra, each species was assigned to a single life-form class – the one in which the renewing buds were less protected. The biological spectra of each habitat were compared pairwise with a homogeneity analysis (Zar 1999) to test whether the life-form proportions were significantly different.

## Results

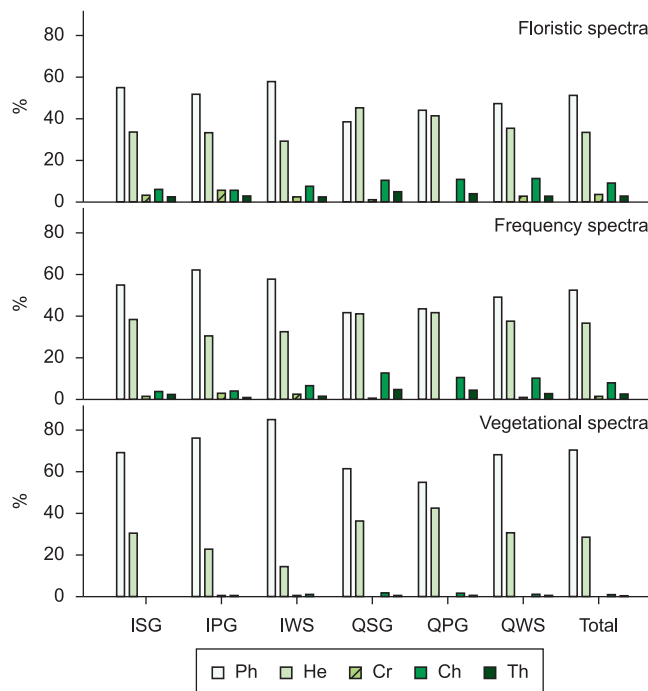
In this survey, 263 vascular species were collected, belonging to 64 families, of which 135 (51.3%) were considered phanerophytes; 88 (33.5%), hemicryptophytes; 23 (8.8%), chamaephytes; nine (3.4%),

cryptophytes and eight (3%), therophytes. Among the phanerophytes, sensu Raunkiaer (1934), 13 species are lianas and one is epiphyte. The families with the greater number of species were Poaceae (28 species), Asteraceae (26), Melastomataceae (19), Fabaceae (17), Rubiaceae (14), Myrtaceae (13), Cyperaceae and Orchidaceae (12) (Table 1).

In the floristic, frequency and vegetational spectra (Figure 1), the most remarkable feature was the high percentage of phanerophytes. The floristic spectra from the different studied habitats did not present any significant difference (Table 2).

Significant differences were found among the frequency spectra of the different studied habitats (Table 2). When comparing the different habitats in the quartzite areas, there was not any significant difference among them, but there were differences when comparing them with the corresponding habitats in the itabirite areas. The frequency of phanerophytes is higher than the other life forms in every studied habitat, but in QSG and QPG the frequency of hemicryptophytes is closer to that of the phanerophytes (Figure 1). Furthermore, the highest frequency of chamaephytes was found in these two habitats. QSG showed a higher frequency of chamaephytes and a lower frequency of phanerophytes than in ISG. IWS presented a higher frequency of phanerophytes and cryptophytes and a lower frequency of chamaephytes, therophytes and hemicryptophytes in comparison to QWS. The frequency spectra did not present significant differences between the grassland (*campos limpos*) and woody savanna (*campos sujos*) physiognomies.

Significant differences among the vegetational spectra of the different studied habitats were found. (Table 2). Quartzite and itabirite



**Figure 1.** Floristic, frequency, and vegetational life-form spectra of rocky outcrop sites (approximately, 20° 10' S – 43° 30' W). Ph = phanerophyte; He = hemicryptophyte; Cr = cryptophyte; Ch = chamaephyte; Th = therophyte; ISG = Grasslands in sloped areas, with bare itabirite rocks, near the mountain summit; IPG = Grasslands on the itabirite plateaus, in the middle of the slope; IWS = Woody savannas in the lower and/or concave parts of the slopes, in valleys or depressions of the itabirite areas; QSG = Grasslands in sloped areas, with bare quartzite rocks, near the mountain summit; QPG = Grasslands on the quartzite plateaus, in the middle of the slope; QWS = Woody savannas in the lower and concave parts of the slopes, in valleys or depressions of the quartzite areas; Total = All the six habitats.

**Table 1.** Species list of rocky outcrop sites (approximately, 20°10' S – 43°30' W) and their respective life-form and mean coverage (%) in the different habitats.

Family/Species	Voucher	LF	Itabirite			Quartzite		
			ISG	IPG	IWS	QSG	QPG	QWS
<b>Acanthaceae</b>	2115	Ph	0	0.03	0.18	0	0.02	0.31
<i>Ruellia macrantha</i> (Mart. ex Ness) Lindau								
<b>Anacardiaceae</b>	1898	Ph	0	0	0	0	1.42	3.82
<i>Tapirira guianensis</i> Aubl.								
<b>Anemiaceae</b>	2000	He	0	0	0	0.01	0	0
<i>Anemia ferruginea</i> Humb. & Bonpl. ex Kunth								
<i>Anemia hirsuta</i> (L.) Sw.	1577	He	0	0	0.01	0	0	0
<b>Annonaceae</b>	2268	Ph	0	0	0	0	0	0.35
<i>Guatteria vilosissima</i> A. St.-Hil.								
<i>Xylopia sericea</i> A. St.-Hil.	2066	Ph	0	0	0	0	0	0.7
<b>Apocynaceae</b>	1938	Li	0	0	0	0	0	0.02
<i>Blepharodon pictum</i> (Vahl) W.D.Stevens								
<i>Ditassa laevis</i> Mart.	1708	Li	0.01	0	0.02	0.01	0	0
<i>Ditassa linearis</i> Mart.	1453	Li	0.03	0.04	0.01	0	0	0.02
<i>Ditassa mucronata</i> Mart.	1797	Li	0.02	0.03	0.07	0	0.03	0.05
<i>Forsteronia velloziana</i> (A.DC.) Woodson	2061	Li	0	0	0	0	0	0.02
<i>Mandevilla tenuifolia</i> (J.C.Mikan) Woodson	1447	Th	0.05	0.01	0.01	0	0	0
<i>Minaria decussata</i> (Mart.) T.U.P.Konno & Rapini	1669	Ch	0	0.01	0	0	0	0
<b>Aquifoliaceae</b>	2069	Ph	0.44	0.33	0.82	0	0.08	0.08
<i>Ilex subcordata</i> Reissek								
<b>Araceae</b>	1287	He	0.06	0.03	0.01	0	0	0
<i>Anthurium minarum</i> Sakur. & Mayo								
<i>Philodendron rhizomatosum</i> Sakur. & Maio	1604	Cr	0	0.01	0	0	0	0
<b>Araliaceae</b>	1548	Ph	0.05	0.15	0.35	0	0	0.08
<i>Schefflera morototoni</i> (Aubl.) Maguire <i>et al.</i>								
<b>Aristolochiaceae</b>	1673	He	0	0.01	0.01	0	0	0
<i>Aristolochia fimbriata</i> Cham.								
<i>Aristolochia smilacina</i> (Klotzsch) Duch.	1667	He	0	0.01	0.02	0.02	0	0.04
<i>Aristolochia</i> sp.1	1664	He	0	0	0.02	0	0	0
<i>Aristolochia</i> sp.2	1859	He	0.06	0.01	0	0.11	0.01	0
<b>Asteraceae</b>	2132	Ph	0	0.01	0	0	0	0
<i>Achyrocline satureioides</i> (Lam.) DC.								
<i>Baccharis platypoda</i> DC.	1974	Ph	0	0.03	0.02	0.13	1.79	0.01
<i>Baccharis punctulata</i> DC.	1792	Ph	0	0.05	0.02	0	0	0
<i>Baccharis reticularia</i> DC.	1485	Ph	2.12	0.34	0.79	0.47	0.11	0.79
<i>Baccharis serrulata</i> (Lam.) Pers.	1851	Ph	0	0	0	0.23	0.04	0.02
<i>Calea clematidea</i> Baker	1833	Ph	0	0	0	0.03	0.51	1.27
<i>Chromolaena squalida</i> (DC.) R.M.King & H.Rob.	1487	Ph	0.06	0.02	0.02	0	0	0
<i>Cyrtocymura scorpioides</i> (Lam.) H.Rob.	1894	Ph	0	0	0.02	0.05	0.24	0.11
<i>Dasyphyllum sprengelianum</i> (Gardner) Cabrera	1740	Ph	0.23	0	0	0	0	0
<i>Echinocoryne holosericea</i> (Mart. ex DC.) H.Rob.	1726	Ph	0	0.05	0.15	0	0	0
<i>Eremanthus crotonoides</i> (DC.) Sch.Bip.	2117	Ph	0.4	1.65	2.49	5.7	5.6	5.7
<i>Eremanthus erythropapus</i> (DC.) MacLeish	1475	Ph	0.6	0.8	11.8	2.8	1.16	8.25
<i>Eremanthus incanus</i> (Less.) Less.	1394	Ph	2.5	0	2.5	5.6	0.15	0
<i>Hololepis pendunculata</i> (DC. ex Pers.) DC.	1383	Ph	0.66	0.08	0.09	0	0	0
<i>Koanophyllon adamantium</i> (Gardner) R.M.King & H.Rob	1653	Ph	0	0.02	0.11	0	0	0
<i>Lychnophora pinaster</i> Mart.	1360	Ph	2.23	12.3	0.5	0	0	0
<i>Lychnophora syncephala</i> (Sch.Bip.) Sch.Bip.	1496	Ph	0.03	0.01	0	0	0	0

Voucher: Collect number of MCTB Messias; LF = Life-form; Ph = phanerophyte; He = hemicryptophyte; Cr = cryptophyte; Ch = chamaephyte; Th = therophyte; ISG = Grasslands in sloped areas, with bare itabirite rocks, near the mountain summit; IPG = Grasslands on the itabirite plateaus, in the middle of the slope, with no more than a 10% inclination; IWS = Woody savannas in the lower and/or concave parts of the slopes, in valleys or depressions of the itabirite areas; QSG = Grasslands in sloped areas, with bare quartzite rocks, near the mountain summit; QPG = Grasslands on the quartzite plateaus, in the middle of the slope, with no more than a 10% inclination; QWS = Woody savannas in the lower and concave parts of the slopes, in valleys or depressions of the quartzite areas.



Table 1. Continued...

Family/Species	Voucher	LF	Itabirite			Quartzite		
			ISG	IPG	IWS	QSG	QPG	QWS
<i>Mikania</i> sp.	1982	Li	0	0	0	0	0.06	0.05
<i>Moquinia racemosa</i> (Spreng.) DC.	1651	Ph	0	0	0.3	0	0	0
<i>Pseudobrickellia angustissima</i> (Spreng. ex Baker) R.M. King & H.Rob.	1454	Ph	0.06	0	0	0	0	0
<i>Richterago amplexifolia</i> (Gardner) Kuntze	1714	He	0	0	0.04	0	0	0
<i>Richterago radiata</i> (Vell.) Roque	1779	He	0	0	0	0.12	0.25	0.16
<i>Senecio pohlii</i> Sch.Bip. ex Baker	1666	Ph	0.01	0	0.02	0	0	0
<i>Trichogonia hirtiflora</i> (DC.) Sch.Bip. ex Baker	1720	Ch	0.01	0	0.02	0	0	0
<i>Trichogonia villosa</i> (Spreng.) Sch.Bip. ex Baker	1526	Ph	0	0	0	0.02	0.04	0.02
<i>Vernonia</i> sp.	1988	Ph	0	0	0	0	0.07	0.2
<b>Bignoniaceae</b>	1981	Ph	0	0	0	0	0.05	0.05
<i>Handroanthus albus</i> (Cham.) Mattos								
<b>Bromeliaceae</b>	1705	He	0.02	0.03	0.03	0	0	0
<i>Cryptanthus schwackeanus</i> Mez.								
<i>Dyckia</i> cf. <i>cinerea</i> Mez	1879	He	0.04	0	0	0.31	0	0.06
<i>Dyckia rariflora</i> Schult. & Schult.f.	1689	He	0.32	0.16	0.08	0.83	0	0
<i>Tilandsia stricta</i> Sol.	2168	Ep	0	0	0.01	0	0	0
<i>Vriesea minarum</i> L.B.Sm.	1671	He	0	0.1	0.01	0	0	0
<b>Chrysobalanaceae</b>	2032	Li	0	0	0	0	0.02	0
<i>Hirtella floribunda</i> Cham. & Schtdl.								
<b>Clusiaceae</b>	1783	Ph	0	0	0	0	0.02	0
<i>Kielmeyera coriacea</i> Mart. & Zucc.								
<b>Convolvulaceae</b>	1868	He	0	0	0.02	0	0	0
<i>Jacquemontia prostrata</i> Choisy								
<b>Cyperaceae</b>	1928	He	0	0	0	0.03	0.02	0.02
<i>Bulbostylis capillaris</i> (L.) C.B.Clarke								
<i>Bulbostylis juncooides</i> (Vahl) Kük.	1924	He	0.03	0	0	0.09	0.02	0
<i>Bulbostylis</i> sp.	2016	He	0	0	0	0	0.01	0
<i>Dichromena</i> sp.	1598	He	0	0.01	0	0	0	0
<i>Lagenocarpus rigidus</i> Ness	1292	He	22	4.45	3.15	7.76	1.07	0.03
<i>Rhynchospora corymbosa</i> (L.) Britton	2031	He	0	0	0	0	0	0.4
<i>Rhynchospora tenuis</i> Link	1940	He	0	0.12	0	0.02	0.13	0.14
<i>Rhynchospora</i> sp.1	1930	He	0.5	0.51	0	0	0	0.02
<i>Rhynchospora</i> sp.2	2093	He	0	0	0	0	0.06	0
<i>Scleria hirtella</i> Sw.	1886	He	0	0	0	0.01	0.11	0.05
<i>Scleria</i> sp.	1644	He	0	0.02	0.01	0	0	0
<i>Trilepis microstachya</i> (C.B.Clarke) H.Pfeiff.	1594	He	0.01	0.21	0.03	0	0	0
<b>Dilleniaceae</b>	2274	Li	0	0	0	0	0.1	0
<i>Doliocarpus elegans</i> Eichler								
<b>Dioscoreaceae</b>	1875	Cr	0.02	0	0	0.02	0	0.01
<i>Dioscorea campestris</i> Griseb.								
<i>Dioscorea debilis</i> Uline ex R.Knuth	1675	Cr	0	0.03	0.05	0	0	0
<b>Ericaceae</b>	1421	Ph	0.18	0.15	0	0	0	0
<i>Agarista pulchella</i> var. <i>cordifolia</i> (Meisn.) Judd								
<i>Agarista pulchra</i> (Cham. & Schtdl.) G.Don	1716	Ph	0	0	0.02	0	0	0
<i>Gaylussacia amoena</i> Cham.	1650	Ph	0	0	0.03	0	0	0
<i>Gaylussacia reticulata</i> Mart. ex Meisn. var. <i>reticulata</i>	1670	Ph	0	0.1	0	0	0	0

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Table 1. Continued...

Family/Species	Voucher	LF	Itabirite			Quartzite		
			ISG	IPG	IWS	QSG	QPG	QWS
<b>Eriocaulaceae</b>	1796	He	0	0	0.02	0	0	0
<i>Actinocephalus bongardii</i> (A.St.-Hil.) Sano								
<i>Paepalanthus decussus</i> Körn.	1963	He	0	0	0	0	0.01	0
<i>Paepalanthus dianthoides</i> Mart. ex Körn.	1733	He	0	0	0.03	0	0	0
<i>Paepalanthus cacuminis</i> Ruhland	1719	He	0	0	0.04	0	0	0
<i>Paepalanthus planifolius</i> (Bong.) Körn.	1524	He	0.01	0	0.01	0.02	0.89	0.15
<i>Paepalanthus vaginatus</i> Körn.	1861	He	0	0	0	0.08	0.42	0.2
<b>Erythroxylaceae</b>	1652	Ph	0	0	0.5	0	0	0
<i>Erythroxylum gonocladum</i> (Mart.) O.E.Schulz								
<b>Euphorbiaceae</b>	1478	Ph	0.08	0.02	0	0	0	0
<i>Croton comosus</i> Müll.Arg.								
<i>Croton erythroxylodes</i> Baill.	1397	Ph	0.90	0.99	0.1	0	0	0
<i>Maprounea brasiliensis</i> A.St.-Hil.	1513	Ph	0	0	0	0	0	0.2
<i>Microstachys daphnoides</i> (Mart.) Müll. Arg.	1596	Ph	0	0.02	0.08	0	0	0
<b>Fabaceae (Leguminosae – Caesalpinoideae)</b>	2013	Ph	0.9	0.12	0.05	0.02	0	0
<i>Bauhinia rufa</i> (Bong.) Steud.								
<i>Chamaecrista desvauxii</i> (Collad.) Killip	1993	Ch	0	0	0	0	0.02	0
<i>Chamaecrista flexuosa</i> (L.) Greene	1836	Ch	0	0	0	0.05	0.05	0.01
<i>Chamaecrista mucronata</i> (Spreng.) H.S.Irwin & Barneby	1632	Ph	0	0	0.04	0.01	0.1	0.06
<i>Chamaecrista ochracea</i> (Vogel) H.S.Irwin & Barneby	1828	Ph	0	0	0	0	0	0.02
<i>Chamaecrista rotundifolia</i> (Pers.) Greene	1891	He	0	0	0	0.01	0	0.01
<i>Senna reniformis</i> (G. Don) H.S.Irwin & Barneby	1473	Ph	0.1	0	0	0	0	0.06
<b>Fabaceae (Leguminosae – Papilionoideae)</b>	1558	Ch	0.01	0.02	0.03	0	0	0.01
<i>Aeschynomene elegans</i> Schltldl. & Cham.								
<i>Centrosema coriaceum</i> Benth.	1818	He	0.06	0.02	0.05	0	0	0
<i>Clitoria densiflora</i> (Benth.) Benth.	1702	Ph	0	0	0.01	0	0	0
<i>Desmodium barbatum</i> (L.) Benth.	1913	He	0	0	0	0.01	0	0.01
<i>Galactia martii</i> DC.	1384	He	0.12	0.05	0	0	0	0
<i>Periandra mediterranea</i> (Vell.) Taub.	1522	Ph	1.48	0.37	0.59	0.77	0.18	0.43
<i>Stylosanthes gracilis</i> Kunth	1965	Ch	0	0	0	0.01	0.01	0.01
<i>Stylosanthes ruellioides</i> Mart.	1694	Ch	0	0	0.05	0	0	0
<i>Stylosanthes viscosa</i> (L.) Sw.	1911	Ch	0	0	0	0.01	0.01	0.03
<i>Zornia reticulata</i> Sm.	1889	Ch	0	0	0	0.03	0.01	0.02
<b>Gentianaceae</b>	2162	Ch	0	0	0.01	0	0	0
<i>Calolisianthus pedunculatus</i> (Cham. & Schltldl.) Gilg								
<b>Gesneriaceae</b>	1621	Ch	0.01	0.01	0.06	0	0	0
<i>Nematanthus strigillosus</i> (Mart.) H.E. Moore								
<i>Paliavana sericiflora</i> Benth.	1464	Ph	0.38	0.15	0.22	0	0	0
<b>Gleicheniaceae</b>	1915	He	0	0	0	0.01	0.53	0
<i>Dicranopteris flexuosa</i> (Schrad.) Underw.								
<b>Hypericaceae</b>	2247	Ph	0	0	0	0	0.1	0
<i>Vismia brasiliensis</i> Choisy								
<b>Iridaceae</b>	1914	He	0	0	0	0.01	0	0
<i>Cipura paludosa</i> Aubl.								
<i>Neomarica</i> sp.	1611	Cr	0.01	0.02	0	0	0	0.01
<i>Sisyrinchium</i> sp.	1625	Cr	0.01	0.01	0.04	0	0	0
<i>Trimezia</i> sp.	1674	Cr	0	0.01	0.03	0	0	0

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Table 1. Continued...

Family/Species	Voucher	LF	Itabirite			Quartzite		
			ISG	IPG	IWS	QSG	QPG	QWS
<b>Lamiaceae</b>	1580	Ph	0	0	0.15	0	0	0
<i>Aegiphila verticillata</i> Vell.								
<i>Hyptis homalophylla</i> Pohl ex Benth.	1895	Ch	0	0	0.03	0.03	0.14	0.16
<i>Hyptis monticola</i> Mart.ex Benth.	1685	Ph	0.7	0.27	0.07	0	0	0
<i>Hyptis passerina</i> Mart.ex Benth.	1451	Ph	0.17	0	0	0	0	0
<b>Lauraceae</b>	1790	Ph	0	0.1	0.04	0	0	0
<i>Cinnamomum erythropus</i> (Nees & Mart.) Kosterm.								
<i>Ocotea caesia</i> Mez	1636	Ph	0.15	0	0.93	0	0	0
<i>Ocotea nutans</i> (Nees) Mez	1729	Ph	0	0.3	0.18	0	0	0.08
<i>Ocotea percoriacea</i> Kosterm.	1711	Ph	0	0	0.54	0	0	0
<i>Persea</i> sp.	1718	Ph	0	0	0.02	0	0	0
<b>Lentibulariaceae</b>	1983	Th	0	0	0	0	0.01	0
<i>Utricularia amethystina</i> Salzm. ex A.St.-Hil. & Girard								
<b>Lindsaeaceae</b>	2063	He	0	0	0	0	0	0.01
<i>Lindsaea guianensis</i> (Aubl.) Dryand.								
<b>Loganiaceae</b>	1631	Th	0	0.01	0.03	0	0	0
<i>Spigelia spartioides</i> Cham.								
<b>Loranthaceae</b>	1978	Li	0	0	0	0	0.08	0.04
<i>Phoradendron falcifrons</i> (Hook. & Arn.) Eichler								
<b>Lycopodiaceae</b>	2025	He	0	0	0	0	0.01	0
<i>Lycopodiella cernua</i> (L.) Pic.Serm.								
<b>Lythraceae</b>	1704	Ph	0.44	0.21	0.2	0	0	0
<i>Diplusodon microphyllus</i> Pohl								
<b>Malpighiaceae</b>	1633	Ph	1.28	0.08	1.69	0.3	0	0.33
<i>Byrsonima variabilis</i> A.Juss.								
<i>Heteropterys campestris</i> A.Juss.	1787	Ph	0.28	0.17	0.2	0	0	0
<i>Heteropterys escalloniifolia</i> A.Juss.	1671	Ph	0.07	0.01	0.06	0	0	0
<i>Heteropterys</i> sp.	2062	Ph	0	0	0	0.2	0.15	0.56
<b>Malvaceae</b>	1896	Ch	0	0	0	0.03	0.01	0.03
<i>Sida linifolia</i> Cav.								
<b>Melastomataceae</b>	1684	Ph	0	0	0.02	0	0	0
<i>Acisanthera variabilis</i> (Mart. & Schrank) Triana								
<i>Cambessedesia hilariana</i> (Kunth) DC.	1831	Ch	0	0	0	0.06	0.09	0.05
<i>Clidemia urceolata</i> DC.	2206	Ph	0	0	0	3.85	6.05	4.35
<i>Leandra aurea</i> (Cham.) Cogn.	1583	Ph	0	0	0.02	0	0	0
<i>Leandra australis</i> (Cham.) Cogn.	1709	Ph	0.84	0.42	1.48	1.63	0	0
<i>Leandra dendroides</i> (Naudin) Cogn.	2021	Ph	0	0.05	0.02	0	0	0
<i>Leandra foveolata</i> (DC.) Cogn.	1977	Ph	0	0	0	0	0.06	0
<i>Miconia albicans</i> (Sw.) Triana	1530	Ph	0	0	0	0.21	0.37	0.63
<i>Miconia corallina</i> Spring	1794	Ph	0	0	0.08	0	0	0.03
<i>Miconia ligustroides</i> (DC.) Naudin	1703	Ph	0	0	0.4	0	0	0.1
<i>Miconia stenostachya</i> DC.	1873	Ph	0	0	0	0.02	0.03	0.05
<i>Microlicia crenulata</i> (DC.) Mart.	1551	Ph	0	0.32	0	0	0	0
<i>Microlicia fulva</i> (Spreng.) Cham.	1964	Ph	0	0.02	0	0	0.11	0
<i>Microlicia graveolens</i> DC.	1883	Ph	0	0	0	0.2	0.29	0.04
<i>Tibouchina gardneriana</i> (Triana) Cogn.	1550	Ph	0.02	0.03	0.05	0	0	0
<i>Tibouchina heteromalla</i> (D.Don) Cogn.	1367	Ph	4.25	2.16	1.61	0.31	0.37	1.64
<i>Trembleya laniflora</i> (D.Don) Cogn.	1922	Ph	0	0	2.7	0.31	0.06	0.05

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Table 1. Continued...

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			ISG	IPG	IWS	QSG	QPG	QWS
<i>Trembleya parviflora</i> (D. Don) Cogn.	1976	Ph	0	0	0	0	0.26	0.15
<i>Trembleya</i> sp.	1572	Ph	0	0	0.03	0	0	0
<b>Myrsinaceae</b>	1436	Ph	0	0	0	0	0.59	0.81
<i>Myrsine coriacea</i> (Sw.) R.Br. ex Roem. & Schult.								
<i>Myrsine emarginella</i> Miq.	2166	Ph	0	0	0.1	0	0	0
<i>Myrsine gardneriana</i> A.DC.	1971	Ph	0	0	0	0	0.2	0.08
<i>Myrsine venosa</i> A.DC.	2051	Ph	0	0	0	0	0.5	0.1
<b>Myrtaceae</b>	1683	Ph	0.2	0	0.12	0	0	0
<i>Blepharocalyx salicifolius</i> (Kunth) O.Berg.								
<i>Calypttranthes cordata</i> O.Berg	1544	Ph	0	0.2	0.4	0	0	0
<i>Eugenia puniceifolia</i> (Kunth) DC.	1778	Ph	0	0	0	0	0.19	0
<i>Myrcia amazonica</i> DC.	2075	Ph	0	0	0	0.06	0	1.95
<i>Myrcia eriocalyx</i> DC.	1789	Ph	0	0.22	0.23	0	0	0
<i>Myrcia multiflora</i> (Lam.) DC.	1531	Ph	0	0	0	0.1	0.32	1.09
<i>Myrcia mutabilis</i> (O.Berg) N.Silveira	1489	Ph	0.15	0	0	0	0	0
<i>Myrcia pulchra</i> (O.Berg) Kiaersk.	2254	Ph	0.36	1.5	1.85	0	0	0
<i>Myrcia splendens</i> (Sw.) DC.	1659	Ph	0.5	0.63	0.09	0.1	0.44	1.15
<i>Myrcia subavenia</i> (O.Berg.) N.Silveira	1649	Ph	0	0	0.08	0	0	0
<i>Myrcia venulosa</i> DC.	1869	Ph	0.5	0	1.55	0	0	0.03
<i>Myrciaria floribunda</i> (H.West ex Willd.) O.Berg	1850	Ph	0	0	0	0.3	0.22	0.1
<i>Myrciaria glanduliflora</i> (Kiaersk.) Mattos & D.Legrand	2076	Ph	0	0	0	0	0	0.26
<b>Ochnaceae</b>	2050	Ph	0	0	0	0	0	0.05
<i>Ouratea grandifolia</i> (Planch.) Engl.								
<i>Ouratea semiserrata</i> (Mart. & Nees) Engl.	1638	Ph	0	0.03	0.14	0	0	0
<i>Sauvagesia erecta</i> L.	1927	Ch	0	0	0	0	0.07	0.03
<b>Orchidaceae</b>	1426	He	0.5	0.12	0.1	0.77	0.01	0.03
<i>Acianthera teres</i> (Lindl.) Borba								
<i>Cleistes metallina</i> (Barb.Rodr.) Schltr.	2089	Cr	0	0	0	0	0	0.01
<i>Coppensia blanchetii</i> (Rchb.f.) Campacci	1810	He	0.05	0.04	0.05	0	0	0
<i>Cranichis candida</i> (Barb.Rodr.) Cogn.	2357	He	0	0	0	0	0	0.01
<i>Epidendrum martianum</i> Lindl.	1807	He	0.02	0.01	0.02	0	0	0.01
<i>Epidendrum secundum</i> Jacq.	1772	He	0.03	0.05	0.05	0.15	0.01	0.09
<i>Habenaria secundiflora</i> Barb.Rodr.	2091	Cr	0	0	0	0	0	0.01
<i>Hoffmannseggella caulescens</i> (Lindl.) H.G.Jones	1300	He	0.2	0.13	0.07	0	0	0
<i>Hoffmannseggella cinnabarina</i> (Batem. ex Lindl.) H.G.Jones	1301	He	0.07	0.04	0.05	0.61	0	0.03
<i>Hoffmannseggella crispata</i> (Thunb.) H.G.Jones	2131	He	0.16	0.04	0.04	0	0	0
<i>Nitidocidium gracile</i> (Lindl.) F.Barros & V.T.Rodrigues	1742	He	0.02	0.03	0.01	0	0	0
<i>Veyretia rupicola</i> (Garay) F.Barros	2137	Cr	0.01	0.04	0	0	0	0
<b>Passifloraceae</b>	1460	Li	0.01	0.02	0.01	0	0	0
<i>Passiflora villosa</i> Vell.								
<b>Peraceae</b>	2049	Ph	0	0	0.5	0	0.39	1.75
<i>Pera glabrata</i> (Schott) Poepp. ex Baill.								
<b>Phyllanthaceae</b>	1373	Ch	0	0.01	0	0.17	0.03	0.04
<i>Phyllanthus klotzschianus</i> Müll.Arg.								
<i>Phyllanthus roselus</i> (Müll.Arg.) Müll.Arg.	1375	Th	0	0	0	0.02	0	0.04
<b>Phytolaccaceae</b>	1511	Th	0.01	0.01	0.01	0	0	0
<i>Microtea paniculata</i> Moq.								

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Table 1. Continued...

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			ISG	IPG	IWS	QSG	QPG	QWS
<b>Poaceae</b>	2042	He	0	0	0	0	0.07	0.07
<i>Andropogon bicornis</i> L.								
<i>Andropogon leucostachyus</i> Kunth	1588	He	0	0.02	0	0	0	0
<i>Andropogon selloanus</i> (Hack.) Hack.	1935	He	0	0	0	0.04	0.06	0.04
<i>Andropogon virgatus</i> Desv.	1947	He	0	0	0	0	0.05	0.03
<i>Apochloa poliophylla</i> (Renvoize & Zuloaga) Zuloaga & Morrone	1566	He	5.67	5.66	3.02	1.9	0.08	0.94
<i>Aristida torta</i> (Nees) Kunth	1884	He	0	0	0	0.09	0.1	0.08
<i>Axonopus capillaris</i> (Lam.) Chase	1907	He	0	0	0	0.01	0.02	0
<i>Axonopus laxiflorus</i> (Trin.) Chase	1623	He	1.13	0.52	0.59	0.76	0.03	6.54
<i>Axonopus scoparius</i> (Flüggé) Kuhlm.	1445	He	0	0	0	0	0.01	0
<i>Axonopus siccus</i> (Nees) Kuhlm.	1852	He	0.5	1.54	0.21	0.26	0.14	0.08
<i>Dichantellium sciurotoides</i> (Zuloaga & Morrone) Davidse	2037	He	0	0	0	0	0	0.06
<i>Echinolaena inflexa</i> (Poir.) Chase	1863	He	0	0	0	2.41	11.9	9.1
<i>Eragrostis rufescens</i> Schrad. ex Schult.	1929	He	0	0	0	0	0.01	0
<i>Eragrostis solida</i> Nees	1892	He	0	0	0	0.01	0.02	0.03
<i>Ichnanthus bambusiflorus</i> (Trin.) Döll	1467	He	0.02	0.54	0.26	0	0	0.04
<i>Otachyrium versicolor</i> (Döll) Henrard	1949	He	0	0	0	0	0.07	0.12
<i>Panicum pseudisachne</i> Mez	1672	He	0.04	0.04	0.64	0.03	0.03	0.08
<i>Panicum wettsteinii</i> Hack.	1549	He	0	0.65	0.62	0.02	0	0
<i>Parodiophyllochloa penicillata</i> (Nees ex Trin.) Zuloaga & Morrone	2060	He	0	0	0	0	0	0.02
<i>Paspalum coryphaeum</i> Trin.	2084	He	0	0	0	0	0	0.01
<i>Paspalum hyalinum</i> Nees ex Trin.	1909	He	0	0	0	0	0.09	0
<i>Paspalum lineare</i> Trin.	1878	He	0	0	0	0.04	0.02	0.01
<i>Paspalum multicaule</i> Poir.	1897	He	0	0	0	0.01	0	0
<i>Paspalum pilosum</i> Lam.	1921	He	0	0	0	0.03	0.12	0.08
<i>Paspalum polyphyllum</i> Nees	1999	He	0	0	0	0.09	0.02	0.04
<i>Schizachyrium sanguineum</i> (Retz.) Alston	1961	He	0.25	0.35	0.02	0.02	0.07	0.02
<i>Schizachyrium tenerum</i> Nees	1916	He	1.29	0.61	0.23	0.05	0.01	0.16
<i>Sporobolus metallicolus</i> Longhi-Wagner & Boechat	1931	He	0	0	0	0	0.03	0.09
<b>Polygalaceae</b>	2041	Ch	0	0	0	0	0	0.01
<i>Polygala cuspidata</i> DC.								
<i>Polygala oleifolia</i> A.St.-Hil. & Moq.	1661	Ch	0	0	0.05	0	0	0
<i>Polygala galioides</i> Poir.	1887	Th	0	0	0	0.03	0.08	0.04
<i>Polygala paniculata</i> L.	1888	Th	0	0	0	0.03	0.06	0.03
<b>Polygonaceae</b>	1438	Ph	1.35	4.75	3.2	0	0.1	0.03
<i>Coccoloba acrostichoides</i> Cham.								
<i>Coccoloba scandens</i> Casar.	2011	Li	0	0	0	0	0.23	0.1
<b>Polypodiaceae</b>	1679	He	0	0	0.01	0	0	0
<i>Pleopeltis hirsutissima</i> (Raddi) de la Sota								
<b>Pteridaceae</b>	1798	He	0.01	0.03	0.04	0.01	0	0
<i>Doryopteris ornithopus</i> (Hook. & Baker) J.Sm.								
<i>Pellaea crenata</i> R.M.Tryon	1717	He	0	0	0.01	0	0	0
<b>Rubiaceae</b>	1866	Ph	0	0.07	0.08	0.02	0	0.15
<i>Alibertia rotunda</i> (Cham.) K.Schum.								
<i>Augusta longifolia</i> (Spreng.) Rehder	1574	Ph	0	0	0.01	0	0	0

Voucher: Collect number of MCTB Messias; LF = Life-form; Ph = phanerophyte; He = hemicryptophyte; Cr = cryptophyte; Ch = chamaephyte; Th = therophyte; ISG = Grasslands in sloped areas, with bare itabirite rocks, near the mountain summit; IPG = Grasslands on the itabirite plateaus, in the middle of the slope, with no more than a 10% inclination; IWS = Woody savannas in the lower and/or concave parts of the slopes, in valleys or depressions of the itabirite areas; QSG = Grasslands in sloped areas, with bare quartzite rocks, near the mountain summit; QPG = Grasslands on the quartzite plateaus, in the middle of the slope, with no more than a 10% inclination; QWS = Woody savannas in the lower and concave parts of the slopes, in valleys or depressions of the quartzite areas.

Table 1. Continued...

Family/Species	Voucher	LF	Itabirite			Quartzite		
			ISG	IPG	IWS	QSG	QPG	QWS
<i>Borreria poaya</i> (A.St.-Hil.) DC.	1627	Ch	0	0	0	0	0	0.02
<i>Borreria</i> sp.	2086	Ch	0	0	0	0	0	0.01
<i>Coccocypselum condalia</i> Pers.	2094	Ch	0	0	0.05	0	0.01	0.06
<i>Declieuxia fruticosa</i> (Willd. ex Roem. & Schult.) Kuntze	1540	Ch	0.01	0.03	0	0	0	0
<i>Ferdinandusa</i> sp.	1690	Ph	0	0	0.01	0	0	0
<i>Mitracarpus hirtus</i> (L.) DC.	1904	Ph	0	0	0	0.01	0	0
<i>Palicourea</i> sp.	2266	Ph	0	0	0	0	0	0.02
<i>Psychotria hoffmannseggiana</i> (Willd. ex Schult.) Müll.Arg.	2048	Ph	0	0	0	0	0	0.08
<i>Psychotria pleiocephala</i> Müll.Arg.	2068	Ph	0	0	0	0	0	0.01
<i>Psychotria vellosiana</i> Benth.	1581	Ph	0	0	0.02	0	0	0.02
<i>Psyllocarpus laricoides</i> Mart. ex Mart. & Zucc.	1402	Ch	0.14	0.08	0.05	0.11	0	0.08
<i>Remijia ferruginea</i> (A.St.-Hil.) DC.	1385	Ph	0	0	0.05	0	0	0
<b>Rutaceae</b>	2103	Ph	0	0	0	0.08	0	0
<i>Dictyoloma vandellianum</i> A. Juss.								
<b>Sapindaceae</b>	1492	Ph	0.08	0	0	0	0	0
<i>Matayba marginata</i> Radlk.								
<i>Serjania gracilis</i> Radlk.	2036	Li	0	0	0	0	0	0.11
<b>Selaginellaceae</b>	2082	He	0	0.01	0	0	0	0.01
<i>Selaginella</i> sp.								
<b>Siparunaceae</b>	2054	Ph	0	0	0	0	0	0.79
<i>Siparuna poeppigii</i> (Tul.) A.DC.								
<b>Smilacaceae</b>	2020	Li	0	0	0	0.01	0	0
<i>Smilax minarum</i> A.DC.								
<b>Solanaceae</b>	1776	Th	0	0	0	0.05	0.01	0.02
<i>Schwenckia americana</i> Rooyen ex L.								
<b>Styracaceae</b>	1811	Ph	0	0.03	0.08	0	0	0
<i>Styrax maninul</i> B.Walln.								
<b>Velloziaceae</b>	1881	He	0	0	0	0.08	0	0
<i>Barbacenia flava</i> Mart. ex Schult. & Schult.f.								
<i>Vellozia compacta</i> Mart. ex Schult. & Schult.f.	1845	Ph	46	19	9.3	3.65	0	0.6
<i>Vellozia graminea</i> Pohl	1736	He	0.01	0.14	0.09	0	0	0
<b>Verbenaceae</b>	1480	Ph	0.02	0.04	0.04	0	0	0
<i>Lantana fucata</i> Lindl.								
<i>Lantana trifolia</i> L.	1557	Ph	0	0.02	0	0	0	0
<i>Lippia hermannioides</i> Cham.	1762	Ph	0.05	0.08	0	0	0	0
<i>Lippia organoides</i> Kunth	1450	Ph	0.44	0.41	0	0	0	0
<i>Lippia rubiginosa</i> Schauer	1536	Ph	0.1	0.5	0.22	0	0	0
<i>Stachytarpheta glabra</i> Cham.	1945	Ph	0.71	0.23	0.31	0.97	0.07	0.14
<b>Vochysiaceae</b>	2067	Ph	0	0	0	0	0	0.08
<i>Callisthene major</i> Mart. & Zucc.								
<i>Vochysia emarginata</i> (Vahl) Poir	2149	Ph	0	0	0.28	0	0	0
<b>Xyridaceae</b>	1966	He	0	0	0	0	0.02	0
<i>Xyris</i> sp.1								
<i>Xyris</i> sp.2	1942	He	0	0	0	0	0.04	0.01
<i>Xyris</i> sp.3	1860	He	0	0	0	0.08	0.08	0.09
<i>Xyris</i> sp.4	2087	He	0	0	0	0	0.02	0.01
<i>Xyris</i> sp.5	1951	He	0	0	0	0	0.04	0.01

Voucher: Collect number of MCTB Messias; LF = Life-form; Ph = phanerophyte; He = hemicryptophyte; Cr = cryptophyte; Ch = chamaephyte; Th = therophyte; ISG = Grasslands in sloped areas, with bare itabirite rocks, near the mountain summit; IPG = Grasslands on the itabirite plateaus, in the middle of the slope, with no more than a 10% inclination; IWS = Woody savannas in the lower and/or concave parts of the slopes, in valleys or depressions of the itabirite areas; QSG = Grasslands in sloped areas, with bare quartzite rocks, near the mountain summit; QPG = Grasslands on the quartzite plateaus, in the middle of the slope, with no more than a 10% inclination; QWS = Woody savannas in the lower and concave parts of the slopes, in valleys or depressions of the quartzite areas.

**Table 2.** Comparison among the life-form spectra of quartzite and itabirite rocky outcrop sites.

Spectra	DF	X <sup>2</sup>	P
Floristic vs. frequency	4	7.63	> 0.106
Floristic vs. vegetational	4	271.23	< 0.001
Frequency vs. vegetational	4	413.8	< 0.001
Floristic spectra among the different habitats	20	23.07	> 0.285
Frequency spectra among the different habitats	20	98.74	< 0.001
Vegetational spectra among the different habitats	20	152.46	< 0.001

DF = Degrees of freedom, X<sup>2</sup> = Chi-square value.

areas showed a significant difference in their vegetational spectra ( $X^2 = 80.3$ , d.f. = 4,  $p < 0.001$ ). The dominance of phanerophytes was greater and the hemicryptophytes was lesser in the itabirite habitats. The woody savannas, in both lithologies, have a greater dominance of phanerophytes and a lesser dominance of hemicryptophytes when compared with the grasslands. The vegetational spectra for both kinds of grasslands in the itabirite areas (ISG, IPG) differed from that of the woody savannas in the same lithology (IWS). The grasslands on the quartzitic plateaus (QPG) were different from QWS by the same pattern. However, the vegetational spectrum in QSG did not show the same standard and isn't statistically different from QWS. The greatest hemicryptophyte dominance among all the studied habitats was found at QPG. Grasslands with bare rocks on itabirite (ISG) differed significantly ( $p < 0.05$ ) from the plateaus with the same lithology (IPG), mainly due to the greater proportion of hemicryptophytes. ISG also showed a significant difference from QSG, explained by a greater phanerophyte dominance, followed by a lesser dominance of hemicryptophytes and chamaephytes in ISG. The plateaus with *canga* (IPG) showed the least hemicryptophyte dominance of all the grasslands.

By analyzing all the studied habitats together, the floristic and frequency spectra did not differ significantly from each other ( $X^2 = 7.63$ ,  $p > 0.106$ ) and both were different from the vegetational one ( $X^2 = 271.23$ ,  $p < 0.001$  and  $X^2 = 413.8$ ,  $p < 0.001$  respectively) (Table 2).

Phanerophytes are usually Magnoliopsida, except for *Vellozia compacta* and *Barbacenia flava*, while the hemicryptophytes are mainly Liliopsida, from the Poaceae family (Table 1).

## Discussion

The most counted life-forms (phanerophyte and hemicryptophyte) were the same in all the biological spectra but with different patterns of variation. Phanerophytes, chamaephytes and hemicryptophytes are generally well represented in the biological spectra of Brazilian rocky outcrops: ferruginous (Jacobi et al. 2007, Jacobi & Carmo 2008, Mourão & Stehmann 2007); quartzitic (Alves & Kolbek 2009, Conceição & Giulietti 2002, Conceição & Pirani 2005, Conceição et al. 2007a); granitic (Caiafa & Silva 2005); and nepheline-syenite (Ribeiro et al. 2007). A small proportion of therophytes was also found in the biological spectra of other rocky outcrop sites (Conceição & Pirani 2005, Jacobi et al. 2007, Meinelles et al. 1999, Ribeiro & Medina 2002, Ribeiro et al. 2007). Bazzaz & Morse (1991) related that therophytes are expected to become dominant where growing conditions are so adverse that the probability of survival until the second year becomes very small. However, unfavorable growing conditions for part of the year do not hinder the occurrence of perennials, as they favor selection by other strategies, such as dormant structures that enable species to survive in harsh conditions. Therophytes usually dominate in some of the driest and coldest environments of the world (Harrison et al. 2010). Environmental constraints in rocky outcrops might not have been extreme enough to favor the strategy of the therophytes. Ribeiro

& Medina (2002) suggested that the lack of therophytes in rocky outcrops is due to the difficulty they have to complete their cycle in this harsh environment within the favorable season. According to Ribeiro et al. (2007), therophytes may be rare due to a combination of short growing seasons and low nutrient budgets on rock surfaces that preclude rapid establishment and growth. This is reinforced by the observation that after an extensive wildfire in a rocky outcrop site in Rio de Janeiro, many therophytes established and flowered in large numbers (Ribeiro 2002). According to this author, this was probably due to an input of usually limiting nutrients, mainly phosphorous, that triggered the germination, establishment and growth of annual species.

Some quartzite-sandstone rocky outcrops in *Chapada Diamantina* showed a higher proportion of chamaephytes than phanerophytes (Conceição & Giulietti 2002, Conceição et al. 2007a). However, the authors used the Raunkiaer system adapted by Mueller-Dombois & Ellenberg (1974), where the height separating chamaephytes and phanerophytes is 25 cm higher. In addition, the species height depends on the environmental conditions. One of the kinds of chamaephytes is the woody, erect subshrubs, with all the characteristics of phanerophytes, except size (Adamson 1939). Some species are facultative shrubs, that is, they are trees under more favorable conditions (Cain 1950). Porto & Silva (1989) pointed out that the high level of some toxic metals might cause dwarfness. It may explain how a species like *Tibouchina heteromalla*, usually present in *campos rupestres* surveys, varies from 0.3 m to almost 2 m tall.

The hemicryptophytes are mainly represented by grasses (e.g. *Apochoa poliophylla*, *Axonopus siccus*, *A. laxiflorus*, *Echinolaena inflexa* and *Schizachyrium tenerum*), sedges (e.g. *Lagenocarpus rigidus* and *Rhynchospora* spp.), Orchidaceae and Bromeliaceae species. The grasses and sedges occur in pools of soil, surrounded by bare rocks, or in the sandy, sharp soil in the quartzitic plateaus or valleys. Orchidaceae and Bromeliaceae are mainly epiphytic species showing vegetative reproduction. Some species considered hemicryptophytes in this work e.g. *Epidendrum secundum* and *Coppensia blanchetii* were considered chamaephytes by Conceição & Giulietti (2002). Even though species can appear with different life-forms in different environments, Allan (1937) emphasized the lack of a sharp boundary between chamaephytes and hemicryptophytes and Hagerup (1930) discussed the difficulty of categorizing many short-lived perennials. The environmental constraints resulting from drought and water logging might explain the high dominance of hemicryptophytes in rocky outcrops. They are mainly from Liliopsida, having a fasciculate root system, occupying the superficial layer of the soil. Because the upper layer of the soil contains more organic matter, during the dry season, it has a higher water holding capacity, while on the other hand, during the rainy season, it has a greater oxygen level than the lower ones. It may explain the fact that in the quartzitic plateaus, with poor drainage, hemicryptophytes are more dominant. Besides this, there are other anatomic adaptations favoring monocots in wetlands, as described by Visser et al. (2000).

The floristic spectrum shows more about richness in each life-form than the vegetational feature of each environment. There was not any significant difference in the floristic spectra of the different studied habitats, where all the species had the same mean. However, the biological spectra exhibited differences when the species were weighted by a measure of frequency or coverage. It shows that the usefulness of biological spectra is enhanced by adding quantitative data concerning the species. The floristic and frequency spectra were not significantly different, but both differed statistically from the vegetational one. These results evidenced that the frequency evaluation did not add any significant value to the species list used to construct the biological spectra. Raunkiaer (1934) suggested frequency as a descriptor because of the difficulty of counting the individuals of some species. Even though frequency is a measure of abundance, it is influenced by the spatial distribution of individuals (Mueller-Dombois & Ellenberg 1974) and its relationship with density is logarithmic (Greig-Smith 1983). Frequency is an accurate estimation of density only if there is a random spatial distribution of the individuals, which is not common for plant species, being biased for rare or very common species or for those with clumped distribution (Greig-Smith 1983). According to this author, the advantage of frequency assessment is simply the facility and quickness with which it is obtained. Since density is difficult to obtain in field work for herbaceous communities, some authors have used coverage (Conceição & Giulietti 2002, Conceição & Pirani 2005, 2007, Conceição et al. 2007a, b, Wikum & Shanholtzer 1978). According to Cain (1950), coverage data seems perhaps the most useful, since it is more independent of sample-plot size than are density and frequency. Another advantage of cover as a quantitative measure is that nearly all plant life-forms, from trees to mosses, can be evaluated by the same parameter and thereby in comparable terms (Mueller-Dombois & Ellenberg 1974). Moreover, this evaluation requires only one third to one fifth of the time used for field work (Wikum & Shanholtzer 1978), compared with density methods.

Thus, the vegetational spectrum, where the species were weighted by coverage, was quite distinct from the floristic one and provided a more accurate description of the vegetational physiognomy. The proportion of phanerophytes and hemicryptophytes was greater than the other life-forms, which were very reduced when weighted by their dominance. Since the individual biomass is greater for the phanerophyte species, they were more important in the vegetational spectrum. The hemicryptophytes, which usually have vegetative reproduction, showed more individuals forming dense mats. So, the most important contribution to the coverage is given by density. The greater dominance of phanerophytes in itabirite may be explained by the higher occurrence of narrow vertical fissures in the rocks that permit the rooting of taller species and also by the higher level of some nutrients (Vincent & Meguro 2008). In addition, the higher dominance of *Vellozia compacta* (a phanerophyte which showed the highest coverage among all the species) in ferruginous *campos rupestres*, may be associated with tolerance to high levels of heavy metals and drought (Jacobi et al. 2007). These conditions are usually present in the sharp-rock soils as described by Conceição et al. (2007a), Jacobi et al. (2007), Meguro et al. (1977), Meirelles et al. (1997) and Owoseye & Sanford (1972) and are still harsher in ferruginous soils. This species only grows among rock outcrops, which occur in higher proportion in ferruginous *campos rupestres*, and is absent in quartzite plateaus where bare rocks are rare. Alves & Kolbek (2010) related that mechanically unstable sandy soils, like those found in the quartzitic plateaus, can be unavailable for the longevous, shrubby species of *Vellozia*.

Quartzitic and ferruginous rocky outcrops have similar floristic but quite different vegetational spectra. The greatest difference between

the two lithologies was found in the plateau habitats. The greatest dominance of hemicryptophytes covering the sharp, sandy soil was found in the quartzitic plateaus, while in the itabirite plateaus (IPG), the spectrum presented the smallest occurrence of hemicryptophytes among the grasslands. Viana & Lombardi (2007) also mentioned a lesser occurrence of Poaceae in this kind of environment compared to other kinds of ferruginous rocky outcrops. Phanerophytic shrubs with sclerophyll leaves, common in areas with outcrops like IPG, can extract water from dry soils at low water potential and are typically long-lived. Their high construction costs are amortized over a number of years, but their photosynthetic capacity is low because of internal shading within the leaves and/or high mesophyll resistance to CO<sub>2</sub> diffusion (Lloyd et al. 1992). This feature means that sclerophylls can dominate in some dry environments, such as the grasslands with outcrops, but do not compete effectively in wetter ones like the QPG.

The woody savannas, in both lithologies, have a greater dominance of phanerophytes and lesser dominance of hemicryptophytes when compared with the grasslands, which is probably due to the thicker soil that favors the establishment of shrubs or small trees. On the other hand, the lesser dominance of hemicryptophytes may be explained by the high competitiveness of the phanerophyte species. In itabirite areas, both kinds of grassland presented differences when compared to the woody savannas (IWS). The vegetational spectrum in QSG did not show the same pattern and is not statistically different from QWS. However, the most dominant phanerophytes in grasslands are nanophanerophytes, mainly represented by *Vellozia compacta*, while in QWS, more microphanerophytes were found, varying from 0.7 to 3 m, with shrubs of different specimens of Myrtaceae, Asteraceae, Euphorbiaceae, Lauraceae, Annonaceae, Siparunaceae and others.

The vegetational spectrum would be applied when the aim of the research is the ecological knowledge of the vegetation, rather than the flora of a given site. Cain (1950) suggested that some measure of the relative dominance of each species in the community would provide the most significant data. The vegetational spectra found in these sites fit between phanerophytic and hemicryptophyte. According to Raunkiaer (1934), a phanerophytic climate is typical of the warm humid tropics, while the hemicryptophytic phytoclimate corresponds to a cold-humid climate, typical of high latitudes or high altitudes. The applicability of Raunkiaer's system for tropical communities has been criticized by Sarmiento & Monasterio (1983) because its assumption that the constraint on plant growth is low winter temperatures, which is clearly not a significant issue in these communities. Batalha & Martins (2002) discussed the value of the phytoclimate concept when applied to *cerrado* vegetation, suggesting that water stress, water logging, fire, oligotrophism or aluminum toxicity can be similar to low winter temperatures. Thus, the use of Raunkiaer's system is not only possible, but recommended, when investigating factors, other than climate, that shape the vegetational physiognomy.

The biological spectra of the Brazilian rock outcrop vegetation seem to be somewhat consistent, with phanerophytes and/or chamaephytes and hemicryptophytes always being the most represented classes and with a lack of therophytes. The rather distinct individual differences can be also correlated, in very general terms, with the characteristics of the flora in surrounding areas (Adamson 1939); being the southern portion of Espinhaço Range influenced by the *Cerrado* and the northern one by the *Caatinga* (Viana & Filgueiras 2008). These differences can also be due to the different life-form classification systems used or the plasticity of the height of most species.

Although limited to a small rocky outcrop site, this study did not corroborate Raunkiaer's statement that the frequency spectrum is a good assessment of life-form distribution in plant communities. In addition, the frequency spectrum was not significantly different



from the floristic one. Thus, for these reasons the frequency spectrum is not suggested in studies of rocky outcrop sites. Similarly to that described by Batalha & Martins (2004) for *cerrado* sites, the floristic spectrum is suggested, if working in sufficiently large areas because it could provide an indication of the prevailing phytoclimate. On the other hand, the vegetational spectrum is recommended for small-area analysis, because it provides a detailed description of the physiognomy related with ecological factors. This data analysis supports the suitability of the use of coverage to solve the difficulty of counting individuals in order to construct the vegetational spectra in rocky outcrop sites.

Since the vegetational spectra are different in the different ferruginous rocky outcrop habitats this feature must be considered in the rehabilitation of mining areas. One of the most recent reclamation practices is a topographic reconstruction of mined-out pits, using overburden and spoil material (Griffith & Toy 2001). Even though this improves the aesthetic view, it could inhibit the reestablishment of the microhabitats described by Jacobi et al. (2007) in ferruginous rocky outcrops. In addition, revegetation projects using a “green carpet” approach, mainly with fast-growing grasses, could give rise to changes in the structure of the vegetation, through hemicryptophyte competitiveness, inhibiting the reestablishment of the natural proportion of life-form groups. Within long-term reclamation project, it is important to consider the life-form proportions as well as the successional dynamics of the community in order to have an efficient restoration of the environmental services of these areas.

## Conclusion

Not only lithology but other aspects of the environment, like geomorphology, influence the distribution of plant life-forms in rocky outcrop habitats. This makes the definition “High Altitude Rupestrian Complex” (Semir 1991, Benites et al. 2003) more appropriate as a phytogeographic description of the rocky outcrop of the Espinhaço Range. Phanerophytes and hemicryptophytes were the life-forms with a higher coverage in the studied areas. The ferruginous *campos rupestres* have higher phanerophyte and lower hemicryptophyte coverages than the quartzite ones. The lower and/or concave parts of the slopes have a greater phanerophyte and a lesser hemicryptophyte dominance than the two other geomorphologic habitats with grasslands. The floristic and frequency spectra did not differ from each other, but both differed from the vegetational one. The vegetational spectrum was more efficient for the studied rocky outcrop comparison. This study will support the development of restoration projects of *campos rupestres* by improving the knowledge of flora composition, structure and function.

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J.A.N. Batista (Orchidaceae); L. Bernacci (Passifloraceae); M.S. Marchioretto (Phytollaceae); A.L. Peixoto (Siparunaceae); J.F. Pastore (Polygalaceae); W. Marcondes-Ferreira (Polygonaceae); P.L. Viana (Poaceae); L.C.N. Melo and J.E. Casarino (Pteridophyta); M.S. Ferrucci (Sapindaceae); J.R. Stehmann (Solanaceae); R. Andreato (Smilacaceae); F.O.Souza-Buturi (Styracaceae), M.F. Salimena (Verbenaceae); R. Mello-Silva (Velloziaceae).

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