

Epiphytic microlichens as indicators of phytosociological differentiation between Caatinga and Brejos de Altitude

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ABSTRACT

The present study tested the hypothesis that species richness and composition of epiphytic microlichens can be used to support the phytosociological differentiation between Caatinga and Brejos de Altitude, as exemplified by the Muralha Reserve (Caatinga) and the Parque Estadual Mata do Pau Ferro (Brejo de Altitude), in the state of Paraíba, Brazil. A total of 755 lichen samples were collected, comprising 18 families, 42 genera and 111 species of epiphytic, corticolous microlichens. Overall species richness was higher in the Caatinga, with 67 species, compared to the Brejo, with 46 species. Species richness per sample was significantly higher in the Caatinga compared to the Brejo. Taxonomic composition also differed significantly between the two areas, with *Arthoniaceae*, *Caliciaceae*, *Chrysothricaceae*, *Graphidaceae* (particularly *Graphis*), *Lecanoraceae*, *Mycoporaceae*, *Pertusariaceae*, and *Trypetheliaceae* being dominant in, or exclusive to, the Caatinga, whereas *Coenogoniaceae*, *Graphidaceae* (*Diorygma*, *Fissurina*, *Myriotrema*, *Ocellularia*, *Phaeographis*, *Sarcographa*), *Malmideaceae*, *Porinaceae* and *Strigulaceae* were dominant in, or exclusive to, the Brejo. Five new species were discovered as result of this study. This is the first study to quantitatively compare richness and community patterns of epiphytic microlichens between two major biomes in Northeastern Brazil, and the first detailed lichen study in the state of Paraíba.

Keywords: corticolous microlichens, Mata Pau-Ferro, Reserva Muralha, species composition, species richness

Introduction

Lichens are symbiotic associations between a fungus and one or more species of algae or cyanobacteria (Nash III 2008). Among the fungi involved in this association, *circa* 99% are members of the Ascomycota, while the remaining species belong to the Basidiomycota (Webster & Weber 2007). Lichenization is a successful evolutionary strategy that has resulted in a rich diversity of fungal species (Grube & Kroken 2000). Due to peculiar morphological and ecophysiological characteristics which are a result of the symbiotic relation, lichenized fungi are found almost in all terrestrial ecosystems (Umaña & Sipman 2002; Lakatos *et al* 2006), in nearly all habitats from the tropics to the Polar Regions (Nash III 2008), in environments where they would be unable to live if non-lichenized (Chaparro & Ceballos 2002).

Lichenized fungi constitute a significant portion of forest biodiversity worldwide (DeBolt *et al.* 2007; Feuerer & Hawksworth 2007; Lücking *et al.* 2009), but accurate knowl-

edge of lichen diversity is limited, especially in the tropics (Cáceres 2007). Lichens can be saxicolous, i.e. growing on rocks, terricolous, i.e. on soil, muscicolous or hepaticolous on bryophytes, foliicolous on the surface of living leaves, and corticolous on the bark of trees, which is the majority of epiphytic species. Substrate features and abiotic factors have been shown to influence the distribution and occurrence of lichen species (Purvis 2000; Aptroot & Herk 2007; Dyer & Letourneau 2007; Kärfer *et al.* 2007; 2010; 2015; Bunnell *et al.* 2008; Mezaka *et al.* 2008; Morales *et al.* 2009).

Ecological studies on lichens in northeastern Brazil have been undertaken, first with foliicolous (Cáceres *et al.* 2000), and then corticolous microlichens (Cáceres *et al.* 2007; 2008a; b; Cavalcante 2012; Rodrigues 2012). These works focused mostly on the comparison between different vegetation types at the landscape scale but also analyzed biotic and abiotic features in relation to lichen species richness and composition within a given habitat.

The so-called Brejos de Altitude are Atlantic Forest enclaves in the semiarid region of northeastern Brazil, sur-

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rounded by Caatinga areas, which represent a much drier, seasonal vegetation. Brejos de Altitude are thus islands of montane forest, with altitudes ranging from 600 to 1000 m (Andrade-Lima 1966; Andrade *et al.* 2006). The Brazilian Northeast Region comprises approximately 40 areas of Brejos de Altitude, distributed in the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco (Tabarelli & Santos 2004).

The Caatinga is a seasonally dry forest that covers most of the states of Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia and the northeastern part of Minas Gerais in the Jequitinhonha Valley (Leal *et al.* 2005). Caatinga is a xerophytic vegetation characterized by spiny wooden plants succulents, which are able to resist long periods of drought. The Caatinga lies in a semiarid region; its vegetation lacks the green lushness of tropical rainforests (Leal *et al.* 2005), but it is possible to find high rates of endemism since many species are highly adapted to this biome (Abilio *et al.* 2010).

While Caatinga and Brejos are geographically close and adjacent, their floristic composition is quite different, owing to the different ecological conditions. This has also been shown for lichens at the landscape scale (Cáceres *et al.* 2008), but never been tested using quantitative sampling. The present work thus aimed to analyze the diversity of corticolous lichens in two vegetation types, Caatinga and Brejo de Altitude, in the state of Paraíba, comparing species richness and composition and testing the hypothesis that, using these two variables, lichens can be used as indicators of phytosociological differences between the two biomes.

Material and methods

Lichen specimens were sampled in July 2012 in two areas of Brejo de Altitude and Caatinga in the state of Paraíba, Brazil. The Brejo de Altitude was represented the Mata do Pau Ferro State Park (06°58'S and 35°42'W), with an area of *circa* 600 ha and an altitude between 400 and 600 m, located 5 km West of the municipality of Areia (Barbosa *et al.* 2005; Andrade *et al.* 2006). The vegetation of this park presents itself as a mosaic formed by forest fragments in various stages of ecological succession (Oliveira *et al.* 2006). The Caatinga area was located in the Muralha Reserve (06°36'S and 36°12'W), with a total of 300 ha and an altitude of *circa* 500 m, located in the municipality of Cuité.

The sampling method was adapted from Cáceres *et al.* (2007), according to which five 100 m long parallel transects were delimited in each locality, and each transect was placed 25 m apart from one another. Along each transect a sampling point was marked every 10 m, totaling 50 points for each studied area. At each point, the nearest tree with lichen cover was selected and the lichen thalli were sampled. This way, each tree was considered a sample unit.

Small pieces lichen thalli for determination were removed from the tree trunk using knife and hammer. The

samples were immediately stored in paper envelopes, in which the name of the site, date, transect and point number were recorded. Identification and descriptive work was carried out in Itabaiana, Universidade Federal de Sergipe, using a Leica EZ4 stereomicroscope and a Leica DM500 compound microscope, and also in Soest using an Olympus SZX7 stereomicroscope and an Olympus BX50 compound microscope with interference contrast, connected to a Nikon Coolpix digital camera. Sections have been mounted in tapwater, in which all measurements were taken, and also the reaction of ascospores to IKI (Lugol solution) has been observed. The specimens are preserved in the ISE Herbarium (Universidade Federal de Sergipe, university campus Prof. Alberto Carvalho). Chemistry was investigated by spot reactions (KOH 10%), underlong-wave UV light, and thin-layer chromatography (TLC) using solvent A (Orange *et al.* 2001).

Generalized linear models (GLM's; Gotelli & Ellison 2011) were used to compare the species richness between both areas. Analyses were performed using the software R (R Development CoreTeam 2008 Version 2.14.2). Minimal models were obtained by removal of non-significant variables ($p > 0.05$) (Crawley 2007).

To study the species composition between areas and samples, the degree of similarity was measured with the Sørensen Similarity Index (Sørensen 1948), which states: $S = 2X_{\text{comum}} / (n_a + n_b)$, where S = similarity index; n_{comum} = number of species in common between the two studied localities, "a" (Brejo de Altitude) and "b" (Caatinga) (or two given samples); n_a = total number of species in the locality "a"; n_b = total number of species in locality "b". Thus, the index ranges from 0 (maximum difference) and 1 (maximum similarity).

Furthermore, sample similarity with regard to vegetation type was analyzed using clustering (Cáceres *et al.* 2008a), with Sørensen as distance measure, using PC-ORD 5.33 (McCune & Mefford 2006).

Results

A total of 755 specimens were sampled in the two study areas, representing 18 families, 42 genera and 111 species (Tab. 1). Of these, 13 species were new records for the Northeast region, 14 were recorded for the first time to Brazil and five new records for South America (Fig. 1). All 111 species reported here are also new records for Paraíba, due to lack of previous lichen studies in this state.

Five species were discovered as new to science and are described elsewhere: *Coenogonium chloroticum* (Xavier-Leite *et al.* 2014a); *Polymeridium isohypocrellinum* (Aptroot *et al.* 2013a); *Stirtonia microspora*, *S. nitida*, and *S. nivea* (Xavier-Leite *et al.* 2014b).

Species richness per locality differed for the two areas, with the higher number of species found in the Muralha Reserve (Caatinga), with a total of 67, and 46 species reported for the Parque Estadual Mata do Pau Ferro, the Brejo de

Table 1. Species of epiphytic microlichens found in Caatinga and Brejo de Altitude in the state of Paraíba, indicating new records for Northeast Brazil, Brazil, and South America.

Family	Species	Brejo de Altitude	Caatinga	New occurrence
Arthoniaceae	<i>Arthonia antillarum</i> (Fée) Nyl.		x	Northeast Brazil
	<i>Arthonia complanata</i> Fée		x	Paraíba
	<i>Arthonia parantillarum</i> Aptroot		x	Brazil
	<i>Stirtonia microspora</i> Xavier-Leite, M. Cáceres & Aptroot		x	New species
	<i>Stirtonia nitida</i> Xavier-Leite, M. Cáceres & Aptroot		x	New species
	<i>Stirtonia nivea</i> Xavier-Leite, M. Cáceres & Aptroot		x	New species
Caliciaceae	<i>Amandinea extenuata</i> Müll. Arg.		x	Paraíba
	<i>Buellia yaucoensis</i> Vainio		x	Brazil
	<i>Cratiria obscurior</i> (Stirton) Marbach & Kalb		x	Paraíba
	<i>Dirinaria confluens</i> (Fr.) D. D. Awasthi		x	Paraíba
	<i>Dirinaria leopoldii</i> (Stein) D. D. Awasthi		x	Paraíba
	<i>Hafellia bahiana</i> Malme		x	Paraíba
	<i>Hafellia desertica</i> Marbach		x	Paraíba
	<i>Hafellia dissa</i> (Stirt.) H. Mayrhofer & Sheard		x	Nordeste
<i>Pyxine berteriana</i> (Fée) Imsh.		x	Paraíba	
Chrysothrichaceae	<i>Chrysothrix xanthina</i> (Vain.) Kalb		x	Paraíba
Coenogoniaceae	<i>Coenogonium chloroticum</i> Xavier-Leite, M. Cáceres & Aptroot	x		New species
	<i>Coenogonium luteocitrinum</i> Rivas Plata, Lücking & Umaña	x		Paraíba
	<i>Coenogonium nepalense</i> (G. Thor & Vězda) Lücking, Aptroot & Sipman	x		Northeast Brazil
	<i>Coenogonium saepincola</i> Aptroot, Sipman & Lücking	x		South America
	<i>Coenogonium siquirrense</i> f. <i>denticulatum</i> Rivas Plata & Lücking	x		Northeast Brazil
	<i>Coenogonium subfallaciosum</i> (Vězda & Farkas) Lücking, Aptroot & Sipman	x		Brazil
Eremithallaceae	<i>Eremithallus marusae</i> R. Miranda, Gaya & Lücking	x		South America
Graphidaceae	<i>Chapsa discoides</i> (Stirt.) Lücking		x	Northeast Brazil
	<i>Diorygma poitaei</i> (Fée) Kalb, Staiger & Elix	x		Paraíba
	<i>Fissurina aggregatula</i> Common & Lücking	x		South America
	<i>Fissurina incrustans</i> Fée	x		Paraíba
	<i>Fissurina pseudostromatica</i> Lücking & Rivas Plata	x		South America
	<i>Glyphis scyphulifera</i> (Ach.) Staiger		x	Paraíba
	<i>Graphis albissima</i> Müll. Arg.		x	Brazil
	<i>Graphis arbusculaeformis</i> (Vain.) Lücking		x	Paraíba
	<i>Graphis cincta</i> (Pers.) Aptroot		x	Brazil
	<i>Graphis conferta</i> Zenker		x	Paraíba
	<i>Graphis furcata</i> Fée		x	Paraíba
	<i>Graphis glaucescens</i> Fée	x		Paraíba
	<i>Graphis gonimica</i> Zahlbr.		x	Brazil
	<i>Graphis handelii</i> Zahlbr.		x	Paraíba
	<i>Graphis kelungana</i> Zahlbr.		x	Brasil
	<i>Graphis leptocarpa</i> Fée	x	x	Paraíba
	<i>Graphis marginata</i> Raddi		x	Paraíba
	<i>Graphis lineola</i> Ach.		x	Paraíba
	<i>Graphis oxyclada</i> Müll. Arg.		x	Paraíba
	<i>Graphis pavoniana</i> Fée		x	Paraíba
<i>Graphis pinicola</i> Zahlbr.	x	x	Paraíba	

Continues.

Tabela 1. Continuation.

Family	Species	Brejo de Altitude	Caatinga	New occurrence
	<i>Graphis submarginata</i> Lücking		x	Paraíba
	<i>Leucodecton expallescens</i> (Nyl.) Rivas Plata & Lücking		x	Brazil
	<i>Leucodecton occultum</i> (Eschw.) Frisch		x	Brazil
	<i>Myriotrema clandestinoides</i> Sipman & Lücking	x		Northeast Brazil
	<i>Ocellularia obturascens</i> (Nyl.) Hal	x		Brazil
	<i>Phaeographis brasiliensis</i> (A. Massal.) Kalb & Matthes-Leicht	x		Paraíba
	<i>Phaeographis neotricosa</i> Redinger	x		Paraíba
	<i>Sarcographa labyrinthica</i> (Ach.) Müll. Arg.	x		Paraíba
Gyalectaceae	<i>Ramonia intermedia</i> Kalb	x		Paraíba
	<i>Ramonia microspora</i> Vězda	x		Northeast Brazil
Lecanoraceae	<i>Haematomma persoonii</i> (Fée) A. Massal.		x	Paraíba
	<i>Lecanora achroa</i> Nyl.		x	Paraíba
	<i>Lecanora helva</i> Stizenb.		x	Paraíba
	<i>Lecanora tropica</i> Zahlbr.		x	Paraíba
	<i>Ramboldia haematites</i> (Fée) Kalb		x	Paraíba
Malmideaceae	<i>Malmidea</i> aff. <i>granifera</i> (Ach.) Kalb, Rivas Plata & Lumbsch	x		Paraíba
	<i>Malmidea</i> aff. <i>piperis</i> (Spreng.) Kalb, Rivas Plata & Lumbsch	x		Paraíba
	<i>Malmidea atlantica</i> Cáceres & Kalb	x		Paraíba
	<i>Malmidea furfurosa</i> (Tuck. ex Nyl.) Kalb & Lücking	x		Paraíba
	<i>Malmidea granifera</i> (Ach.) Kalb, Rivas Plata & Lumbsch	x		Paraíba
	<i>Malmidea gyalectoides</i> (Vain.) Kalb & Lücking	x		Paraíba
	<i>Malmidea leptoloma</i> (Müll. Arg.) Kalb & Lücking	x		Paraíba
	<i>Malmidea piperis</i> (Spreng.) Kalb, Rivas Plata & Lumbsch	x		Paraíba
	<i>Malmidea vinosa</i> (Eschw.) Kalb, Rivas Plata & Lumbsch	x		Paraíba
Monoblastiaceae	<i>Anisomeridium albisedum</i> (Nyl.) R.C. Harris	x		Brazil
	<i>Anisomeridium tamarindi</i> (Fée) R. C. Harris		x	Paraíba
Mycoporaceae	<i>Mycoporum eschweileri</i> (Müll. Arg.) R.C. Harris		x	Brasil
Pertusariaceae	<i>Pertusaria dehiscens</i> Müll. Arg.		x	Paraíba
	<i>Pertusaria flavens</i> Nyl.		x	Paraíba
	<i>Pertusaria quassiae</i> (Fée) Nyl.		x	Paraíba
Porinaceae	<i>Porina conspersa</i> Malme	x		Paraíba
	<i>Porina curtula</i> Malme	x		Paraíba
	<i>Porina imitatrix</i> Müll. Arg.	x		Paraíba
	<i>Porina nucula</i> Ach.	x		Paraíba
	<i>Porina subepiphylla</i> Lücking & Vězda	x		Paraíba
	<i>Porina subpungens</i> Malme	x		Northeast Brazil
Pyrenulaceae	<i>Pyrenula anomala</i> (Ach.) Vain.		x	Paraíba
	<i>Pyreneula aspistea</i> (Ach.) Ach.		x	Northeast Brazil
	<i>Pyrenula brunnea</i> Fée	x		Northeast Brazil
	<i>Pyrenula infraleucotrypa</i> Aptroot & M. Cáceres	x		Paraíba
	<i>Pyrenula inframamillana</i> Aptroot & M. Cáceres	x		Northeast Brazil
	<i>Pyrenula quassiaeicola</i> Fée		x	Paraíba

Continues.

Family	Species	Brejo de Altitude	Caatinga	New occurrence
	<i>Pyrenula septicollaris</i> (Eschw.) R. C. Harris	x		Paraíba
	<i>Pyrenula subglabrata</i> (Nyl.) Müll. Arg.		x	Brazil
Ramalinaceae	<i>Bacidia cuyabensis</i> Malme		x	Northeast Brazil
Roccellaceae	<i>Chiodecton malmei</i> G. Thor		x	Paraíba
	<i>Enterographa punctula</i> (Nyl.) Redinger		x	Paraíba
	<i>Enterographa sipmanii</i> Sparrius		x	Paraíba
	<i>Enterographa subserialis</i> (Nyl.) Redinger		x	South America
	<i>Mazosia ocellata</i> (Nyl.) R. C. Harris	x		Paraíba
	<i>Opegrapha aperiens</i> Vain	x		Northeast Brazil
	<i>Opegrapha aff. contracta</i> Vain.	x		Paraíba
	<i>Opegrapha cylindrica</i> Raddi	x		Paraíba
	<i>Opegrapha robusta</i> Raddi		x	Paraíba
	<i>Sclerophyton elegans</i> Eschw.		x	Paraíba
Strigulaceae	<i>Strigula phaea</i> (Ach.) R. C. Harris	x		Brazil
Trypetheliaceae	<i>Arthopyrenia cinchonae</i> (Ach.) Müll. Arg.		x	Paraíba
	<i>Mycomicrothelia oleosa</i> Aptroot		x	Northeast Brazil
	<i>Polymeridium multiforme</i> Aptroot		x	Paraíba
	<i>Polymeridium proponens</i> (Nyl.) R. C. Harris		x	Paraíba
	<i>Polymeridium quinqueseptatum</i> (Nyl.) R. C. Harris		x	Paraíba
	<i>Polymeridium isohypocrellinum</i> A. B. Xavier-Leite, M. Cáceres & Aptroot		x	New species
	<i>Trypethelium aeneum</i> (Eschw.) Zahlbr.		x	Paraíba
	<i>Trypethelium eluteriae</i> Spreng.		x	Paraíba
	<i>Trypethelium ochroleucum</i> (Eschw.) Nyl.		x	Paraíba
	<i>Trypethelium subeluteriae</i> Makhija & Patw.		x	Paraíba
	<i>Trypethelium tropicum</i> (Ach.) Müll. Arg.		x	Paraíba

Altitude area (Fig. 2). Species richness at sample scale was significantly higher for the Caatinga area ($p < 0.05$). Among the species recorded for the Caatinga, 65 (97%) occurred exclusively in this biome and 44 taxa (93%) were exclusive to the Brejo de Altitude.

The families with highest species richness in the Caatinga were *Graphidaceae* and *Caliciaceae*, and *Graphis* was the most representative genus. For the Brejo de Altitude, the most diverse families were *Graphidaceae* and *Malmideaceae*, and the genus *Malmidea* had the higher number of species. While *Graphidaceae* were dominant in both vegetation types, different genera and species of the family were characteristic for each type.

Coenogoniaceae, *Eremithallaceae*, *Gyalectaceae*, *Malmideaceae*, *Porinaceae* and *Strigulaceae* were families found only at the Mata do Pau Ferro State Park, together with the genera *Coenogonium*, *Eremithallus*, *Diorygma*, *Fissurina*, *Myriotrema*, *Ocellularia*, *Phaeographis*, *Sarcographa*, *Ramonia*, *Malmidea*, *Porina*, *Mazosia* and *Strigula*, which were not present in the Caatinga.

On the other hand, restricted to the Caatinga were the families *Arthoniaceae*, *Caliciaceae*, *Chrysothrichaceae*, *Lecanoraceae*, *Mycoporaceae*, *Pertusariaceae*, *Ramalinaceae* and *Trypetheliaceae*. The genera *Arthonia*, *Arthothelium*, *Stirtonia*, *Arthopyrenia*, *Mycomicrothelia*, *Amandinea*, *Chrysothrix*, *Chapsa*, *Leucodecton*, *Haematomma*, *Lecanora*, *Ramboldia*, *Mycoporum*, *Pertusaria*, *Buellia*, *Cratiria*, *Dirinaria*, *Hafellia*, *Pyxine*, *Physcia*, *Hyperphyscia*, *Bacidia*, *Chiodecton*, *Dirina*, *Enterographa*, *Sclerophyton*, *Polymeridium*, and *Trypethelium* were only found in the Caatinga.

The families *Graphidaceae*, *Monoblastiaceae*, *Pyrenulaceae*, and *Roccellaceae*, and the genera *Anisomeridium*, *Glyphis*, *Graphis*, *Opegrapha*, and *Pyrenula*, plus the three species, *Glyphis scyphulifera*, *Graphis leptocarpa* and *Graphis pinicola*, were found both in Brejo de Altitude and in the Caatinga. Consequently, the Sørensen similarity index between the two areas amounts to only 4%. The clear phytosociological distinction in species composition of epiphytic microlichens between the two areas was also evident in the cluster analysis, with the formation of two distinct clusters representing Caatinga and Brejo de Altitude (Fig. 3).

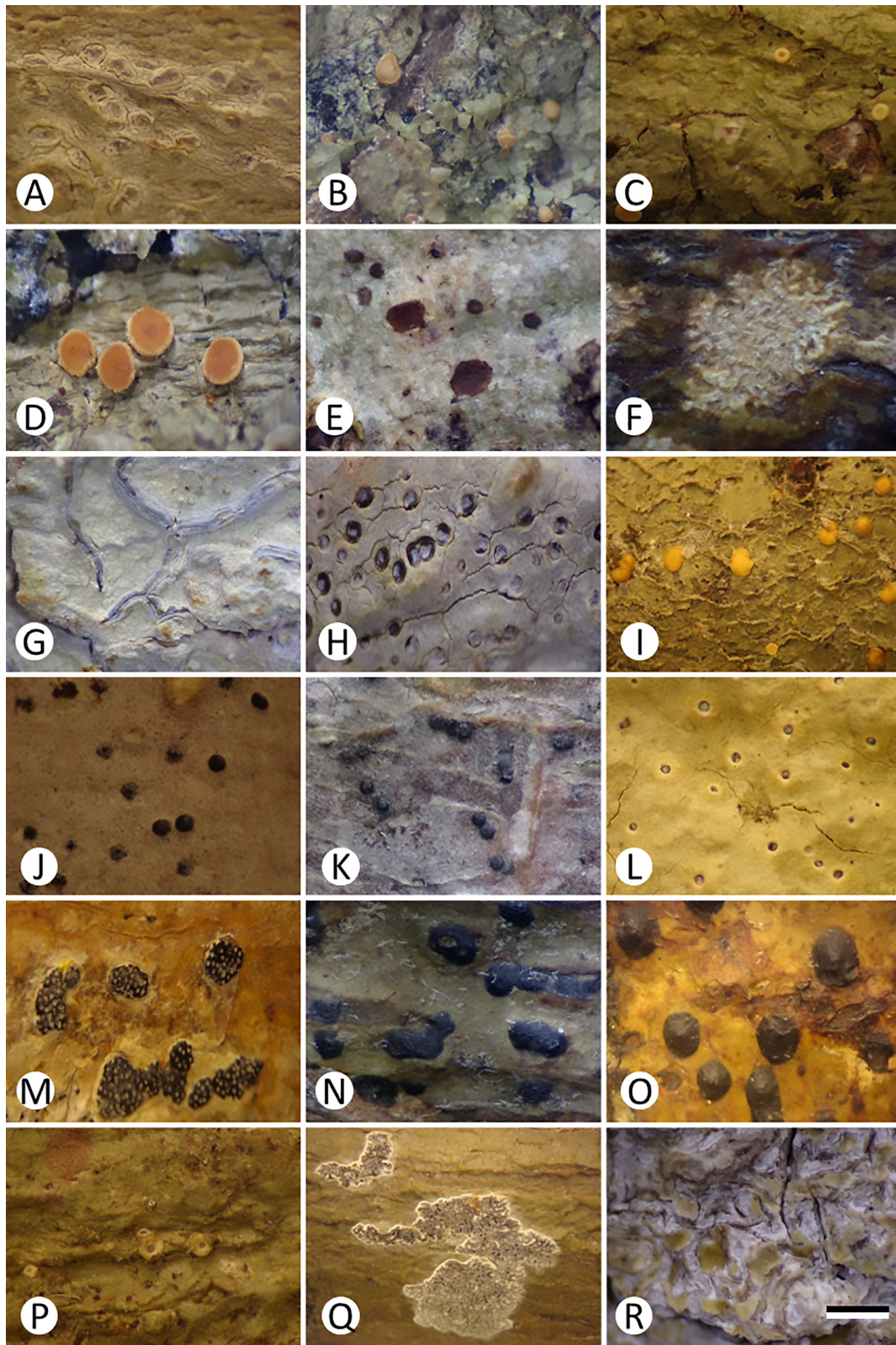


Figure 1. Selected epiphytic microlichens from this study. (A) *Chapsa discoides* (Stirt.) Lücking; (B) *Coenogonium chloroticum* A. B. Xavier-Leite, M. Cáceres & Aptroot; (C) *Coenogonium nepalense* (G. Thor & Vezda) Lücking, Aptroot & Sipman; (D) *Coenogonium siquirrense* f. *denticulatum* Rivas Plata & Lücking; (E) *Eremithallus marusae* R. Miranda, Gaya & Lücking; (F) *Fissurina pseudostromatica* Lücking & Rivas-Plata; (G) *Graphis glaucescens* Fée; (H) *Leucodecton occultum* (Eschw.) Frisch; (I) *Malmidea gyalectoides* (Vain.) Kalb & Lücking; (J) *Mycomicrothelia oleosa* Aptroot; (K) *Mycoporum eschweileri* (Müll. Arg.) R.C. Harris; (L) *Ocellularia obturascens* (Nyl.) Hale; (M) *Pyrenula anómala* (Ach.) Vain.; (N) *Pyrenula infraleucotrypa* Aptroot & M. Cáceres; (O) *Pyrenula inframamillana* Aptroot & M. Cáceres; (P) *Ramonia microspora* Vězda; (Q) *Sarcographa labyrinthica* (Ach.) Müll. Arg.; (R) *Stirtonia nivea* A. B. Xavier-Leite, M. Cáceres & Aptroot. Scale bars: 0.5 mm.

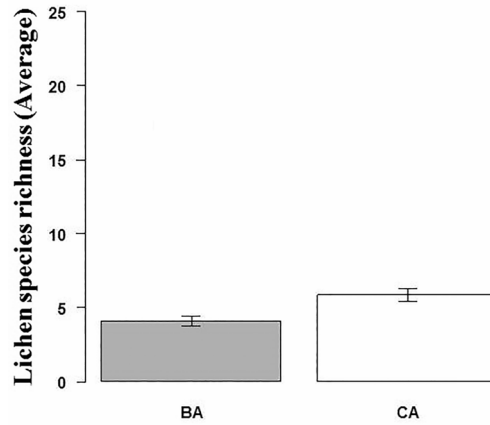


Figure 2. Means species richness (\pm SE) per sample of epiphytic microlichens for the areas of Brejo de Altitude (BA) and Caatinga (CA). ($p < 0.05$)

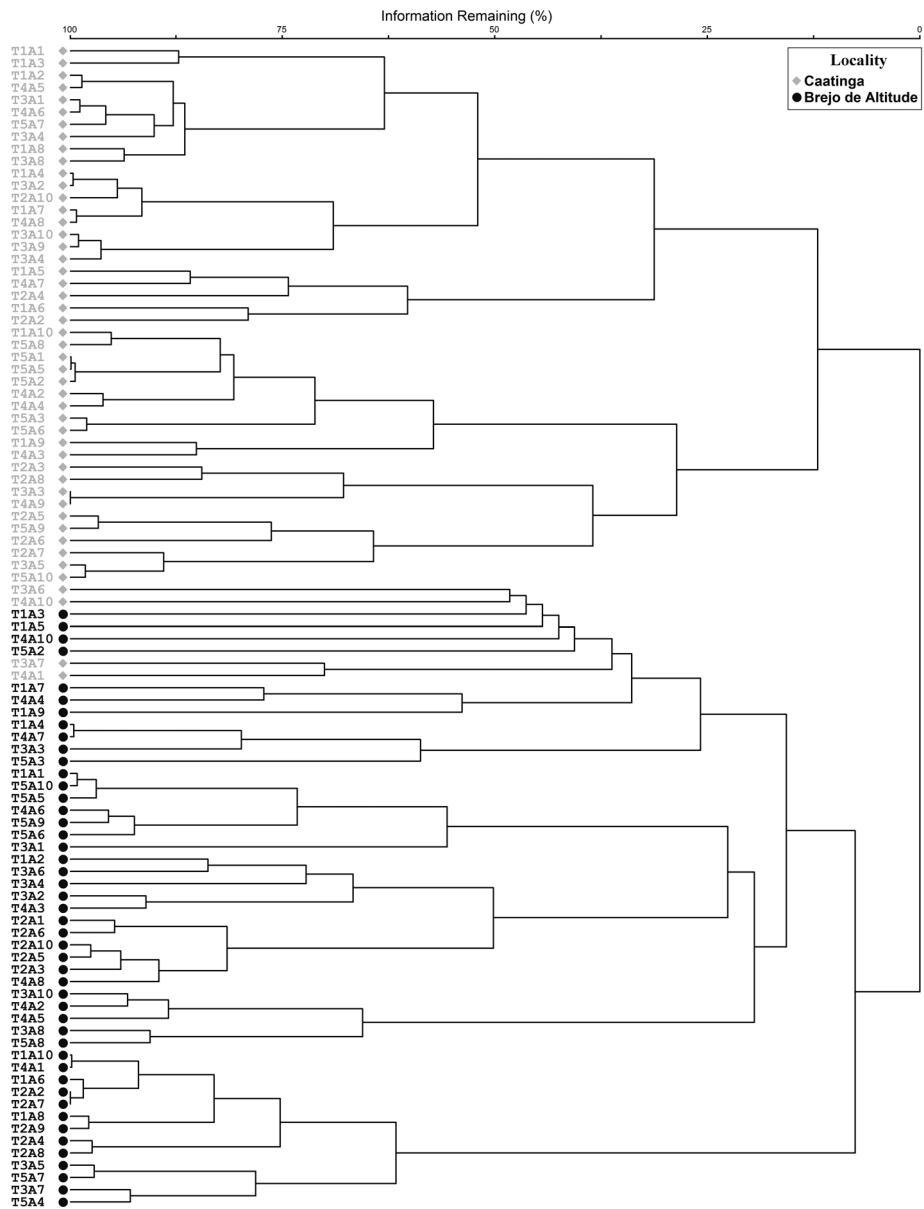


Figure 3. Cluster dendrogram of the studied samples and their grouping based on lichen species composition, correlating strongly with vegetation type.

Discussion

No lichen study has previously been carried out in the Parque Estadual Mata do Pau-Ferro. The only inventories undertaken in this park concerned the species diversity and floristic composition of bryophytes (Pôrto *et al.* 2004; 2005) and phanerogams (Andrade *et al.* 2006; Oliveira *et al.* 2006). In the Reserva Muralha, there was only one study on the diversity of phanerogams (Barbosa *et al.* 2005). The only previous investigations concerning lichens in Paraíba dealt with species of *Cladoniaceae* (Ahti *et al.* 1993) and the lichen *Cladonia verticillaris* (Villarouco *et al.* 2007). Thus, this is the first comprehensive work on lichen diversity, focusing on epiphytic microlichens, in the state of Paraíba.

The comparison of species richness between the two areas showed a higher value for the Caatinga compared to the Brejo de Altitude, in contrast to what was found by Cáceres *et al.* (2008a), where the Brejos de Altitude were more diverse. The different results found here may be due to the disparity in sampling technique, since opportunistic sampling had been used in the previous work. Cáceres *et al.* (2008b) showed that the sampling method is critical for estimating species richness of lichens within a given area, indicating that the transects (quantitative method) used in the present study is most efficient for microlichen inventories. On the other hand, since the same technique was used for both regions, this might not actually explain the differences. Another reason could be that the Caatinga sites studied by Cáceres *et al.* (2008a) were less well conserved than the site studied here and hence had lower lichen species richness. A further possible explanation for the lower species richness found here in the Brejo de Altitude would be increased competition with organisms such as bryophytes due to the climatic conditions. According to Pôrto *et al.* (2005), epiphytic bryophyte biomass in the Brejo de Altitude areas of Paraíba State is rather high, and this competition can result in a change in community structure along the tree trunk in favor of bryophytes (Martins & Marcelli 2011).

The low similarity in species composition, with a value of only 4% between the two areas, corroborates the findings by Cáceres *et al.* (2008a), where the differences in species composition between the Caatinga and Brejo de Altitude were similarly high. Yet, high occurrence of *Graphidaceae* for these two areas and *Malmideaceae* for the Brejo de Altitude, with the most common genus being *Graphis* for Caatinga and *Malmidea* for Brejo de Altitude, is in accordance with what was previously found by Cáceres (2007). This confirms that *Graphidaceae* is an important component of tropical lichenized mycota and generally abundant in both vegetation types, and that *Malmideaceae* is more typical of humid forests such as the more closed rainforests of the Brejo de Altitude.

Most of the taxa recorded here for the Caatinga area were also shown to be present in this vegetation type in other states in previous studies. *Anisomeridium tamarindi*, *Chrysothrix xanthina*, *Enterographa sipmanii* and *Graphis oxyclada* had been already cited by Cáceres (2007) for Pernambuco. There

are also previous records for *Graphis arbusculaeformis*, *G. handellii*, *Hafellia bahiana*, *H. curatellae*, and *H. desertica* for Alagoas (Menezes *et al.* 2011; Cavalcante 2012). For the semi-arid region in Sergipe and Alagoas, *Graphis lineola* had also been reported (Cavalcante 2012; Rodrigues 2012). *Dirinaria confluens*, *Lecanora helva*, and *Pyxine berteriana* were previously registered for Pernambuco and Alagoas (Cáceres 2007; Menezes *et al.* 2011; Cavalcante 2012). *Cratiria obscurior*, *Dirinaria leopoldii*, *Graphis submarginata*, *Haematomma personii*, *Pertusaria dehiscens*, *P. flavens*, and *Ramboldia haematites* were previously mentioned for the states of Alagoas, Pernambuco and Sergipe (Cáceres 2007; Menezes *et al.* 2011; Cavalcante 2012; Rodrigues 2012).

The species found here in the Brejo de Altitude were similar to those previously cited for other Northeastern montane and Atlantic forests, since the vegetation type is similar, with a strong resemblance to the coastal rainforest (Andrade *et al.* 2006), such as the species *Fissurina incrustans*, *Porina curtula*, and *P. conspersa*, found already in Alagoas (Cáceres 2007). *Coenogonium luteocitrinum*, *Diorygma poitaei*, *Graphis glaucescens*, *Malmidea atlantica*, *M. furfurosa*, *M. granifera*, *M. gyalectoides*, *M. pipers*, *Mazosia ocellata*, *Opegrapha cylindrica*, *Phaeographis neotricosa*, *Ramonia intermedia*, and *Sarcographa labyrinthica* had all been previously reported for the states of Alagoas, Sergipe, Pernambuco and Rio Grande do Norte (Cáceres 2007).

Among the species common to both areas, only *Glyphis scyphulifera* was previously cited for Caatinga and Atlantic Forest in northeastern Brazil (Cáceres 2007), and *Graphis leptocarpa* and *G. pinicola* were reported from the Caatinga by Menezes *et al.* (2011) and Rodrigues (2012). Since Brejos de Altitude are considered Atlantic Forest enclaves forming islands of rainforest in the middle of the semiarid region (Andrade-Lima 1966), the emergence of species common to Caatinga in areas of Brejo de Altitude should occur because these montane forests are being degraded and disturbed, with the vegetation becoming more open in some places (Cáceres *et al.* 2007).

This distinction between composition species of corticolous lichens between these two areas was evident in the cluster analysis, with the formation of two clusters in the points represented by the area of Caatinga and the Brejo de Altitude (Fig. 3).

Regarding new records of corticolous lichens for the Northeast region, the species *Amandinea extenuata*, *Hafellia dissa*, *Opegrapa aperiens* and *Pyrenula brunnea* were cited before for the Rio Grande do Sul (Spielmann 2006). *Pyrenula inframamillana* was cited by Aptroot *et al.* (2013b) for the state of Rondônia.

Regarding new records for Brazil, the species *Anisomeridium albisedum*, *Pyrenula aspistea* and *Strigula phaea* were previously referenced by Aptroot *et al.* (2008) for Costa Rica, as well as *Chapsa discoides*, *Myriotrema clandestinoides*, *Leucodecton expallescens*, *L. occultum* and *Ocellularia obturascens* for the same country by Sipman *et al.* (2012). Also with previous

records for Costa Rica, Rivas-Plata *et al.* (2006) reported the species *Coenogonium nepalense*, *C. siquirrense* f. *denticulatum* and *C. subfallaciosum*. Other new records for the country are *Arthonia parantillarum* cited from Taiwan by Aptroot & Sparrius (2003), *Buellia yaucoensis* mentioned by Marbach (2000) for the Caribbean, *Ramonia microspora* from Argentina by Lücking *et al.* (2009), and *Graphis gonimica* referenced from China and *Fissurina pseudostromatica* from Colombia by Rincón-Espitia (2011). For South America the new record *Coenogonium saepincola* was cited by Rivas-Plata *et al.* (2006) for Costa Rica. *Eremithallus marusae* was previously mentioned by Lumbsch *et al.* (2011) from Mexico, and *Fissurina aggregatula* by Lücking *et al.* (2011) from the United States.

In conclusion, the present work is one of the first studies about lichen diversity in the state of Paraíba and the first to study the lichens of Brejos de Altitude, comparing its composition and richness with that of Caatinga vegetation in the same state. As our results show, such studies can reveal significant, previously unrecognized organismic diversity, in this case 111 new records for the state five new species to science. Such studies are of paramount importance for the understanding of species richness and composition for Brejos de Altitude and Caatinga, as well as serving as a basis and further incentive for studies to be undertaken. The main conclusion, however, is that lichens serve as indicators of phytosociological differences between these major biomes in Northeastern Brazil, as their community composition strongly correlates with vegetation type.

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