Diversity of bryophytes in priority areas for conservation in the Atlantic forest of northeast Brazil

Mércia Patrícia Pereira Silva¹,³ and Kátia Cavalcanti Pôrto²

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ABSTRACT
The northeastern Brazilian Atlantic forest is the region with the greatest diversity of bryophytes in the country. However, knowledge about bryophytes is irregularly distributed among Brazilian regions. Therefore, we aimed to contribute to knowledge about bryophytes on a regional scale in the northeastern Atlantic forest, to identify the centers of bryophyte diversity in that region, and to reiterate the importance and identify locations for which new protected areas should be created. We built a database of bryophytes in 23 locations of the region, based on a literature review and new floristic inventories. To identify the locations of greatest relevance to bryophyte conservation, we considered 1) total and endemic species richness, 2) phylogenetic diversity (PD), and 3) functional diversity (proportion of shade specialists). The northeastern Atlantic rainforest contains 396 spp., representing 26% of the taxa occurring in the country, 13 of which are endemic. Generalist species predominated (164 spp.), followed by shade (133 spp.) and sun (92 spp.) specialists. The Murici Ecological Station had the highest richness, number of endemic species, and phylogenetic diversity.

Keywords: conservation units, liverwort, moss, richness, tropical forest

Introduction
The Atlantic forest is the phytogeographic domain that shelters the greatest diversity of bryophytes in Brazil (Gradstein et al. 2001). The same authors also state that in the Neotropics, the diversity of bryophytes in the Atlantic Forest is surpassed only by those of the forests of the northern Andes and Central America. In addition, the Atlantic Forest is remarkable for its relevance and urgency of conservation, sheltering 16 of the 17 threatened Brazilian bryophyte species (Fundação Biodiversitas 2005; MMA 2008).

Currently, 378 (94% of all Brazilian) genera and 1,351 (88% of Brazilian) species of bryophytes are recorded for the Atlantic forest (Costa et al. 2014). According to Gradstein & Costa (2003) and Santos et al. (2011), Montane Atlantic Forest areas, particularly in the southeast, have many records of endemic bryophytes, many liverwort species, and interesting affinities with the bryoflora of the Andes. These authors also state that the number of endemic species occurring in the Atlantic coast region is twice that in the Amazon region, including 12 endemic families. With respect to mosses in particular, the endemism level for that domain is even greater with 190 species (20%), whereas only 10 endemic species (1%) are recorded in the Amazon Rainforest (Costa et al. 2011).

Despite its great biodiversity, the Atlantic Forest is one of the main targets of environmental degradation by exploitative human activities, such as the expansion of agriculture and urban areas and logging (Conservação Internacional do Brasil et al. 2000; Angelo 2013). According to Campanili & Prochnow (2006), this is the second most threatened vegetation domain on the planet, the first being the nearly extinct forests of the island of Madagascar off the coast of Africa. In the Brazilian Northeast Atlantic Forest, where the exploitation of forest resources is secular (Tabarelli et al. 2005), large gaps in the knowledge of the distribution of bryophytes in different states are notable.

Several important floristic surveys of the bryophytes of northeast Brazil have been published in the last two decades, particularly focusing on the state of Pernambuco (Pôrto 1990; Germano & Pôrto 1996; 1997; 1998; Sá & Pôrto 1996), and allowed Pôrto & Germano (2002) to compile 315 species of bryophytes for the state. Most records (84%) are derived from refuges of lowland Atlantic forest (Pôrto 1990; Pôrto et al. 1993; Germano &

¹ Universidade Federal da Bahia, Instituto de Biologia, Departamento de Botânica, Laboratório Taxonomia de Briófitas, Campus de Ondina, Ondina, Salvador, BA, Brazil
² Universidade Federal de Pernambuco, Centro de Ciências Biológicas, Departamento de Botânica, Laboratório Biologia de Briófitas, Av. Prof. Moraes Rego, 1235, Cidade Universitária, Recife, PE, Brazil
³ Author for correspondence: merciapps@yahoo.com.br
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Pôrto 1996; 1998; Sá & Pôrto 1996), or tropical altitudinal wet forests, “Brejos de altitude” (Yano & Andrade-Lima 1987; Pôrto 1990; Pôrto et al. 1999; 2000; Valdevino et al. 2002). Efforts have been recently made to increase the knowledge of bryophytes in other states, for example in Alagoas and Bahia with respect to bryoflora (Bastos & Yano 2004; Valente & Pôrto 2006; Valente et al. 2009; 2011) as well as conservation of populations and communities (Alvarenga et al. 2009; 2010; Oliveira et al. 2011; Silva & Pôrto 2009; 2010).

To the best of our knowledge, this work is the first effort to contribute to the information about bryophytes in the northeastern Atlantic forest on a regional scale and to identify the centers of floristic (total number of species and endemics), phylogenetic (proportions of species and topological differences between them) and functional (proportions of functional groups) diversity for bryophytes. Furthermore, we aimed to test whether these parameters are influenced by a latitude gradient through the northeastern Atlantic forest and to highlight locations where stronger conservation measures, viareinforcement of existing protected areas or creation of new ones, are urgently required.

Material and methods

Study area

The study was conducted in the northern part of the Atlantic Forest, sensu lato, covering the states of Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, and Sergipe (34°51'41"-37°20'32"W, 5°51'00"-10°45'16"S) (Table 1, Fig. 1) (hereafter, northeastern Atlantic forest), covering a linear distance of 595 km from north to south through 6° of latitude. This forest is mainly distributed up to 1,000 m altitude (Tabarelli et al. 2006), including tropical altitudinal wet forests, “Brejo de altitude,” enclaves of moist forest sur-rounded by a near-desert vegetation (sensu Andrade-Lima 1982). The average temperature in the region is 25 °C and

<table>
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<th>Altitude (m)</th>
<th>Reference</th>
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annual precipitation varies between 1,300 and 2,400 mm, with a rainy season from March to September (Veloso et al. 1991).

Database

We built a comprehensive database of the bryophytes of the northeastern Atlantic forest. To this end, we reviewed literature of all bryophyte records in the area to identify sites with systematic bryophyte sampling, resulting in 10 locations that were integrated into the study (Table 1).

After the initial diagnosis of gaps in bryophyte sampling in the Northeast Atlantic Forest, 13 sites were selected to conduct further bryophyte surveys. To identify the highest possible bryoflora diversity, these locations were sampled for three days, during which exploratory walks were taken to collect plant material. Information from this sampling was incorporated into the literature review, so that the total database was composed of 23 sites in the Atlantic rainforest.

Study Material

The samples were identified to species level based on the literature (Ochi 1980; 1981; 1982; Sharp et al. 1994; Buck 1998; Reiner-Drehwald 1998; 2000; Gradstein & Costa 2003; Pursell 2007; Costa 2008) and submitted to the UFP herbarium, Department of Botany, Federal University of Pernambuco.

If necessary, the taxonomic nomenclature was updated using taxonomic revisions and checklists (Buck 1998; Crosby et al. 1999; Gradstein & Costa 2003; Bastos & Yano 2004; Pócs & Bernecker 2009), and the query database of the Missouri Botanical Garden (http://mobot.mobot.org/Pick/Search/most.html). The classification system of Crandall-Stotler et al. (2009) was adopted for liverwort and Goffinet et al. (2009) for mosses.

Data Analysis

For the determination of endemic taxa of the Atlantic Forest, Gradstein & Costa (2003) and Costa et al. (2011; 2014) were consulted.

To establish the distributions of functional groups, species were classified into functional groups according to their microhabitat preference, in the form of tolerance to light exposure (sun specialist, shade specialist or generalist) based on specialized work (Ochi 1980; 1981; 1982; Gradstein 1992; Sharp et al. 1994; Buck 1998; Heinrichs et al. 1998; Reiner-Drehwald 1998; 2000; Reiner-Drehwald & Goda 2000; Gradstein et al. 2001; Gradstein & Costa 2003; Bastos 2004; Bischler-Causse et al. 2005; Visnadi 2006; Pursell 2007; Reiner-Drehwald & Pôrto 2007; Costa 2008; Ilkiu-Borges & Alvarenga 2008; Alvarenga et al. 2009; 2010; Silva & Pôrto 2009; 2010; 2013; Oliveira et al. 2011; Glime 2012), expert consultation, and field experience of the authors. These functional groups have shown effective responses to loss and fragmentation of habitat in the Atlantic rainforest in previous studies (Alvarenga et al. 2009; 2010; Silva & Pôrto 2009; 2010; 2013; Oliveira et al. 2011). Owing to insufficient or duplicated information, four species were excluded from this analysis (Supplemental material 1).

Phylogenetic diversity (PD) was calculated using an adaptation of the method proposed by Faith (1992). However, for bryophytes, particularly for tropical species, there is no single classification system based on molecular analysis. Thus, the “phylogenetic tree” used was based on the taxonomic hierarchy of species, as indicated by Warwick & Clarke (1995; 1998). The calculation was performed with R 2.15.1 using the “vegan” package.

To identify the locations of greatest relevance to the conservation of bryophytes, three criteria were considered: 1) total richness and endemic species of the Atlantic Forest, 2) phylogenetic diversity (PD), and 3) proportion of indicator species for forest conservation (shade specialists).

Simple linear regression was used to identify dependences among these criteria and latitude using Statistica 8.0. Variables were logarithmically transformed (Zar 1999).

Results and discussion

Based on the literature survey, 371 specific taxa were compiled, distributed in 147 genera and 52 families, three
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hornworts (one family and two genera), 193 liverworts (18 families and 58 genera), and 178 mosses (34 families and 89 genera). Bryophyte sampling contributed 200 species, distributed in 95 genera and 40 families, with 103 liverworts (42 genera and 13 families), and 97 mosses (53 genera and 27 families). These inventories added 27 new species to the list based on the literature.

The combination of literature and sampling information thus led to a total of 396 spp. (3 hornworts, 203 liverworts, and 190 mosses), distributed in 52 families (Fig. 2). Of the 396, 13 species (3%) are endemic to the Atlantic Forest (9 liverworts and mosses) and 145 (37%) occur in only one location. Among the ten most frequent species, nine are generalist and one is a sun specialist: Octoblepharum albidum (22), Cheilolejeunea rigidula (21), Sematophyllum subsimplex (21), Lejeunea laetevirens (20), Calymperes palisotii, Isopterygium tenerum, Leptolejeunea elliptica, Symbiezidium barbiflorum, and Taxithelium planum (18 each) and Sematophyllum subpinnatum (17) (Supplemental material 1).

Together, the 396 bryophyte species of the northeastern Atlantic forest comprised an appreciable fraction of the total in the country, accounting for 26% of the total diversity of bryophytes in Brazil (1,527 spp. sensu Costa et al. 2014), 10% of the neotropics (4,000 spp.; Gradstein et al. 2001) and 2% of the world (18,000 spp.; Goffinet & Shaw 2009). Furthermore, 101 species were recorded for the first time for at least one of the five Brazilian states sampled. This result shows the importance of broad-scale studies to increase knowledge of Brazilian bryophytes. On the other hand, it also demonstrates sampling gaps in some Brazilian states. For example, Chryso-hypnum diminutivum is a widely distributed species in Brazil, being reported in 20 (77%) Brazilian states (Costa et al. 2014; Silva & Pôrto 2010; 2013; Oliveira et al. 2011). However, the present study includes the first record for Paraiba and Sergipe, probably owing to a lack of previous sampling in those areas. This situation can be observed for several other species, such as Fissidens zollingeri and Pilosium chlorophyllum, recorded in 23 (88%) and 24 (92%) of the states of Brazil, respectively (Costa et al. 2014), and here reported for the first time in the state of Rio Grande do Norte.

Certainly owing to the large size of Brazil, studies of bryophyte diversity on a regional scale are rare. The studies of Santos et al. (2011) for the Atlantic Forest and Mota de Oliveira et al. (2009) and Mota de Oliveira (2010) for the Amazon rainforest can be cited. Santos et al. (2011) recorded 192 species of bryophytes in Restinga Forest and Lowland Forest areas in the Southeast and found that, when evaluated in terms of landscape, the two forest formations formed distinct floristic groups. However, at the regional level the bryophytes had more affinities with one another than with those of other phyto-physionomically similar areas of the Atlantic Forest.

For the Amazon Rainforest, Mota de Oliveira et al. (2009) and Mota de Oliveira (2010) presented a systematic approach to identify community structures of epiphytic bryophytes in a transect from east to west across the Amazon Basin that resulted in the identification of 225 species and 38 morphospecies. For the Atlantic Forest, the present study is the first contribution to the knowledge of communities of bryophytes at the regional level. It was observed that, even considering differences in methodologies, overall bryofloristic richness was higher in the northeastern Atlantic forest than in the Amazon, an observation that is recurrent in the literature (Gradstein et al. 2001; Gradstein & Costa 2003; Costa et al. 2011).

Figure 2. Representatives of the main families of bryophytes, compiled by literature review and inventory performed in the present study.
In total, 300 species of liverworts (Gradstein & Costa 2003) and 350 species of mosses (Costa et al. 2011) have been registered for the Amazon rainforest, whereas in the Atlantic forest these figures are larger (500 spp. of liverworts and 700 spp. of mosses). However, these authors argue that the great richness of the Atlantic Forest is due to the presence of areas with high elevation (>1000 m), especially in the southeast, which are unusual in the Amazon Rainforest. For the northeast, areas with an altitude between 30 and 990 m were analyzed, and even then, the higher floristic variety of the Atlantic Forest was confirmed.

It is noteworthy that generalist species predominated (164 spp., 41%), followed by specialists in shade (133 spp., 34%) and sun (92 spp., 23%) (for 7 spp., 2%, there was no information on specialism). This result is recurrent in the literature for the Northeast Atlantic Forest (Alvarenga & Pôrto 2007; Silva & Pôrto 2009; 2010) and other tropical forests (Acebey et al. 2003). These studies showed that shade specialists are more sensitive to deforestation, and sometimes are completely absent from degraded sites, followed by sun specialists, whereas generalists are indifferent. Thus, degradation and loss of habitat recurring in the region (sensu Tabarelli et al. 2006) are indicated as causes of the predominance of generalists (Naaf & Wulf 2010).

Species richness ranged from 12 (PDU and APA) to 199 spp. (MUR) (Table 2). An increase in richness (R² = 0.35, p < 0.01), phylogenetic diversity (R² = 0.41, p < 0.001) and the proportion of shade specialists (R² = 0.26, p = 0.01) in a north-to-south direction (that is, with increasing latitude), was observed. However, the number of endemic species did not vary significantly with latitude (R² = 0.08, p = 0.17).

The Murici Ecological Station (MUR) also had the highest number of endemic species (5 spp.), followed by VSO (3 spp.). These two sites, together with FCA (119 spp.), harbor high diversity, a result in agreement with several reports on ecological groups including birds (Roda & Pereira 2006), reptiles (Guedes et al. 2011), mammals (Asfora Mendes & Pontes 2009), bryophytes (Pôrto 1990; Pôrto et al. 2006), and angiosperms (Grillo et al. 2006).
Among the studied Conservation Units, the Murucí Ecological Station stood out. It is an Integral Protection Conservation Unit and was created to protect one of the largest remnants of Atlantic Forest in the northeast of Brazil (ca. 6,100 ha) and to promote the development of scientific research and environmental education programs. It is the site with the highest concentration of threatened taxa in northeast Brazil: 27 taxa endemic to Centro Pernambuco (sensu Olmos 2005) and 5 more widely distributed taxa (Olmos 2005). The area has been the subject of several studies (Ferrarezi & Freire 2001; Olmos 2005; Moura 2006; Roda & Pereira 2006; Guadanucci et al. 2007; Rodrigues & Buckup 2007; Ilkiu-Borges & Alvarenga 2008; Alvarenga et al. 2009; 2010; Guedes et al. 2011; Nascimento & Campos 2011; Oliveira et al. 2011; Silva & Pório 2009; 2010; Pório et al. 2012).

On the other hand, even though the reserve is still widely covered, most forest fragments do not reach 1,000 ha and all are immersed in a very inhospitable matrix, consisting of pasture for cattle and sugar cane (Silva & Pório 2009; Pório et al. 2012). Selective logging, firewood, hunting, and animal poaching, particularly of birds for captive breeding and wildlife trafficking (Pório et al. 2012), are additional problems. Thus, we emphasize the vital significance of the Conservation Unit for regional bryophytes and suggest the implementation of effective public policies in APA Murucí, a buffer zone in areas surrounding the Murucí Ecological Station, especially in the areas of remaining private forest belonging to the sugar mills in the region.

It is noteworthy that *Fissidens flabellatus* and *Syrrophodon brasiliensis*, endemic mosses endemic of Brazil, have been reported here for the first time in the Brazilian Northeast, recorded in MET and ITA, respectively.

Despite the high richness and presence of endemic species relevant to conservation in the Northeast Atlantic Forest, logging, cultivation of sugar cane, and hunting are common practices. Thus, we emphasize the vital importance of the Northeast Atlantic Forest to the national bryophytes and suggest the implementation of effective conservation activities in the region, especially in the Murucí Ecological Station and FCA as well as in private forest remnants.

## Acknowledgments

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## References


