

Ferns and lycophytes from Serra dos Carajás, an Eastern Amazonian mountain range

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Abstract

In the state of Pará (Brazil), until the beginning of last decade little was known about the composition of the fern and lycophyte flora. The ferruginous mountains of Carajás are located in Southeastern Pará, mostly inserted in the Floresta Nacional de Carajás. The objective of this work is to present a complete and updated list of fern and lycophyte species occurring in all vegetation types from Carajás ferruginous mountains as a contribution to the knowledge of these plant groups from the Brazilian Amazon. The species list was based on specimens collected between 2007 and 2013. About 1068 specimens deposited in the BHCB Herbarium were studied. A total of 186 species of pteridophytes were recorded, 175 species of ferns distributed in 22 families and 68 genera, and 11 species of lycophytes distributed in three families and four genera. The fern and lycophyte flora of Serra dos Carajás region corresponds to 64% of the Pará state flora of these groups and 34% of the Brazilian Amazon fern and lycophyte flora. Seven taxa are presented as new records for Pará state: *Asplenium abscissum*, *A. otites*, *A. praemorsum*, *Blechnum lanceola*, *Elaphoglossum minutum*, *Doryopteris collina*, and *Hemionitis tomentosa*. Three species are endemic to Serra dos Carajás, *Isoetes cangae*, *I. serracarajensis*, and *Selaginella stomatoloma*.

Key words: Amazonia, canga, FLONA Carajás, floristic, pteridophytes.

Resumo

No estado do Pará (Brasil), até o início da última década pouco se sabia sobre a composição da pteridoflora. As serras ferruginosas de Carajás estão localizadas na região sudeste do Estado, em sua maior parte inseridas na Floresta Nacional de Carajás. O objetivo deste trabalho é apresentar uma listagem completa e atualizada das espécies de samambaias e licófitas ocorrentes em todas as formações vegetacionais das serras ferruginosas da região de Carajás como uma contribuição ao conhecimento da pteridoflora da Amazônia Brasileira. A listagem de espécies foi elaborada com base nos espécimes coletados entre 2007 e 2013 durante expedições botânicas. Foram estudados cerca de 1068 espécimes que estão depositados no herbário BHCB. Foram registradas 175 espécies de samambaias distribuídas em 22 famílias e 68 gêneros, e 11 espécies de licófitas, distribuídas em três famílias e quatro gêneros. A pteridoflora da região de Carajás corresponde a 64% da flora de samambaias e licófitas do Pará e a 34% da pteridoflora da Amazônia Brasileira. Sete táxons são apresentados como novos registros para o estado do Pará: *Asplenium abscissum*, *A. otites*, *A. praemorsum*, *Blechnum lanceola*, *Elaphoglossum minutum*, *Doryopteris collina* e *Hemionitis tomentosa*. Três espécies são endêmicas da região de Carajás, *Isoetes cangae*, *Isoetes serracarajensis* e *Selaginella stomatoloma*.

Palavras-chave: Amazonia, canga, FLONA Carajás, florística, pteridófitas.

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Introduction

Currently, 10,578 species of ferns and 1,338 species of lycophytes are recognized (PPG I 2016). In Brazil, according to the Brazilian Flora online, 1,330 species of ferns and lycophytes have been recorded, of which 538 occur in the Amazon and 289 in the state of Pará (Flora do Brasil 2020, under construction).

In the state of Pará, until the beginning of last decade, little was known about the composition of the fern and lycophyte flora, besides the pioneering studies of Huber (1898, 1902, 1906), Sampaio (1930), Cain *et al.* (1956) and Pires (1992). However, from 2003 on, there was a great advance in the knowledge about seedless vascular plants in Pará state due to several floristic and taxonomic studies carried out in forest fragments located around the state capital, Belém (Rodrigues *et al.* 2004; Costa *et al.* 2006; Costa & Pietrobon 2007, 2010; Maciel *et al.* 2007; Ferreira *et al.* 2009; Miranda 2009; Silva 2009), and also in Castanhal (Tavares 2009), Tomé-Açu (Maciel 2008; Maciel & Pietrobon 2010a,b), Portel (Silva & Rosário 2008; Pietrobon *et al.* 2009), Salgado (Costa 2009), Tucuruí (Fernandes *et al.* 2012), Redenção (Fonseca 2010), Monte Alegre (Silva 2010), and in the protected areas of “Calha Norte” (Góes-Neto 2011), as well as new records and other studies (Góes-Neto & Pietrobon 2012a,b; Almeida & Salino 2015; Pallos *et al.* 2016), which have contributed significantly to improve the knowledge on the fern and lycophyte flora in Pará and in the Amazon region.

The Amazon Rainforest is the largest tropical forest on the planet and houses an invaluable biological heritage (Silva *et al.* 2005). Nevertheless, the biome currently has only 80% of its original coverage (Souza Jr. *et al.* 2013), and the creation of protected areas is vital for habitat protection and reduction of deforestation rates. In this context, the Floresta Nacional de Carajás (Flona Carajás) represents an important protected area located in Southeastern Pará and was created with the basic goal of sustainable multiple uses of natural resources and scientific research. Among the mineral wealth found in Flona Carajás, there are extensive ferruginous mountains, which contain one of the largest iron resources on the planet. Together with the mountains of Quadrilátero Ferrífero in Minas Gerais state, these ferruginous outcrops represent 97% of the Brazil's iron reserves (Porto & Silva 1989). Flona Carajás harbors a great variety of vegetation types, from

rainforests to grasslands and savannas, presenting a mosaic associated with various types of soils, rocks, elevations, slopes and microclimates (Cleef & Silva 1994).

The vegetation and flora studies at Serra dos Carajás has begun around 1969 by researchers from the Museu Paraense Emílio Goeldi. The first floristic checklist of the region was published by Secco & Mesquita (1983). According to Viana *et al.* (2016), this work was pioneer and stimulated other floristic studies in the region, and at least five other floristics papers were published between 1986 and 1996. Still, all floristic studies carried out up to that time in Carajás region focused on angiosperms or bryophytes, and only one species of fern was cited by Silva *et al.* (1996).

The fern and lycophyte flora of Serra dos Carajás began to be investigated in 2007 when a group of researchers and collectors associated with the Laboratory of Plant Systematics and BHC B Herbarium from the Universidade Federal de Minas Gerais started to increase sampling of these plants following environmental impact studies at Flona Carajás. From 2009 on there was a considerable increment in fern and lycophyte collections with fieldwork been led by specialists, initially by Thaís Elias Almeida and André Jardim Arruda, and later in 2012 with Alexandre Salino. The largest collection effort was conducted between 2009 and 2013 and generated about 1,000 specimens that are housed at BHC B herbarium. From that collection six new species were described: two *Blechnum* (Dittrich *et al.* 2012), one *Goniopteris* (Salino *et al.* 2014), one *Selaginella* (Valdespino 2015), and two *Isoetes* (Pereira *et al.* 2016).

In 2014 a project entitled “Flora of the *canga* of the Serra dos Carajás, Pará, Brazil” started from a partnership between the Museu Paraense Emílio Goeldi (MPEG) and the Instituto Tecnológico Vale de Desenvolvimento Sustentável (ITVDS), in collaboration with the Universidade Federal de Minas Gerais. From this project, floristic treatments of 22 families of fern and lycophyte occurring at the *canga* in Carajás were published between 2016 to 2018: Aspleniaceae (Moura *et al.* 2016), Cyatheaceae (Salino & Arruda 2016a), Dennstaedtiaceae (Salino & Arruda 2016b), Dryopteridaceae (Moura & Salino 2016a), Lycopodiaceae (Salino & Arruda 2016c), Lygodiaceae (Salino & Arruda 2016d), Oleandraceae (Salino & Arruda 2016e), Pteridaceae (Moura & Salino 2016b), Schizaeaceae (Almeida 2017), Selaginellaceae (Góes-Neto *et*

al. 2016), Thelypteridaceae (Moura *et al.* 2016), Anemiaceae (Pallos *et al.* 2017a), Blechnaceae (Salino *et al.* 2017), Gleicheniaceae (Lima & Salino 2017), Hymenophyllaceae (Pallos *et al.* 2017b), Isoetaceae (Pereira *et al.* 2017), Lindsaeaceae (Pallos *et al.* 2017c), Marattiaceae (Salino & Lima 2017), Nephrolepidaceae (Viveros & Salino 2017a), Polypodiaceae (Almeida *et al.* 2017), Tectariaceae (Viveros & Salino 2017b) and Ophioglossaceae (Salino 2018). These monographs included 70 species occurring in the open vegetation formations of the tops of the hills, known as vegetation associated with *canga* (Viana *et al.* 2016). Despite the high endemism and the importance of these unique habitats in Serra dos Carajás, areas of rainforests mostly associated with slopes and mountain bases present a great variety of microhabitats and consequently a high diversity of vascular plants. For this reason, this work aims to present a complete and updated list of fern and lycophyte species occurring in all vegetation formations at the Carajás ferruginous mountains.

Materials and methods

The Carajás ferruginous mountains are located in Southeastern Pará, 550 km south of the state capital Belém. These mountains are mostly located inside the limits of Flona Carajás and Parque Nacional dos Campos Ferruginosos (Fig. 1), between the valleys of the Tocantins and Xingu rivers (Viana *et al.* 2016). Flona Carajás is in the territory of Parauapebas, Canaã dos Carajás and Água Azul do Norte municipalities (STCP 2003). Parque Nacional dos Campos Ferruginosos is in Canaã dos Carajás and Parauapebas municipalities. The ferruginous outcrops are distributed along different mountains in an extension of 120 by 60 km. The main ranges are Serra Norte, Serra Sul and part of the Serra Leste (Ab'Saber 1986). Together, these mountains represent one of the largest iron resource in Brazil, whose magnitude and economic importance is equivalent to Quadrilátero Ferrífero resource (Porto & Silva 1989). According to Álvares *et al.* (2014), the region climate is Am, presenting a warm and humid moonson tropical climate. The

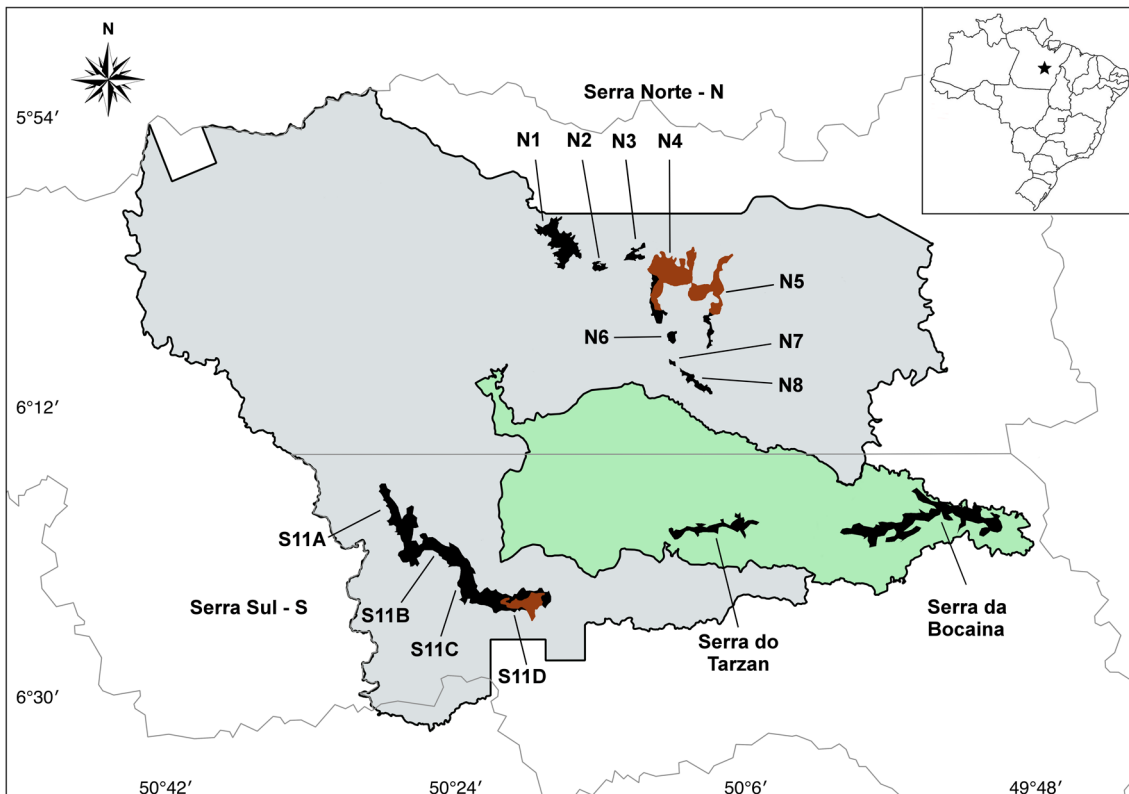


Figure 1 – Study area, indicating the canga plateaux sampled. In black, remaining canga areas; in red, suppressed canga areas (representation based on satellite image taken in December 2016, available on Google Earth). In grey, Floresta Nacional de Carajás. In green, Parque Nacional dos Campos Ferruginosos. Source: Mota *et al.* (2018).

average annual rainfall is of approximately 1600 mm, presenting a rainy season that can reach up to 1300 mm and a dry winter with average less than 320 mm, with the mean of the driest months sometimes reaching less than 60 mm (Moraes *et al.* 2005). The altitude range from 250 m in the foothills to 700 to 800 m in the flattened tops, where the open vegetation types associated with the iron outcrops stand out from the surrounding tropical forest. More detailed information on climate, relief and vegetation in Serra dos Carajás can be found in Mota *et al.* (2015) and Viana *et al.* (2016).

The species list was elaborated based on the collection from BHCb herbarium. Duplicates were sent mainly to the Carajás (HCJS) and the Museu Paraense Emílio Goeldi (MG) herbaria, and also to other herbaria in Brazil and abroad. The checklists contain only one voucher per species. We included in our survey four different ferruginous mountain ranges, of which two are located inside the Flona Carajás (Viana *et al.* 2016): i) Serra Sul (S11A, S11B, S11C, S11D), ii) Serra Norte (N1, N3, N4, N6 and N8); and two are currently included in the Parque Nacional dos Campos Ferruginosos: iii) Serra do Tarzan and iv) Serra da Bocaina (Fig. 1).

Species identification used specialized bibliographies, such as floras, taxonomic reviews, thesis, and dissertations, and as well by comparison with material already determined by specialists deposited in herbaria. When needed, materials and images were sent to specialists for confirmation and/or determination.

Results and discussion

A total of 186 species of pteridophytes were recorded for Serra dos Carajás, which places this study as one of the most representative surveys for the Brazilian Amazon. This number of species (186) corresponds to 64% of the ferns and lycophytes species recorded for Pará (289 spp.) and 34% of the fern and lycophyte flora of the Brazilian Amazon (538 spp.), making Serra dos Carajás one of the most diverse areas in Pará, and Brazilian Amazon.

The most representative families were Pteridaceae (36 spp.), Dryopteridaceae and Polypodiaceae (19 spp. each), Thelypteridaceae (18 spp.), Hymenophyllaceae (16 spp.), Aspleniaceae (13 spp.), Blechnaceae (9 spp.), and Tectariaceae (8 spp.). The expressive richness in families that are predominant in higher areas, such as Blechnaceae and Polypodiaceae, and also of families with known diversity in the Amazon

region such as Pteridaceae, Hymenophyllaceae and Selaginellaceae, corroborate the results obtained in other studies in Pará (Costa *et al.* 2006; Costa & Pietrobon 2007; Maciel *et al.* 2007; Maciel 2008; Fernandes *et al.* 2012). Among the most representative fern genera are *Adiantum* (17 spp.), *Asplenium* (12 spp.), *Trichomanes* (8 spp.), *Blechnum* (7 spp.), *Nephrolepis* (6 spp.), *Cyathea* and *Campyloneurum* (5 spp. each), *Elaphoglossum*, *Microgramma*, *Pteris*, *Triplophyllum*, and *Tectaria* (4 spp. each) (Tab. 1). The richness observed in *Adiantum* and *Trichomanes* corroborates Tryon & Tryon (1982) remarks that the flora of Brazilian Amazon is well represented by species of those genera. Surprisingly, the richness found for Thelypteridaceae (18 spp.) contrasts greatly with results presented in other studies in the Amazon that do not found this family to be among the most representative ones (*e.g.*, Costa & Pietrobon 2007; Maciel 2008; Costa *et al.* 2006b; Maciel *et al.* 2007; Zuquim *et al.* 2008).

The lycophytes are represented in the area by three families: Isoetaceae (*Isoetes*) with two species, Lycopodiaceae (*Phlegmariurus* and *Palhinhaea*) with two species, and Selaginellaceae (*Selaginella*) with seven species (Tab. 2).

Seven taxa listed here are new records for Pará (Tab. 1, 2). Three species are endemic to Serra de Carajás: *Isoetes cangae*, *Isoetes serracarajensis* and *Selaginella stomatoloma*, and *Goniopteris indusiata* is endemic to Pará.

Regarding life forms, we observed that most species are exclusively terrestrial (70 spp or 37.5%), followed by species sharing rupicolous/terrestrial habit (28 spp. or 15%), exclusively rupicolous (22 spp or 11.8%), epiphytic (18 spp. or 9.7%), and species sharing rupicolous/epiphytic habits (14 spp or 7.5%). Species exclusively hemiepiphytic or aquatic represented only 3.2% (six spp.) and 2.2% (four spp.) of total, respectively. It is also noteworthy that only 35% of the species present more than one habit (65 spp.), while most species (121 spp. or 65%) have an exclusive habit. From the non-terrestrial species with exclusive habit we highlight four aquatic species: *Isoetes cangae*, *I. serracarajensis*, *Ceratopteris pteridoides* and *C. thalictroides*; five hemiepiphytic species: *Polybotrya caudata*, *P. osmundacea*, *Lomariopsis japurensis*, *L. nigropaleata* and *L. prieuriana*; and one climbing species: *Lygodium venustum*.

The low percentage of exclusively epiphytic species found in Carajás (18 spp. or 10%) may be related to the marked presence of savanna

Table 1 – List of families and species of ferns occurring in the ferruginous mountains of Carajás, State of Pará, Brazil, with indication of environments and mountain ranges, life forms and vouchers. Subtitles: Habitat: DRF (dense rainforest); OF (open field); ORF (open rainforest); RV (rock vegetation), SF (swampy field); SFC (seasonal forest on canga). Life form: TE (Terrestrial); EP (Epiphytic); RU (Rupicolous); HE (Hemiepiphytic); AQ (Aquatic). (▲) = new species, (■) = new records for Pará, (✱) = species occurring in the *canga* of Carajás, (◆) = species occurring in the Quadrilátero Ferrífero (MG), (✚) = species occurring in the Maço do Urucum (MS).

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
ANEMIAEAE							
<i>Anemia elegans</i> (Gardner) C. Presl ✱ ◆	DRF			S11D		RU	Costa 815
<i>Anemia oblongifolia</i> (Cav.) Sw. ✱ ◆	SFC			S11A,C,D		RU	Salino 15567
<i>Anemia phyllitidis</i> (L.) Sw. ✱ ◆	SFC/ORF			S11C,D		RU/TE	Viana 4133
ASPLENIACEAE							
<i>Asplenium abscissum</i> Willd. ✱ ■ ◆	DRF		N3	S11A		RU	Salino 15238
<i>Asplenium cristatum</i> Lam. ◆	DRF			S11C		TE	Almeida 2248
<i>Asplenium cruegeri</i> Hieron.	DRF	X	N1	S11C,D	X	RU/TE	Almeida 2349
<i>Asplenium formosum</i> Willd. ✱ ◆ ◆	SFC/ORF	X	N3,4	S11A,C,D	X	RU	Almeida 2172
<i>Asplenium hostmanii</i> Hieron.	DRF		N4,6	S11A,C,D		RU	Salino 15228
<i>Asplenium juglandifolium</i> Lam.	DRF		N1				Paula 528
<i>Asplenium otites</i> Link ■ ◆ ◆	DRF			S11D		TE	Almeida 2215
<i>Asplenium poloense</i> Rosenst.	DRF	X		S11A,B,D		RU/TE	Almeida 2181
<i>Asplenium praemosum</i> Sw. ■ ◆	DRF	X		S11A,B,D		EP/RU	Mota 1954
<i>Asplenium salicifolium</i> L. ✱	SFC/ORF		N6,8	S11A,C,D		EP/RU	Salino 15229
<i>Asplenium serratum</i> L. ✱ ◆	SFC/ORF/DRF		N4	S11A,C,D	X	EP/RU	Arruda 579
<i>Asplenium stuebelianum</i> Hieron. ✱ ◆	SFC/ORF	X		S11A,B,D		RU	Arruda 222
<i>Hymenasplenium delitescens</i> (Maxon) L. Regalado & Prada	DRF			S11D		TE	Almeida 2347
ATHYRIACEAE							
<i>Diplazium cristatum</i> (Desr.) Alston ◆ ✱	DRF		N1	S11D		TE	Almeida 2206

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
BLECHNACEAE							
<i>Blechnum areolatum</i> V.A.O. Dittrich & Salino ▲*	SFC/ORF	X	N8	S11B,D		RU	Almeida 2255
<i>Blechnum asplenoides</i> Sw. ♦	DRF			S11D		RU	Viana 4347
<i>Blechnum heringeri</i> Brade *	SFC/ORF	X			X	RU/TE	Mota 1921
<i>Blechnum lanceola</i> Sw. ▽	DRF			S11A,D		RU	Salino 15504
<i>Blechnum longipilosum</i> V.A.O. Dittrich & Salino ▲*	SFC/ORF	X	N1,6	S11C,D		RU	Viana 4148
<i>Blechnum occidentale</i> L. * ♦ ♦	SFC/ORF		N1,6	S11C,D		TE	Salino 15237
<i>Blechnum polypodioides</i> Raddi * ♦ ♦	SFC/ORF	X	N1,6	S11B,C,D		RU	Almeida 2165
<i>Neoblechnum brasiliense</i> (Desv.) Gasper & V.A.O. Dittrich * ♦ ♦	SFC/ORF			S11C,D		TE	Almeida 2525
<i>Telmatoblechnum serrulatum</i> (Rich.) Perrie, D.J.Ohlsen & Brownsey * ♦	SF		N1	S11A,D		TE	Arruda 348
CYATHEACEAE							
<i>Alsophila cuspidata</i> (Kunze) D.S. Conant	DRF	X		S11D		TE	Almeida 2350
<i>Cyathea delgadii</i> Sternb. ♦ ♦	DRF			S11C		TE	Viana 4141
<i>Cyathea macrosoara</i> (Baker ex Thurm) Domin var. <i>reginae</i> (P.G. Windisch) A.R. Sm.	DRF			S11A,B,D		TE	Almeida 2351
<i>Cyathea microdonia</i> (Desv.) Domin ♦ ♦	DRF			S11D		TE	Arruda 349
<i>Cyathea pungens</i> (Raddi) Domin *	ORF/DRF	X		S11A,B,C,D		TE	Salino 15498
<i>Cyathea spectabilis</i> (Raddi) Domin var. <i>spectabilis</i>	DRF		N1	S11D		TE	Salino 15499
DENNSTAEDIACEAE							
<i>Hypolepis repens</i> (L.) C. Presl †	DRF		N1	S11A		TE	Arruda 623
<i>Pteridium arachnoideum</i> (Kaulf.) Maxon * ♦ ♦	ORF	X		S11	X	TE	Salino 15954
DRYOPTERIDACEAE							
<i>Bolbitis semipinnatifida</i> (Fée) Alston	DRF			S11A,B		RU/TE	Almeida 2424

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Bolbitis serratifolia</i> (Mert. ex Kaulf.) Schott +	DRF		N4	S11A,B,C,D		EP/RU/TE	Salino 15304
<i>Ctenitis nigrovenia</i> (H. Christ) Copel. *	SFC/ORF		N4	S11A,C	X	RU/TE	Salino 15512
<i>Ctenitis refulgens</i> (Klotzsch ex Mett.) C. Chr.	DRF		N3,4,6	S11A,C,D		TE	Salino 15211
<i>Cyclodium guianense</i> (Klotzsch) van der Werff ex L.D. Gómez	DRF	X	N1,6	S11A,B,C,D		TE	Arruda 485
<i>Cyclodium inerme</i> (Fée) A. R. Sm.	DRF	X	N1,4,6	S11A,B		TE	Arruda 1134
<i>Cyclodium meniscioides</i> (Willd.) C. Presl var. <i>meniscioides</i>	DRF		N3,4,6	S11A,C		HE/TE/RU	Almeida 2433
<i>Dryopteris huberi</i> (Christ) C. Chr. * +	SFC/ORF/DRF			S11A,C,D	X	RU	Arruda 586
<i>Elaphoglossum flaccidum</i> (Fée) T. Moore	DRF		N1	S11A,D		EP	Salino 15268
<i>Elaphoglossum glabellum</i> J. Sm. * +	SFC/ORF			S11D		EP	Viana 4115
<i>Elaphoglossum luridum</i> (Fée) H. Christ +	DRF			S11A,C,D		EP/RU	Almeida 2500
<i>Elaphoglossum minutum</i> (Pohl ex Fée) T. Moore	DRF			S11D		EP	Almeida 2265
<i>Parapolystichum effusum</i> (Sw.) Ching +	DRF	X	N1	S11A,C,D		TE	Salino 15244
<i>Mickelia guianensis</i> (Aubl.) R.C. Moran et al.	DRF		N1,3	S11A,C,D		HE/TE	Arruda 227
<i>Mickelia nicotianifolia</i> (Sw.) R. C. Moran et al.	DRF		N1,4	S11D		HE/TE	Salino 15190
<i>Olfersia cervina</i> (L.) Kunze +	DRF		N1	S11A		HE	Arruda 549
<i>Polybotrya caudata</i> Kunze	ORF		N1	S11D		HE	Arruda 622
<i>Polybotrya osmundacea</i> HuSFC. & Bonpl ex Willd.	DRF			S11A		HE	Almeida 2436
<i>Polybotrya sorbifolia</i> Mett. ex Kuhn *	DRF	X	N1	S11A,B,D		HE/TE	Arruda 1151
GLEICHENIACEAE							
<i>Dicranopteris flexuosa</i> (Schrad.) Underw. * + +	SFC		X			TE	Cavalcante 2155 (MG)
<i>Gleichenella pectinata</i> (Willd.) Ching * +	ORF		N1	S11D		TE	Almeida 2276
HYMENOPHYLLACEAE							
<i>Abrodictyum rigidum</i> (Sw.) Ebihara & Dubuisson +	DRF		N1			RU	Paula 527

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Didymoglossum ekmannii</i> (Wess. Boer) Ebihara & Dubuisson	DRF		N1			EP	Salino 15131
<i>Didymoglossum kappelerianum</i> (Sturm) Ebihara & Dubuisson	DRF	X	N4	S11A,B		RU	Salino 15254
<i>Didymoglossum kraussii</i> (Hook. & Grev.) C. Presl *	DRF			S11D		EP	Viana 4112
<i>Didymoglossum ovale</i> E. Fourn.	DRF			S11D		RU	Almeida 2466
<i>Hymenophyllum polyanthos</i> (Sw.) Sw. *	DRF			S11B		EP/RU	Arruda 1183
<i>Polyphlebium diaphanum</i> (Kunth) Ebihara & Dubuisson *	DRF		N1			EP	Arruda 619
<i>Trichomanes accedens</i> C. Presl *	DRF			S11D		EP/RU/TE	Arruda 464
<i>Trichomanes ankersii</i> C. Parker ex Hook. & Grev.	DRF			S11A		EP	Almeida 2439
<i>Trichomanes crispum</i> L. *	SFC/ORF/DRF			S11D		EP/RU	Viana 4346
<i>Trichomanes elegans</i> Rich. * *	DRF		N1,4	S11A		TE	Almeida 2185
<i>Trichomanes hostmannianum</i> (Klotzsch) Kunze	DRF		N1,6	S11D		RU	Salino 15281
<i>Trichomanes pedicellatum</i> Desv.	DRF		N1			HE/RU	Paula 529
<i>Trichomanes pinnatum</i> Hedw. * *	SFC/ORF	X	N6	X		RU/TE	Arruda 870
<i>Trichomanes vittaria</i> DC. ex Poir.	DRF		N4			TE	Arruda 990
<i>Vandenboschia radicans</i> (Sw.) Copel. * *	DRF		N1	S11D	X	RU/TE	Almeida 2361
LINDSAEACEAE							
<i>Lindsaea divaricata</i> Klotzsch	ORF			S11D		RU/TE	Arruda 350
<i>Lindsaea guianensis</i> (Aubl.) Dryand. ssp. Guianensis *	ORF			S11A		TE	Almeida 2442
<i>Lindsaea lancea</i> (L.) Bedd. var. <i>lancea</i> * *	SF/ORF		N1,4	S11B,D		TE	Arruda 484
<i>Lindsaea pallida</i> Klotzsch	ORF	X	N1			RU/TE	Arruda 554
LOMARIOPSIDACEAE							
<i>Cyclopetis semicordata</i> (Sw.) J. Sm.	DRF			S11B,D	X	TE	Arruda 1326

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Lomariopsis japurensis</i> (Mart.) J. Sm.	DRF		NI	S11A,D		HE	Salino 15250
<i>Lomariopsis nigropaleata</i> Holttum *	DRF		NI		X	HE	Salino 15197
<i>Lomariopsis prieuriana</i> Fée	DRF		N4	S11C		HE	Almeida 2339
LYGODIACEAE							
<i>Lygodium venustum</i> Sw. * + *	ORF	X		S11D		TP	Almeida 2278
MARATTIACEAE							
<i>Danaea cartilaginea</i> Christenh. & Tuomisto *	DRF		NI	S11D		TE	Salino 15240
<i>Danaea lepreurii</i> Kunze *	DRF	X		S11A,C		TE	Arruda 1142
METAXYACEAE							
<i>Metaxya parkeri</i> (Hook. & Grev.) J. Sm.	DRF		NI,6	S11B,C		TE	Salino 15232
NEPHROLEPIDACEAE							
<i>Nephrolepis biserrata</i> (Sw.) Schott	ORF			S11C,D		EP/TE	Almeida 2218
<i>Nephrolepis brownii</i> (Desv.) Hovenkamp & Miyam. *	SFC/DRF	X	NI			TE/EP	Arruda 1246
<i>Nephrolepis hirsutula</i> (G. Forst.) C. Presl *	OF/ORF	X	NI			RU/EP/TE	Arruda 1251
<i>Nephrolepis pectinata</i> (Willd.) Schott * + *	SFC/DRF	X				RU/EP/TE	Mota 2022
<i>Nephrolepis rivularis</i> (Vahl) Mett. ex Krug	SF/ORF			S11A,D		EP/TE	Almeida 2440
<i>Nephrolepis undulata</i> (Afzel. ex Sw.) J. Sm. *	SFC/ORF			S11A,B,C		RU/TE	Arruda 1107
OLEANDRACEAE							
<i>Oleandra pilosa</i> Hook. *	SFC/ORF			S11A,C,D		EP/RU	Arruda 468
OPHIOGLOSSACEAE							
<i>Ophioglossum nudicaule</i> L. *	SF	X				TE	Mota 1909
POLYPODIACEAE							
<i>Campyloneurum abruptum</i> (Lindm.) B. Leon	DRF			S11C,D		EP/TE	Almeida 2335
<i>Campyloneurum angustifolium</i> (Sw.) Fée	DRF			S11A		EP	Almeida 2195
<i>Campyloneurum centrobrasiliatum</i> Lellinger * + *	SFC			S11D		EP	Almeida 2254

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Campyloneurum phyllitidis</i> (L.) C. Presl *+*	SFC/ORF/DRF			S11A,C,D		EP/RU	Salino 15152
<i>Campyloneurum repens</i> (Aubl.) C. Presl	DRF		N1,4	S11D		EP	Arruda 1149
<i>Microgramma dictyophylla</i> (Kunze ex Mett.) de la Sota	DRF		N1,4	S11B,C		EP	Almeida 2230
<i>Microgramma lycopodioides</i> (L.) Copel *	SFC/ORF	X	N1,4	S11A,C		EP	Arruda 833
<i>Microgramma percussa</i> (Cav.) de la Sota *	DRF			S11A,B,C		EP/TE	Almeida 2242
<i>Microgramma persicariifolia</i> (Schrad.) C. Presl *	SFC/ORF	X	N4	S11A,B,D		EP/TE	Salino 15150
<i>Niphidium crassifolium</i> (L.) Lellinger *	DRF		X			EP	Salino 15141
<i>Pectuma hygrometrica</i> (Splitg.) M.G. Price	DRF			S11B,C		EP	Salino 15589
<i>Pectuma plumula</i> (Willd.) M.G. Price *+*	SFC			S11A		EP/RU	Almeida 2495
<i>Phlebodium decumanum</i> (Willd.) J. Sm. *+*	ORF	X	N8	S11C,D		EP/RU	Arruda 526
<i>Pleopeltis astrolepis</i> (Liebm.) E. Fourn. *+*	DRF	X		S11A,D		EP/RU	Almeida 2216
<i>Pleopeltis desvauxii</i> (Klotzsch) Salino	DRF		N1	S11A,B,C,D		EP/RU/TE	Arruda 1228
<i>Pleopeltis polypodioides</i> var. <i>burchelli</i> (Baker) A. R. Sm. *	RV/SFC/ORF	X	N4,8	S11B,C,D		EP/RU/TE	Salino 15571
<i>Polypodium flagellare</i> Christ	DRF			S11C		EP	Almeida 2219
<i>Serpocaulon attenuatum</i> (C. Presl) A.R. Sm. *	RV/SFC/ORF		N4	S11C,D	X	EP/RU/TE	Salino 15149
<i>Serpocaulon richardii</i> (Klotzsch) A.R. Sm.	DRF		N1	S11A,B		EP/RU	Arruda 545
PTERIDACEAE							
<i>Acrostichum danaeifolium</i> Langsd. & Fisch.	SF			S11D		TE	Almeida 2318
<i>Adiantopsis radiata</i> (L.) Fée *+*	SFC/ORF/DRF	X		S11A,B,C,D	X	RU/TE	Arruda 605
<i>Adiantum adiantoides</i> (J. Sm.) C. Chr.	DRF		N1			TE	Salino 15196
<i>Adiantum argutum</i> Splitg.	DRF			S11A,D	X	TE	Almeida 2340
<i>Adiantum cajennense</i> Willd. ex Klotzsch	DRF		N4	S11B,C,D		TE	Arruda 1133
<i>Adiantum cinnamomeum</i> Lellinger & J. Prado	DRF		N1,8			TE	Salino 15140
<i>Adiantum deflectens</i> Mart. *+*+*	SFC/ORF/DRF	X		S11D		RU/TE	Mota 2010

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Adiantum dolosum</i> Kunze	DRF		N4			TE	Salino 15221
<i>Adiantum glaucescens</i> Klotzsch *	DRF	X	N1,8	X		TE	Arruda 1146
<i>Adiantum humile</i> Kunze	DRF				X	TE	Viana 4069
<i>Adiantum lucidum</i> (Cav.) Sw.	DRF	X	N4	S11A,C		TE	Almeida 2227
<i>Adiantum nudum</i> A.R. Sm.	DRF			S11D		RU	Almeida 2353
<i>Adiantum obliquum</i> Willd.	DRF		N1,8	S11A,B,D		RU/TE	Arruda 552
<i>Adiantum pectinatum</i> Kunze ex Baker	DRF			S11A,C		TE	Almeida 2197
<i>Adiantum petiolatum</i> Desv.	DRF	X	N4			TE	Arruda 1403
<i>Adiantum puberulentum</i> L.	DRF		N1	S11D		TE	Arruda 617
<i>Adiantum terminatum</i> Kunze ex Miq.	DRF	X	N1	S11A		TE	Salino 15280
<i>Adiantum tetraphyllum</i> Willd.	DRF		N4	S11A		TE	Salino 15216
<i>Adiantum villosum</i> L.	DRF				X	TE	Mota 1211
<i>Ananthacorus angustifolius</i> (Sw.) Underw. & Maxon *	SFC/ORF/DRF			S11B,C,D		EP	Almeida 2222
<i>Ceratopteris pteridoides</i> (Hook.) Hieron.	DRF			S11D		AQ	Almeida 2358
<i>Ceratopteris thalictroides</i> (L.) Brogn. *	RV/SF	X				AQ	Mota 2578
<i>Doryopteris collina</i> (Raddi) J. Sm. * ■ * * *	RV/SFC			S11D	X	RU	Arruda 776
<i>Doryopteris varians</i> (Raddi) J. Sm. *	SFC/ORF			S11D		RU/TE	Arruda 456
<i>Hemionitis palmata</i> L.	SFC/ORF		N4,8	S11A,D	X	RU/TE	Arruda 228
<i>Hemionitis rufa</i> (L.) Sw.	DRF			S11D	X	EP/RU	Arruda 1315
<i>Hemionitis tomentosa</i> (Lam.) Raddi * ■ * * *	SFC			S11D		RU	Giorni 361
<i>Lytoneuron ornithopus</i> (Hook & Baker) J.C. Yesilyurt * *	RV/SFC		N3	S11C,D		RU/TE	Almeida 2410
<i>Pityrogramma calomelanos</i> (L.) Link * * * *	OF/SF		N1	S11D		TE	Arruda 1248
<i>Polytaenium citrifolium</i> (L.) Schuettp.	DRF			S11D		EP	Viana 4386
<i>Polytaenium guayanense</i> (Hieron.) Alston	DRF			S11D		EP/RU	Almeida 2262

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Pteris bicaurita</i> L.	ORF	X		S11D		TE	Arruda 524
<i>Pteris denticulata</i> Sw. var. <i>denticulata</i> ♦♦	DRF		N4	S11A	X	RU/TE	Arruda 590
<i>Pteris pungens</i> (Willd.) Domin	DRF		N1	S11B,D	X	RU/TE	Paula 547
<i>Pteris quadriaurita</i> Retz. ♦♦	DRF	X			X	TE	Arruda 593
<i>Vittaria lineata</i> (L.) J. Sm. ♦♦♦	SFC/ORF/DRF			S11A,D		EP	Arruda 1164
SACCOLOMATACEAE							
<i>Saccoloma chartaceum</i> G.B. Nair	DRF		N1,8	S11A,B,C		TE	Almeida 2217
<i>Saccoloma inaequale</i> (Kunze) Mett. ♦	DRF		N1			RU/TE	Salino 15132
SCHIZAEACEAE							
<i>Actinostachys subtrijuga</i> (Mart.) C. Presl *	SF			S11C		TE	Viana 4134
TECTARIACEAE							
<i>Tectaria heracleifolia</i> (Willd.) Underw. *	DRF			S11C,D	X	RU/TE	Almeida 2246
<i>Tectaria incisa</i> Cav. ♦♦	DRF	X	N1			RU/TE	Arruda 580
<i>Tectaria lepreurii</i> (Mett. ex Diels) C. Chr.	DRF		N1	X		RU/TE	Salino 15500
<i>Tectaria trinitensis</i> Maxon	DRF				X	TE	Arruda 588
<i>Triplophyllum dicksonioides</i> (Fée) Holttum	DRF		N1,8			TE	Salino 15209
<i>Triplophyllum funestum</i> (Kunze) Holttum	DRF	X	N6	S11A	X	RU/TE	Arruda 1398
<i>Triplophyllum glabrum</i> J. Prado & R.C. Moran *	DRF		N6	S11A,B,D		RU/TE	Salino 15224
<i>Triplophyllum hirsutum</i> (Holttum) J. Prado	DRF		N1			TE	Arruda 550
THELYPTERIDACEAE							
<i>Christella conspersa</i> (Schnrad.) Á. Löve & D. Löve ♦♦	DRF		N1	S11D		TE	Almeida 2478
<i>Christella hispidula</i> (Decne.) Holttum ♦♦♦	DRF	X		S11C,D	X	TE	Almeida 2342
<i>Christella patens</i> (Sw.) Pic.Serm. ♦	DRF		N1	S11D		TE	Arruda 1273
<i>Cyclosorus interruptus</i> (Willd.) H. Ito ♦♦	OF/SF/ORF	X	N1	S11B		TE	Arruda 582
<i>Goniopteris abrupta</i> (Desv.) A.R. Sm. *	DRF			X	X	TE	Salino 15161

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
<i>Goniopteris amazonica</i> (Salino & R.S. Fernandes) Salino & T.E. Almeida	DRF		NI		X	TE	Salino 15246
<i>Goniopteris biformata</i> (Rosenst.) Salino & T.E. Almeida	DRF			S11D		TE	Almeida 2537
<i>Goniopteris biolleyi</i> (Christ) Brade	DRF		NI	S11D	X	TE	Almeida 2371
<i>Goniopteris indusiata</i> (Salino) Salino & T.E. Almeida ▲	DRF		NI	S11D	X	TE	Salino 15156
<i>Goniopteris pennata</i> (Poir.) Pic.Serm. *	DRF			S11A	X	TE	Almeida 2200
<i>Goniopteris poiteana</i> (Bory) Ching	ORF				X	TE	Salino 15573
<i>Goniopteris tetragona</i> (Sw.) C. Presl *	DRF			S11D	X	TE	Almeida 2363
<i>Goniopteris tristis</i> (Kunze) Brade *	DRF		NI		X	TE	Arruda 1313
<i>Macrothypteris torresiana</i> (Gaudich.) Ching ♦ ♦	ORF				X	TE	Paula 539
<i>Meniscium chrysodioides</i> Fée ♦	DRF		NI,4	S11A,C		TE	Salino 15191
<i>Meniscium maxonianum</i> (A.R. Sm.) R.S. Fernandes & Salino ♦ ♦	SF/ORF		N4,8	X		TE	Arruda 963
<i>Meniscium nesioiticum</i> (Maxon & C.V. Morton) Pic.Serm.	DRF			X		TE	Salino 15584
<i>Meniscium serratum</i> Cav. ♦	DRF			S11D		TE	Almeida 2359

Table 2 – List of families and species of lycophytes occurring in the ferruginous mountains of Carajás, state of Pará, Brazil, with indication of environments and mountain ranges, life forms and vouchers. Subtitles: Habitat: DRF (dense rainforest); OF (open field); ORF (open rainforest); PP (permanent pond); RV (rock vegetation), SF (swampy field); SFC (seasonal forest on canga). Life form: TE (Terrestrial); EP (Epiphytic); RU (Rupicolous); HE (Hemiepiphytic); AQ (Aquatic). (▲) = new species, (■) = new records for Pará, (*) = species occurring in the *canga* of Carajás, (◆) = species occurring in the Quadrilátero Ferrífero (MG), (⊕) = species occurring in the Maçico do Urucum (MS).

Family/Species	Habitat	Serra da Bocaina	Serra Norte	Serra Sul	Serra do Tarzan	Life forms	Voucher
ISOETACEAE							
<i>Isoetes cangae</i>							
J.B.S. Pereira, Salino & Stützel ▲ *	SF			S11D		AQ	Arruda 1329
<i>Isoetes serracarajensis</i>							
J.B.S. Pereira, Salino & Stützel ▲ *	PP	X	N3,4,6,7	S11B	X	AQ	Almeida 2157
LYCOPODIACEAE							
<i>Palhinhaea cernua</i>							
(L.) Vasc. & Franco * ◆ ⊕	SF/DRF		N1	S11B		TE	Arruda 212
<i>Phlegmariurus dichotomus</i>							
(Jacq.) W.H. Wagner	DRF		N1	S11A,D		EP	Salino 15142
SELAGINELLACEAE							
<i>Selaginella flagellata</i> Spring							
	SFC/DRF		N4	S11D		RU/TE	Arruda 500
<i>Selaginella producta</i> Baker							
	DRF			X		RU	Arruda 865
<i>Selaginella radiata</i>							
(Aubl.) Spring *	RV/SFC/DRF		N2,3,4	S11A,D	X	RU	Salino 15206
<i>Selaginella simplex</i>							
Baker *	OF/SFC/DRF			S11A,C,D		RU/TE	Salino 15256
<i>Selaginella sulcata</i>							
(Desv. ex Poir.) Spring ex Mart.	DRF		N1	S11A,C,D		RU/TE	Almeida 2187
<i>Selaginella stomatoloma</i>							
Valdespino ▲	DRF			S11D		RU	Almeida 2518
<i>Selaginella tenella</i>							
(P. Beauv.) Spring	DRF		N4	S11D		RU	Salino 15214

and grassland formations, which start at 600 m altitude and occupy most of the higher parts of the mountains, thus not favoring the epiphytism due to low density of tree hosts. In addition, a possible predominance of epiphytes that are restricted to the forest canopy, which is generally inaccessible and difficult to observe, may have directly influenced the reduced number of epiphytes recorded.

Regarding the vegetation types, we observed that most species (130 spp. or 70%) were found

exclusively in forest environments. From the 130 species that occurs exclusively in forest environments, 88.5% (115 spp.) occur exclusively in Dense Ombrophilous Forest, followed by 13 (10 %) occurring in Open Ombrophylous Forest. Four species are exclusive from seasonal forest *canga* on the hilltops: *Anemia oblongifolia*, *Campyloneurum centrobrasillianum*, *Pecluma plumula*, and *Hemionitis tomentosa*. Only 13 species (7%) are unique to non-forest environments.

In addition, three species are exclusive of swampy fields: *Telmatoblechnum serrulatum*, *Acrostichum danaeifolium*, and *Actinostachys subtrijuga*. We also found two species growing exclusively in ponds: *Isoetes cangae* and *Isoetes serracarajensis*, which occurs exclusively in permanent and temporary ponds, respectively.

The occurrence of ferns and lycophytes in Carajás was not uniform. From the 186 recorded species, 153 (82%) occurred at Serra Sul, of which 60 species (32%) recorded only exclusive at this mountain range, followed by 99 species (53%) recorded in Serra Norte, with 16 exclusive species (8.5%); 44 species (23%) recorded in Serra da Bocaina, with only three exclusive species (1.5%); and 37 species (20%) in Serra do Tarzan, with only five exclusive species (2.5%). These values may be biased due to an unbalanced sample effort in these mountains, with bigger sampling effort at Serra Sul and Serra Norte. In Serra do Tarzan, for example, the sampling effort was not exhaustive due to difficulties accessing the most preserved areas. In addition, the mountain ranges differed as to their conservation status. During the sampling period, Serra Sul presented more preserved vegetation formations than Serra da Bocaina that was at the time outside the limits of a protected area and showed bigger anthropic influence in its vegetation.

Along with the mountain ranges of Serra dos Carajás, two other regions in Brazil stand out as the most relevant mountain formations with ferruginous substrate: Quadrilátero Ferrífero (QF) in Minas Gerais state and Maciço do Urucum (MU) in Mato Grosso do Sul state. Salino & Almeida (2008) recorded the occurrence of 380 species of ferns and lycophytes in QF and Assis (2007) recorded 83 species in the MU. From the 186 species recorded in the Carajás region, 65 (35%) also occur in QF and 32 (17%) in MU (Tab. 1, 2).

The surveys and studies focusing on ferns and lycophytes from Serra dos Carajás over the last 12 years revealed a high diversity of species and yielded the discovery of six new species, three ferns (Dittrich *et al.* 2012; Salino *et al.* 2014) and three lycophytes (Valdespino 2015; Pereira *et al.* 2016), as well as three new records for Brazil (Almeida & Salino 2015) and seven new records for Pará state. The knowledge about ferns and lycophytes from Serra dos Carajás contributed to the increase of 31 species known to Pará state. These data reinforce the importance of floristic studies as tools to support and direct conservation policies and emphasize the importance of preserving

ecosystems associated with ferruginous outcrops, not only in the Amazon. Additionally, the high number of taxa and new records for Pará reinforces the existence of collection gaps not only in the state but mainly in the Amazon region (Almeida & Salino 2016).

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