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Bryophyte flora of two Natural Parks in Amapá: richness, composition and new records

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Abstract: The aim of this study is to investigate the richness and composition of the bryophytes of two Municipal Natural Parks in Amapá, eastern Amazon. Bryophytes were collected in the Arivaldo Gomes Barreto Municipal Natural Park (AGBMNP), Macapá municipality, and Cancão Municipal Natural Park (CMNP), Serra do Navio municipality, in October 2010 and October 2012, respectively. Ten plots of 10 x 10 m were established in each park for sampling, and, in addition, random collections were made, in order to maximize the knowledge on the local bryophyte flora. In total, 53 species were identified in AGBMNP, and 110 species in CMNP. The results shown a lower richness in AGBMNP than in CMNP, which may be related to the own size of each park, the level of conservation, and its localization. In terms of abundance, the neotropical pattern and the species locally rare were most representative in both parks, however, the floristic composition diverged. The AGBMNP is composed mostly by generalist species, while the CMNP by both generalists and shade specialists. The present study recorded 54% of the known bryophyte flora of Amapá, 63 new records for the state and, in addition, three new records for the North region of Brazil.

Key words: Amazonia, Amapá flora, conservation units, taxonomy.

INTRODUCTION

The Amapá is the most preserved state in Brazil because of its legally protected areas. Its several ecosystems and high richness in plant species are under low degree of anthropic alterations, excepting Macapá municipality, which suffered and undergoes modifications due to urban growth (CI-BRASIL 2007, 2009).

Legally protected areas are part of the biodiversity corridor of Amapá, which account for more than 72% of its territory, divided into 19 conservation units (12 national, five state, and two municipal) (Drummond et al. 2008). These conservation units were created aiming scientific purposes and preservation of portions of the state's ecosystems (Brito 2008, Drummond et al. 2008, Jaster 2009).

The conservation units from Amapá encompass at least six major vegetation types included in the bioma Amazonia, such as shrub vegetation, mangroves, sandy coastal plain (restingas), lagoons and wetlands (flooded fields), palm forests, and most predominantly, tropical rainforests (Drummond et al. 2008). The prevalence of shaded environments in tropical rainforest, besides the warm and humid climate, even in dry periods, is conducive to the development and reproduction of bryophyte species (Gradstein & Pócs 1989, Gradstein 1995, Hallingbäck & Hodgetts 2000, Gradstein et al. 2001, Shaw et al. 2011).

Despite the highly conserved environments, bryophyte flora of Amapá is poorly known in comparison to other states in Brazil. This knowledge may be gathered in the publications

of Crosby (1969), Grolle (1984), Yano (1981, 1982, 1984a, 1992), Yano et al. (1985), Yano & Lisboa (1988), Churchill (1998), Gradstein & Costa (2003), Lisboa et al. (2006), and Gentil & Menezes (2011). These sources reunited records mostly from isolate collections, without a reference to the environment or substrate. The only exceptions are the latter two publications, which dealt with a delimited study area and indicated the environment and substrates where the species were collected.

Crosby (1969), Grolle (1984), and Yano et al. (1985) reported only one species each for Amapá. Crosby (1969) cited *Pilotrichum bipinnatum* (Schwägr.) Brid from Araguari River, while Grolle (1984) and Yano et al. (1985) recorded *Cyclolejeunea convexistipa* (Lehm. & Lindenb.) A. Evans and *Sphagnum palustre* L. from Oiapoque, respectively.

Yano (1981, 1984a) cited species of mosses (1 sp.) and liverworts (1 sp.) in Amapá, gathering records in literature for Brazilian checklists. The species *Leucobryum martianum* (Hornsch.) Hampe, *Octoblepharum albidum* Hedw., and *Octoblepharum pulvinatum* (Dozy & Molk.) Mitt. were reported by Yano (1982), in different locations of Amapá.

The first study directed to bryophytes from Amapá was carried out by Yano & Lisboa (1988). They identified 43 species (30 mosses and 13 liverworts) collected along highways in different municipalities, of which 41 were new occurrences for the state.

While reviewing Leucobryaceae for Brazil, Yano (1992) added *Leucobryum cripum* Müll. Hal. for Amapá. Churchill (1998) and Gradstein & Costa (2003) increased in 24 species the list of mosses and 21 of liverworts to the state, respectively. The largest list of species for Amapá thitherto was produced by Lisboa et al. (2006) and included 74 bryophytes species, of which 20 new occurrences of mosses and 24 liverworts.

Gentil & Menezes (2011) carried out the most recent study with bryophytes in Amapá, in a fragment of upland rainforest in the campus of the Universidade Federal do Amapá, where 45 species were registered.

According to the literature, 100 bryophyte species were recorded to Amapá (Crosby 1969, Grolle 1984, Yano 1982, Yano & Lisboa 1988, Churchill 1998, Gradstein & Costa 2003, Lisboa et al. 2006, Gentil & Menezes 2011). However, surveys in much smaller areas in eastern Amazon shown higher or equal number of records (Lisboa & Ilkiu-Borges 1995, Ilkiu-Borges et al. 2009, 2013, Tavares-Martins et al. 2014, Fagundes et al. 2016, Costa 2017, Costa et al. 2017). The variable sorts of environments present in Amapá need to be considered as well. Therefore, it is an indicative of the need for more comprehensive studies on the bryophyte flora of Amapá.

The aim of this study is to investigate the richness and composition of the bryophytes of two Municipal Natural Parks in Amapá, eastern Amazon.

MATERIALS AND METHODS

Study area

The Arivaldo Gomes Barreto Municipal Natural Park (AGBMNP), 00º02'26,6"S and 51°05'44,5"W, located in the municipality of Macapá, and the Cancão Municipal Natural Park (CMNP), 00º55'22.7"N and 052º00'11,9"W, located in the municipality of Serra do Navio (Figure 1).

The AGBMNP was created in 2009, according to law number 1670/2009, to regulate the former Macapá Municipal Zoo Botanical Park, created in 1997. This Park comprises a fragment of upland Amazon forest of about 56 hectares. The climate is of the subtype Am3, according to the Köppen classification, the relief is plain, the soil is dystrophic Yellow Latosol, the annual media temperature is 27° C, and the annual media

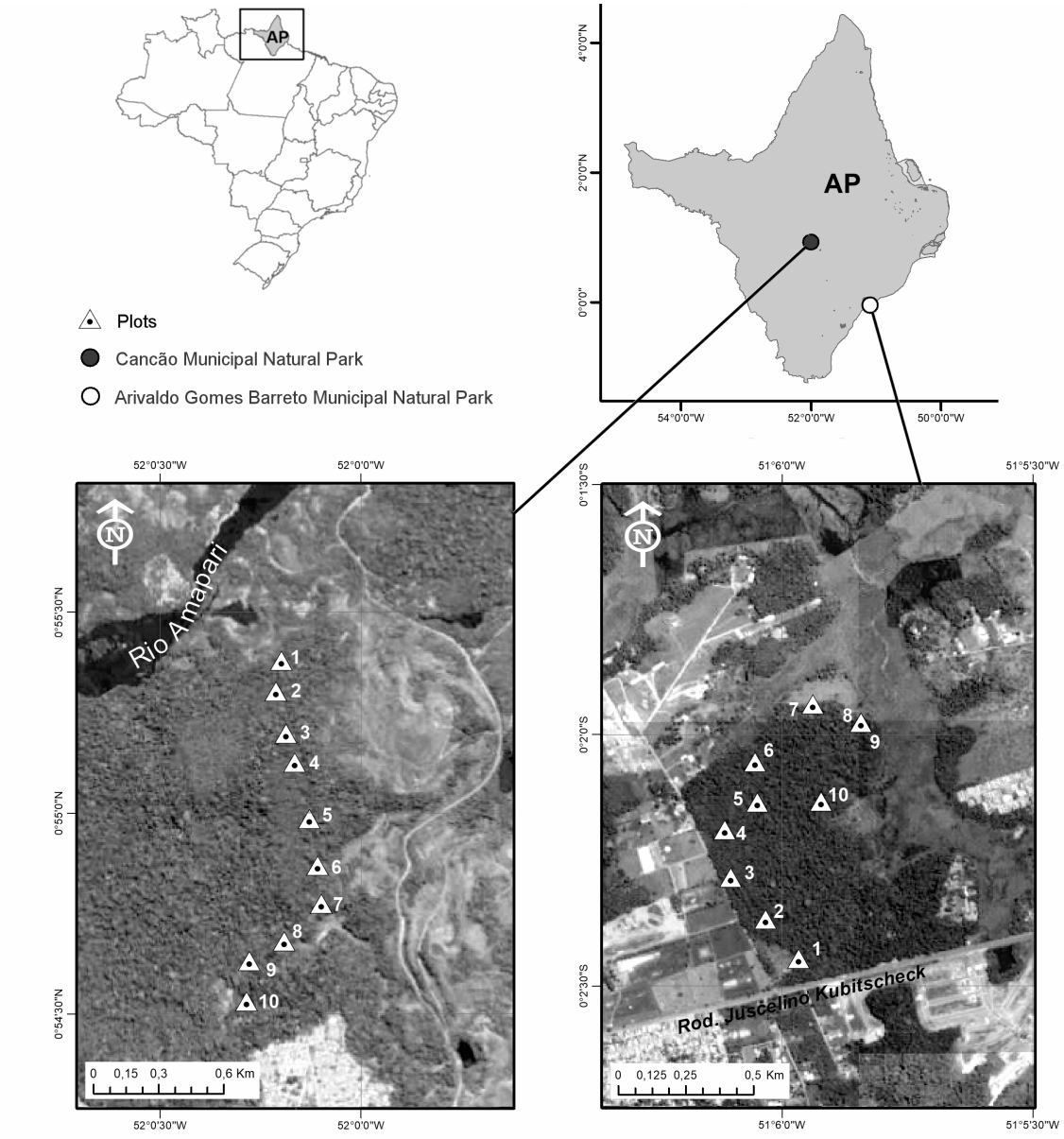

Figure 1. Localization map of the two Municipal Natural Parks, Amapá state, Brazil. Source: Spatial Analysis Laboratory (UAS), Museu Paraense Emilio Goeldi (MPEG).

precipitation is 2,500 mm (INMET 2018), and it is situated between 14 to 70 meters elevation.

The CMNP was created in 14th November 2007 by the municipal decree number 85/2007PMSN. The Park consists of 370.26 hectares of upland Amazon forest. The climate is of the type Amw, according to the Köppen classification, the soil is predominantly the dystrophic Red Latosol and dystrophic Red-Yellow Latosol, and the relief is rugged, formed by mountain ranges, hills and mounds (Drummond et al. 2008), and it is situated between 70 to 144 meters elevation.

Data collection and identification

The botanical material was collected in October 2010 and October 2012. The methods of collection, storage and preservation of specimens were described by Yano (1984b). Ten plots of 10 x 10 m

were established in each park, with a distance of at least 200 m from each other. In both parks, the plots where selected using the longest trail available for facilitating the access. In AGBMNP the plots were settled parallel to the trail *Trilha da Vigilância*, while in CMNP the plots were settled parallel to the trail *Trilha da Mata do Cancão*.

In addition to the collections within each plot, random collections were made, considering specific microenvironments or substrates, such as exposed soil, rocks and banks of watercourses, in order to maximize the knowledge on the local bryophyte flora.

The identification of the collected material was based on specialized literature, such as Yano (1992), Lisboa (1993), Reese (1993), Sharp et al. (1994), Grolle & Reiner-Drehwald (1997), Gradstein et al. (2001), Buck (2003), Gradstein & Costa (2003), Pursell (2007), and Gradstein & Ilkiu-Borges (2009). The taxonomic classifications adopted are in accordance with Goffinet et al. (2009) and Crandall-Stotler et al. (2009) for Bryophyta and Marchantiophyta, respectively.

The examined material will be deposited in the João Murça Pires Herbarium (MG) of the Museu Paraense Emílio Goeldi (MPEG).

Data analysis

The Brazilian and worldwide geographic distribution of the identified species were based on Costa et al. (2011), Yano (2011), Gradstein & Costa (2003), and BFG (2018).

The guild of tolerance (sun specialists, shade specialists, and generalists) were inferred on the base of the studies of Richards (1984), Gradstein et al. (2001), Gradstein & Ilkiu-Borges (2009), Tavares (2009), Santos et al. (2011), Visnadi (2013), Brito & Ilkiu-Borges (2014), Macedo & Ilkiu-Borges (2014), and Fagundes et al. (2016).

Considering plots as sampled unit and normal distribution of the data, the difference between richness and density of the species of the two parks were tested by the Tukey test in the software Past 3.24 (Hammer et al. 2013).

RESULTS AND DISCUSSION

Overall species richness

The field expeditions generated 465 samples (papers bags) containing bryophytes (254 from AGBMNP and 211 from CMNP), in which 1504 bryophyte specimens were identified (620 from AGBMNP and 884 from CMNP). The AGBMNP presented 53 species, 32 genera, and 13 families, while in the CMNP were registered 110 species, 57 genera and 22 families (Table SI - Supplementary Material).

Statistically, there was a significant difference between richness ($t = 11.33$, $p < 0.001$) and density ($t = 5.23$, $p < 0.001$) of bryophytes in the two parks (Figure 2). The average richness and density of species among the plots from CNMP was 40 and 84 specimens, respectively, and from AGBMNP was 16 and 50 specimens.

Despite the greater number of samples, the AGBMNP presented lower species and specimen richness when compared to CMNP. It was probably influenced by conservation level, localization, and size of each park.

In both parks, liverworts prevailed with 62% of the total richness, mainly by the large number of Lejeuneaceae species (60 spp.), which was more frequent as well, corresponding to 771 specimens of 1504. This family of leafy liverworts is largely known by its great distribution, diversity and importance in the neotropical region (Gradstein et al. 2001, Gradstein & Costa 2003, Gradstein & Ilkiu-Borges 2009). After Lejeuneaceae, Calymperaceae (15 spp./178 specimens) and Sematophyllaceae (5 spp./190 specimens) were also prevalent in the study areas (Figure 3).

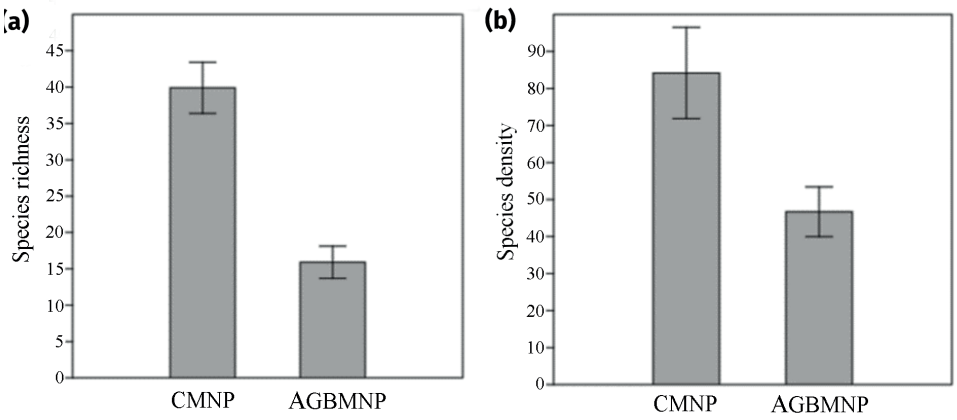

Figure 2. Average number and standard deviation of bryophytes in each studied Park in Amapá state. (a) Species richness. (b) Species density. CMNP= Cancão Municipal Natural Park; AGBMNP= Arivaldo Gomes Barreto Municipal Natural Park.

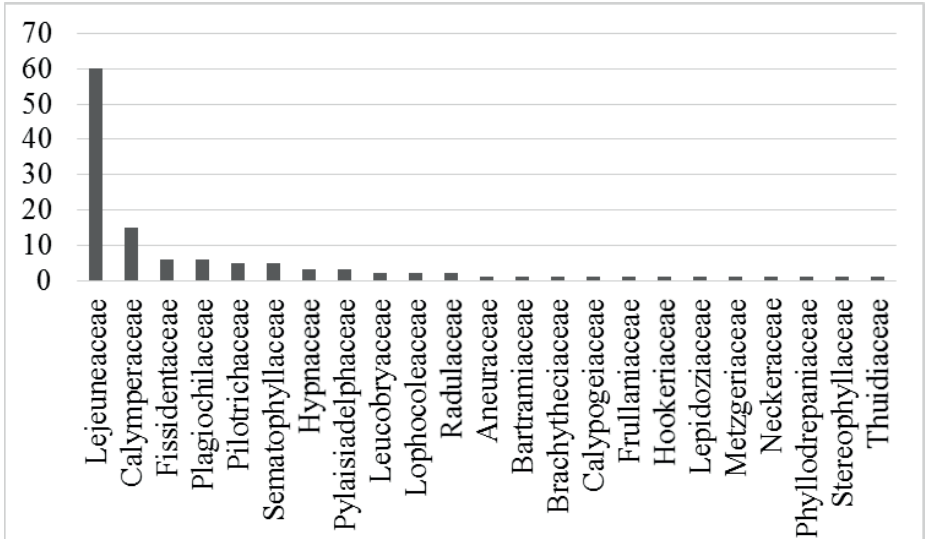

Figure 3. Species richness by bryophyte families in the two Municipal Natural Parks, Amapá state, Brazil.

Frequency of species

The species *Microcalpe subsimplex* (Hedw.) W. R.Buck, *Calymperes erosum* Müll. Hal., and *Cheilolejeunea oncophylla* (Ångstr.) Grolle & M.E.Reiner prevailed in the AGBMNP with 106, 50 and 48 occurrences, respectively. The species *Symbiezidium barbiflorum* (Lindenb. & Gottsche) A.Evans, *Prionolejeunea denticulata* (F.Weber) Schiffn.,*Ceratolejeunea cornuta* (Lindenb.) Steph., and *C. coarina* (Gottsche) Schiffn. were predominant in the CMNP with 43, 39, 39 and 34 occurrences, respectively. These species are well distributed in the Neotropics and are often recorded in the Amazon, as well as in Amapá State (Yano & Lisboa 1988, Yano 1992, Reese 1993, Gradstein 1994, Grolle & Reiner-Drehwald 1997, Churchill 1998, Gradstein & Costa 2003, Dauphin 2003, Lisboa et al. 2006, Gentil & Menezes 2011, Ilkiu-Borges 2016).

There are also a large number of rare species in the study area, which confirms rarity pattern generally found in the Amazon, where a small number of species obtained a large number of occurrences, while most species occurred one to five times (Magurran 2013). This pattern was found in several bryophyte studies conducted in Brazil, either in the Amazon or in the Atlantic Forest (e.g., Zartman 2003, Tavares-Martins et al. 2014, Pantoja et al. 2015, Fagundes et al. 2016, Valente et al. 2017, Oliveira-da-Silva & Ilkiu-Borges 2018).

Among rare species stand out *Zoopsidella serra* (Spruce) R.M.Schust. and *Cololejeunea contractiloba* A. Evans, with one and three occurrences, respectively. Both species are endemic to Brazil (Schuster 1999, Gradstein & Costa 2003). *Ceratolejeunea desciscens* (Sande Lac.) Schiffn., an endemic species to Brazil and the northern Andes (Dauphin 2003), presented only three occurrences in the CNMP.

Further species with rare occurrence numbers (*Caudalejeunea lehmanniana* (Gottsche) A. Evans, *Chrysohypnum diminutivum* (Hampe) W.R.Buck, *Frullania exilis* Taylor) are typical of open environments (Gradstein 1994, Gradstein et al. 2001, Hentschel et al. 2009), although the study areas enclosed upland forest only. It may explain their local rarity.

Some rare species are endemic to the Neotropics and were recorded in Brazil only to the Amazon region, such as *Cyclolejeunea foliorum* (Nees) Grolle, *Cololejeunea crenata* (A.Evans) Pócs, *Lejeunea asperrima* Spruce, *Pictolejeunea picta* (Steph.) Grolle, *Prionolejeunea muricatoserrulata* (Spruce) Steph., and *Thysananthus innovans* (Spruce) Sukkharak & Gradst. (Gradstein & Costa 2003, Ilkiu-Borges 2005, 2006, Zartman & Ilkiu-Borges 2007, Pócs & Bernecker 2009). *Cololejeunea sicaefolia* (Gottsche) Pócs & Bernecker, however, has a wider and disjunct distribution, being recorded in northern (Amazonas State), southeastern (São Paulo State), and northeastern Brazil (Pernambuco State) (Zartman & Ilkiu-Borges 2007).

Fissidens lagenarius var. *muriculatus* Pursell was registered in the Amazon region, but has a restricted distribution (Amazonas, Pará, Mato Grasso, and Rondônia States), if compared to *Fissidens lagenarius* Mitt. var. *lagenarius*, which is widespread in Brazil (Bordin 2013).

In addition to the species mentioned above, some species considered as rare in the study area have indeed a wide distribution in Brazil, such as *Cololejeunea cardiocarpa* (Mont.) A.Evans, *Cheilolejeunea acutangula* (Nees) Grolle, *C. holostipa* (Spruce) Grolle & R. L.Zhu, *Dibrachiella parviflora* (Nees) X. Q. Shi, R. L. Zhu & Gradst., *Diplasiolejeunea pellucida* (Spreng.) Schiffn., *Lepidopilum surinamense* Müll. Hal., *Metalejeunea cucullata* (Reinw. et al.) Grolle, *Metzgeria auriantica* Steph., *Neckeropsis undulata* (Hedw.) Reichardt, *Radula flaccida* Lindenb. & Gottsche, *Philonotis hastata* (Duby) Wijk. & Marg., *Plagiochila gymnocalycina* (Lehm. & Lindenb.) Mont. & Nees, *Pilotrichum evanescens* (Müll. Hal.) Crosby, *Syrrhopodon cymbifolius* Müll. Hal., *S. disciformis* Dusén, *S. rigidus* Hook. & Grev., *S. simmondsii* Steere, and *Zelometeorium patulum* (Hedw.) Manuel.

Substrates colonization

In the two studied parks, corticolous specimens were more commonly collected (867 specimens), followed by epixylous (378), epiphyllous (202), saxicolous (28), terricolous (22), and the ones growing on termite mounds (7) (Figure 4).

The richness of corticolous species is due to the diversity of trees, roots, vines, and woody lianas available for colonization in tropical rain forests. Bryophytes, however, rarely occur in soil in this type of vegetation, since litter covers the ground, but can colonize ravines or slopes (Richards 1984).

Epiphyllous species are important indicators of shaded and usually well preserved environments (Lisboa & Ilkiu-Borges 1995, Costa 1999, Zartman 2003). Indeed more than 95% of the epiphyllous species occurred in the CMNP. Alternatively, more than 97% of the saxicolous species occurred in the AGBMNP. In addition to rocks, however, most of the saxicolous species occurred on walls and sidewalks. Such substrates were not observed in CMNP. Bryophyte species colonize walls and sidewalks as an adaptive

strategy in anthropized environments (Lisboa & Ilkiu-Borges 1995, Bordin & Yano 2009).

Cheilolejeunea oncophylla (Ångstr.) Grolle & M. E.Reiner, *Fissidens pellucidus* Hornsch., *F. prionodes* Mont., *Microcalpe subsimplex* (Hedw.) W. R.Buck, *Octoblepharum albidum* Hedw., and *Syrrhopodon cryptocarpus* Dozy & Molk were the only species collected on termite mounds. Ilkiu-Borges (2000), while studying bryophytes in the Caxiuanã National Forest, Pará State, considered termite mounds a specific substrate because although being on or near the forest ground and formed mostly by soil, it also presented traces of decomposing wood.

Worldwide and Brazilian distribution

Seven different patterns of geographic distribution were recognized. The neotropical pattern was the most representative, presented by 75 species, followed by the pantropical pattern with 22 species. Nine species were exclusively distributed in South America, six in the Americas, six Afro-American, two were endemic to Brazil (*Zoopsidella serra* and *Cololejeunea contractiloba*), and one is distributed in Brazil and in the northern Andes (*Ceratolejeunea desciscens*).

The major distribution patterns found in the bryophyte community in the two studied parks in Amapá followed the ones found in several studies in Brazil, especially the neotropical and pantropical patterns (e.g., Valente & Pôrto 2006, Imbassahy et al. 2009, Santos et al. 2011, Valente et al. 2009, 2013, Brito & Ilkiu-Borges 2013, 2014, Garcia et al. 2014, Tavares-Martins et al. 2014, Fagundes et al. 2016, Carmo & Peralta 2016, Oliveira-da-Silva & Ilkiu-Borges 2018).

Among the endemic species, only *Cololejeunea contractiloba* has already been registered outside of the Amazon. It was recorded in Distrito Federal, which is included in the Cerrado biome. *Zoopsidella serra* and *Ceratolejeunea desciscens*, were recorded only for the states of Amazonas and Pará.

Arivaldo Gomes Barreto MNP versus Cancão MNP

The results shown a lower richness in AGBMNP than in CMNP (Figure 5), which may be related to the own size of each park, level of conservation, and its localization (Alvarenga & Pôrto 2007,

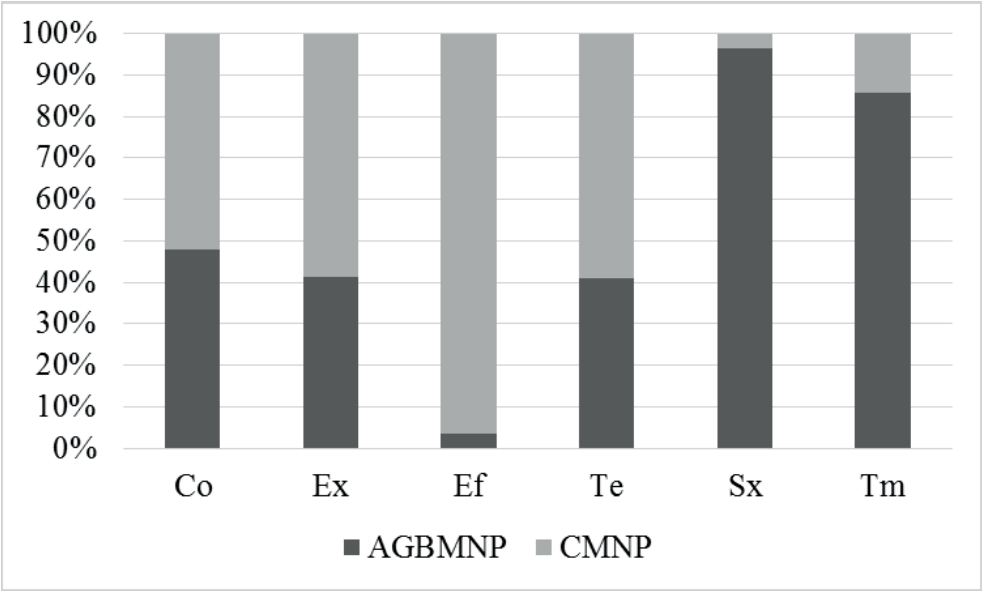

Figure 4. Distribution of bryophyte species per substrates in the two Municipal Natural Parks, Amapá state, Brazil. Co= Corticolous; Ex= Epixylous; Ef= Epiphyllous; Te= Terricolous; Sx= Saxicolous; Tm= Termite mound; CMNP= Cancão Municipal Natural Park; AGBMNP= Arivaldo Gomes Barreto Municipal Natural Park.

Zartman 2003, Zartman & Nascimento 2006, Silva & Pôrto 2009, Fagundes et al. 2016). The AGBMNP is a much smaller fragment of upland forest, about 15% of the CMNP's size, located in the urban area of Macapá, the state's capital. The proximity of the largest urban center of Amapá affected the area by urban grown, pollution, and, in addition, it is usually visited for recreation and public leisure.

The CMNP, in contrary, is a larger area (370.26 ha), located in the central portion of Amapá, on the banks of the Amapari River in the Serra do Navio, which is still in good condition and it was not enclosed by the urban area. However, even in a good state of conservation, the park is near to the county seat of Serra do Navio municipality, which also have to undergo mining activities (Drummond et al. 2008).

The AGBMNP, for being influenced by the Macapá urban center, presented the species *Calymperes palisotii* Schwägr., cited by Reese (1979), Lisboa & Ilkiu-Borges (1995), and Yano & Câmara (2004) as a species of high frequency in urban or disturbed areas. In addition, a large number of families registered in CMNP, were not registered in the AGBMNP, such as Aneuraceae, Brachytheciaceae, Hookeriaceae, Lophocoleaceae, Metzgeriaceae, Neckeraceae, Phylodrepaniaceae, and Radulaceae. Moreover, the AGBMNP lacked species typical of more preserved environments, such as species of *Cyclolejeunea* A.Evans and *Prionolejeunea* (Spruce) Schiff.

Another important difference between the two parks is the species composition. The bryophyte flora of the AGBMNP is composed mostly by generalist species (50%), while the CMNP is composed by both generalists (46%) and shade specialists (36%).

Isolation and size of the forest fragment are related to richness of generalist and specialist species, besides the presence of epiphyll species (Alvarenga & Pôrto 2007). Indeed, how less isolated and larger is the forest fragment, higher is the richness of shade specialists and epiphyllous species, especially epiphyllous liverworts. However, how more isolate and smaller is the fragment, higher is the number of generalist species.

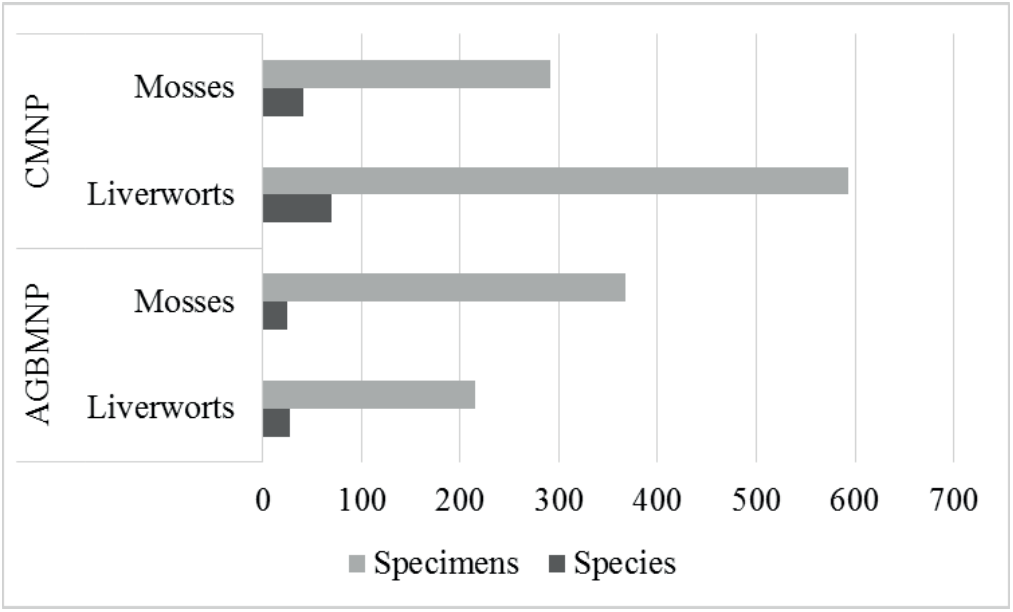

Figure 5. Number of species and specimens of mosses and liverworts in the two Municipal Natural Parks, Amapá state, Brazil .CMNP= Cancão Municipal Natural Park; AGBMNP= Arivaldo Gomes Barreto Municipal Natural Park.

A further factor indicated to explain a greater occurrence of generalist species and lower occurrence of specialist species is the microclimate of the fragment, in spite of its size (Silva & Pôrto 2009). The presence of urban pressure near to a fragment is a factor of raising richness of generalist species as well (Fagundes et al. 2016).

Therefore, it is believed that habitat fragmentation is favoring the predominance of generalists in the AGBMNP, and good conservation status of the CMNP is favoring the appearance of shade specialists.

Increase of species for Amapá

The literature about bryophytes in Amapá indicate the register of 100 species (Crosby 1969, Grolle 1984, Yano 1982, Yano & Lisboa 1988, Churchill 1998, Gradstein & Costa 2003, Lisboa et al. 2006, Gentil & Menezes 2011). This study recorded 54% of the known bryophyte flora and added further 63 new records for Amapá State and three new records for the Northern region of Brazil (*Neurolejeunea breutelii* (Gottsche) A. Evans, *Prionolejeunea mucronata* (Sande Lac.) Steph., and *Plagiochila aerea* Taylor).

These results highlight the importance of continuously perform floristic surveys, particularly in poorly explored regions. Although highly conserved, the Amapá State is unwell known with regard to its flora, more specifically to its bryophyte flora. Hallingbäck & Hodgetts (2000) pointed out that in spite of the vast number of publications, the bryophyte flora in the Neotropics was incompletely known. Their statement (loc. cit.) that large parts of the Amazonia were basically "*terra incognita*" is still up to date, even though successful efforts have been made to study important and unexplored areas such as Amazonian mountains (Costa 2017, Costa et al. 2017, Oliveira-da-Silva & Ilkiu-Borges 2018), remnants of the Amazonian forests in Maranhão State (Brito & Ilkiu-Borges 2014, Macedo & Ilkiu-Borges 2014), the Marajó island (Brito & Ilkiu-Borges 2013), among others.

Considering the current knowledge on the Amapá bryophyte flora, the two studied parks are important conservation units that present a significant portion (67.5%) of the bryophyte diversity of the state. The registration of many new occurrences for Amapá and three new records for the Northern region of Brazil contributes to the knowledge of the richness, floristic composition, and distribution of bryophytes in the state and in Amazonia.

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SUPPLEMENTARY MATERIAL

Table SI.

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