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# Beta-diversity: Effect of geographical distance and environmental gradients on the rocky outcrop bryophytes

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**Abstract** – The rocky outcrops are indeed islands amidst a "sea" of soil and thus their floristic composition and species diversity are influenced by stochasticity. Our discovery was settled to regional level, mainly from the Mantel tests (rM = 0.41, p = 0.01) and partial Mantel (rM = 0.41, p = 0.03), significant when contrasting the floristic *x* geographical distances and floristic *x* geographical distances with environment distance weighted, respectively. At the local level, clustering by Group mean (UPGMA) did not show a general pattern for the geographical distance, suggesting that in outcrops stochastic processes are the major actors at the regional scale while the local level need to be more intensely studied in order to reach better conclusions.

**Bryophytes / plant communities / dispersion / similarity / Inselberg**

## INTRODUCTION

Biodiversity is irregularly distributed over the planet (Carvalho, 2011) as species have different ecological requirements, and their individual demands will modify plant community compositions depending on the concentrations of resources available to each (see the Resource-Dependent Hypothesis in Tilman (1985)). Heterogeneity in plant communities is commonly expressed along water and light intensity gradients (Tilman, 1984), which, allied to the adaptive capacities of species, provide them with opportunities for establishment, success, and domination (Cardoso & Schiavini, 2002).

The forces acting on the structuring of different plant communities have not yet been fully elucidated (Svenning *et al.*, 2004), however, and there are two principal theories used to explain their organization: the Neutral (see Hubbel, 2001) and Deterministic theories (see Chase & Meyers, 2011). A number of projects have been undertaken to establish what factors influence bryophyte distributions (*e.g.*, Grytnes *et al.*, 2006; Ah-Peng *et al.*, 2007; Corrales *et al.*, 2010; Silva & Pôrto, 2013) and the resultant similarities and differences between different areas (*e.g.*, Oliveira et al., 2009; Santos *et al.*, 2011; Santos *et al.*, 2014), and researchers have found generally that bryophyte distributions are more closely related to niche conditions than to stochastic processes (the latter being seen in forest formations). Studies of this type that focus on plant communities in rocky environments have been rare (*e.g.*, Valente *et al.*, 2013; Sun *et al.*, 2013),

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however, and have only examined a single spatial scale – which leads to the question of whether deterministic processes are similarly acting to determine the distributions of bryophytes on rock outcrops, even though these environments are unique and isolated?

Spatial scales are important elements in understanding diversity patterns, and although regional diversity can often be explained by the dispersal capacities of species, their ecological requirements and interspecific interactions (*e.g.*, competition) will determine where they can successfully occur and persist (demonstrating fitness) – which will of course determine local diversity (ter Steege & Zagt, 2002). As such, both scales (regional and local) should be considered together (Ricklefs & Schluter, 1993).

The species that occupy a given rock outcrop can differ greatly from those at another site (Burke, 2002), depending on the environmental filters acting in each environment (Durigan *et al.*, 2003; Grytnes *et al.*, 2006; Ah-Peng *et al.*, 2007; Oliveira *et al.*, 2009), even in the same climatic domain.

Within this context, we hypothesize that environmental filters are determinants for the compositions of plant communities (especially of bryophytes) on rock outcrops as beta diversity (regional) can vary according to habitat heterogeneity and other environmental factors, with deterministic processes acting intensively at local scales (Ricklefs & Schluter, 1993). As such, we would expect that environmental filters related to water (Gabriel & Bates, 2005) and light availability (Bergamini & Peintinger, 2002) could largely explain the composition, richness, and similarities between bryophyte communities at both regional (among different rock outcrops) and local scales (among different soil islands within the same rock outcrop).

We therefore sought to evaluate the influence of abiotic factors (*e.g.,* altitude, latitude, temperature, and water availability) on bryophyte species distributions at both local and regional scales to better understand their phytogeographical patterns.

## MATERIALS AND METHODS

### Study locality and descriptions of the areas

Eighteen rock outcrops (ROs) were selected in northeastern Brazil. Eight were selected using the Google Earth program available at http://www.softonic.com.br/s/google-earth-2012, considering both abiotic (*e.g.,* altitude and their numbers of soil islands) and biotic parameters (*e.g.,* vegetation cover and surrounding matrix). Complementary information (*e.g.,* use of the areas by local populations and/or visitors) was obtained through informal conversations with local inhabitants. Bryo-floristic lists from 10 additional outcrops in the same region of the country and derived from the following studies were incorporated into the analyses: Valente & Pôrto (2006); Silva (2012) (unpublished data), and Silva & Germano (2013).

The ROs were surrounded by matrices of either Caatinga (dryland vegetation) or altitudinal forests (Fig. 1). Altitudinal forests in the region demonstrate disjunct distributions in the midst of the Caatinga but contain species found in both Atlantic and Amazon Forest habitats (Andrade-Lima, 2007).

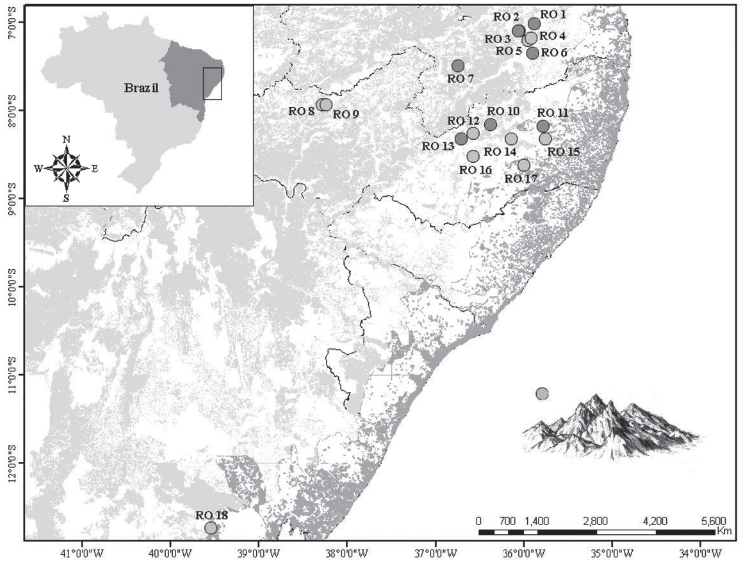

Fig. 1. Location of the 18 Rocky Outcrops (RO) sampled in the Caatinga and Atlantic Forest remaining in northeastern Brazil. The RO were listed according to the latitudinal gradient. Circle refers to RO. Light gray in the principal map means Caatinga remaining; dark gray means Atlantic Forest remaining. These remaining shapes are data from 2008 and 2007 years, respectively.

All of the climatic variables available in the DIVA-GIS 5.2 software program (Hijmans *et al.,* 2005a) were used, based on World-Clim data (2.5 arc-minutes) (Hijmans *et al,.* 2005b). Latitudinal and altitudinal data (from a hand-held GPS) were incorporated, as well as the distances to the coast as derived from Google Earth images (Table 1).

## Experimental design

The bryophytes were removed from the substrate by a knife or spatula and placed in paper bags. In addition, the microhabitat, collector number, area and soil depth of soil island (when on island), were noted on the paper bag. The samples (when wet) were spread in a room in one layer and until dried and then sent to the herbarium. This technique was described in Yano (1984), Gradstein *et al*. (2001) and Frahm (2003). The total of 177 samples was collected from all of the substrates typically available on rock outcrops: soils (soil islands), tree trunks, rock surfaces, and crevices.

Five of the eight ROs sampled here (RO1, RO6, RO7, RO10 and RO13) were used to evaluate the similarity of the bryoflora at the local level (between different soil islands on the same RO). We adopted the concept of soil islands as being any soil plot larger than 10 cm$^2$ with or without plant cover (adapted from Conceição *et al.,* 2007). The rock outcrops selected for these analyses were chosen based on the numbers of soil islands (more than 60 islands on each RO) and their plant cover (the presence of dense vegetation on rocky outcrop top). The soil islands of these ROs were visually mapped from the tops of the outcrops to their bases, and 60 of them were marked – and 15 to 20 were subsequently randomly selected for analysis.

Table 1. Location and environmental data from Rocky Outcrops (RO) sampled and from literature
Ca = Caatinga biome; Af = Altitudinal forest

Geographical world and in Brazil distribution and phytogeographic domains of occurrence of bryophytes found in Rocky Outcrops of the Paraíba, Pernambuco and Bahia states. * = New record for Paraíba state; ** = New record for Pernambuco state; ! = New record for Pernambuco state according to Silva (2012) (unpublished data). Species with no markings and no match for the states mentioned above have been given from listings in bryophyte literature.

| ***Rocky Outcrop*** | ***State*** | ***Coordinates*** | ***Annual precipitation (mm)*** | ***Annual mean temperature (ºC)*** | ***Altitude (m)*** | ***Distance from sea (Km)*** | ***Matrix*** |
|---|---|---|---|---|---|---|---|
| RO1 | Paraíba (PB) | 7º00’57.83”S<br>35º52’49.07”W | 623 | 23.1 | 616 | 118.53 | Af |
| RO2 | Paraíba (PB) | 7º05’49.57”S<br>36º03’38.12”W | 362 | 23.3 | 682 | 135.22 | Af |
| RO3 | Paraíba (PB) | 7º06’13.39”S<br>36º03’18.48”W | 362 | 23.3 | 577 | 134.22 | Af |
| RO4 | Paraíba (PB) | 07°14’91”S<br>35°97’64”W | 520 | 23.7 | 575 | 127.5 | Af |
| RO5 | Paraíba (PB) | 7º08’62”S<br>35º58’31”W | 418 | 24.2 | 661 | 123.22 | Af |
| RO6 | Paraíba (PB) | 7°21'10.34"S<br>35°54'11.25"W | 466 | 24.7 | 584 | 122.2 | Af |
| RO7 | Paraíba (PB) | 7º29’51.44”S<br>36º44’29.89”W | 393 | 24.2 | 701 | 212.89 | Af |
| RO8 | Pernambuco (PE) | 7º49’21.9” S<br>38º03’19.4”W | 638 | 24.9 | 1165,5 | 375.95 | Af |
| RO9 | Pernambuco (PE) | 7º56’10.9” S<br>38º18’11.3”W | 633 | 24.8 | 657,5 | 357.99 | Af |

Table 1. Location and environmental data from Rocky Outcrops (RO) sampled and from literature *(continued)*
Ca = Caatinga biome; Af = Altitudinal forest

Geographical world and in Brazil distribution and phytogeographic domains of occurrence of bryophytes found in Rocky Outcrops of the Paraíba, Pernambuco and Bahia states. * = New record for Paraíba state; ** = New record for Pernambuco state; ! = New record for Pernambuco state according to Silva (2012) (unpublished data). Species with no markings and no match for the states mentioned above have been given from listings in bryophyte literature.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RO10 | Pernambuco (PE) | 8º08’33.16”S<br>36º22’22.58”W | 522 | 22.6 | 1189 | 160.81 | Ca |
| RO11 | Pernambuco (PE) | 8º10’54.09”S<br>35º46’56.39”W | 589 | 22.4 | 836 | 97.01 | Ca |
| RO12 | Pernambuco (PE) | 8°14’28.5”S<br>36°23’08.9”W | 511 | 22.8 | 997,5 | 165.66 | Af |
| RO13 | Pernambuco (PE) | 8º19’40.26”S<br>36º42’21.26”W | 609 | 21.7 | 1094 | 192.17 | Af |
| RO14 | Pernambuco (PE) | 8°19’33”S<br>36°08’34”W | 432 | 23.2 | 867,5 | 131.37 | Af |
| RO15 | Pernambuco (PE) | 8º19’37.6”S<br>35º45’12.7”W | 642 | 22.1 | 696 | 89.31 | Ca |
| RO16 | Pernambuco (PE) | 8°30’13”S<br>36°56’41.7”W | 540 | 23.1 | 639 | 212.24 | Af |
| RO17 | Pernambuco (PE) | 8°37’28.1”S<br>35°58’51.1”W | 672 | 23.3 | 524 | 105.19 | Ca |
| RO18 | Bahia (BA) | 12º44’06.59”S<br>39º32’40.88”W | 600 | 24 | 800 | 151.89 | Af |

## Sample treatments

The bryophyte taxa were identified based on the works of Bischler-Causse *et al.* (2005), Reese (1993), Buck (1998), Sharp *et al.* (1994), Gradstein *et al.* (2001), Gradstein & Costa (2003), and Goffinet & Buck (2004), as well as theses concentrating on certain groups, and by consulting specialists (when necessary). The classification systems adopted followed Crandall-Stotler *et al.* (2009) for liverworts and Goffinet *et al.* (2009) for mosses. The nomenclature was confirmed following Brummit & Powell (1992).

The geographical distributions of the species were determined based on the "Flora do Brasil" site of the Rio de Janeiro Botanical Garden <http://floradobrasil.jbrj.gov.br/> and the catalogs prepared by Yano (1989-2011); the phytogeographical patterns of the species were obtained from the Missouri Botanical Garden site (http://www.tropicos.org/Home.aspx), the Flora of North America <http://floranorthamerica.org/families>, and related publications (*e.g.*, Santos *et al.*, 2011).

The specimens collected were stored in the Geraldo Mariz Herbarium (UFP) at the Federal University of Pernambuco (UFPE) and a duplicate was sent to the Manuel de Arruda Câmara Herbarium (UEPB) at the State University of Paraíba, registered with the collector number S 172.

## Data analysis at the regional level

In order to minimize effects of noise in the analyses, we performed outlier analyses with a general cutoff of 2.0 based on the standard error, using PCOrd software ((McCune & Mefford, 1999).

The Sørensen similarity index was used to produce a dendrogram demonstrating the similarities between the areas – as this index lends greater weight to the repeated presence of species (Valentin, 2012). As the floristic data were obtained from many different studies, we chose the Weighted Pair Group Method With Arithmetic Means (WPGMA) to minimize the effects of varying sampling efforts (Valentin, 2012). We used the "rule of thumb" technique (cf. Hair *et al.* (2006)), in which groupings are considered more consistent when their Cophenetic Correlation Coefficients (CCC) have values above 0.80.

We employed Multi-response Permutation Procedures (MRPP) to test the consistencies of the group generated by the WPGMA using Simple Euclidian distances (McCune & Grace, 1999), with PCOrd software. The change-corrected (A) was calculated (with A = 0 signifying that heterogeneities within and outside the group are equivalent; and A = 1 signifying that the members of a given group are identical among themselves).

Principal Component Analysis (PCA) was employed to avoid multicolinearity between the environmental variables – generating an ordination diagram that used only the variables that best explained (both statistically and biologically) the groupings among the ROs. The environmental matrix was standardized through 'ranging' to determine the least redundant variables with the greatest abilities to explain the separations or unions of the experimental points. The Broken Stick method was adopted as a stopping rule for the retention of the principal components. Based on these results, Canonical Correspondence Analysis (CCA) was employed using LC scores to maximize the correlations between the two data sets (bryophyte compositions x environmental variables), applying Monte Carlo randomizations (Monte Carlo test with 999 randomizations) to evaluate their significance. Both tests (PCA and CCA) were run using FITOPAC 2.1 software (Shepherd, 2010).

To evaluate the influence of the geographical distances between the rock outcrops and the environmental variables that act on their bryofloristic compositions, we calculated the Mantel coefficient of the correlation matrix (rM) with 999 permutations (cf. Legendre & Legendre, 1998). To that end, we prepared a geographical matrix of the distances between the rock outcrops, a bryofloristic matrix (presence x absence among the ROs), and an environmental matrix. To measure the effects of the environmental variables on the presence of bryophytes while controlling for the effects of geographical distances – and vice-versa – we calculated the Mantel Partial Coefficient (Smouse *et al.*, 1986). These analyses were performed using PASSaGE 2 software (Rosenberg & Anderson, 2011).

### Data analyses at the local level

A soil island *x* species matrix was constructed with the marker variable being the size classes island soil. In terms of the size classes, we classified the soil islands as follows: small (0-5 $m^2$), intermediate (> 5-10 $m^2$), and large (> 10 $m^2$). However, as the dendrogram generated from the marker size of the island showed no pattern of clustering and visualization has become confused, we prefered to use the dendrogram with no marker size.

The procedures used to identify outliers and to apply the similarity indices were identified to those used in analyses at the regional level (among rock outcrops).

In order to ordinate the different bryophyte species and detect similarities between islands, we produced an Unweighted Pair Group Method with Arithmetic Mean (UPGMA) dendrogram based on their *Sørensen* similarity indices, and used the "rule of thumb" technique (see Hair *et al.* (2006)) to evaluate its consistency.

## RESULTS

### Regional level bryofloristic richnesses and distribution patterns

At the regional level (*i.e.*, the 18 ROs studied) a total of 90 species were encountered, distributed among 24 families and 50 genera. Of these, 18 families, 34 genera, and 54 species belonged to the Bryophyta, while six families, 16 genera, and 36 species belonged to the Marchantiophyta.

The best represented liverwort families were Lejeuneaceae (14 spp.) and Frullaniaceae (10 spp.), followed by Metzgeriaceae (5 spp.). The best represented moss families were Bryaceae, Calymperaceae, Fissidentaceae, and Orthotrichaceae (6 spp., each), followed by Leucobryaceae and Pottiaceae (5 spp., each).

Most of the species demonstrated Neotropical distributions (42.7%), followed by those that were widely distributed (28.8%), Pantropical (21.3%), from Africa and the Americas (6.7%), endemic to Brazil (2.2%), and Holarctic (1%). Of the species endemic to Brazil, *Riccia taeniaeformis* Jovet-Ast occurs only rarely (in only two states), while *Odontoschisma longiflorum* (Taylor) Steph. represented a new occurrence for Pernambuco state (referred to the Annex for additional detailed floristic information).

## Regional level composition and similarity, and correlations with environmental variables

None of the rocky outcrop was sufficiently different from the others to be disconsidered through outlier analysis (Table 2). Sørensen's similarity index demonstrated the most similar rocky outcrop pairs with 0.78 and 0.82 values. While the lowest similarity value was 0.00 for the pairs less similar (Table 2).

The grouping analyses (WPGMA) did not show consistent groups by states, with a Cophenetic Correlation Coefficient (CCC) of 0.70 (Fig. 2). Even discounting the rare species (recorded in only a single RO), the consistency of the analysis did not vary (CCC 0.73) and the groupings were not modified. For that reason, we chose to work with all of the species inventoried.

The results of the MRPP demonstrated that the groups formed using WPGMA were coherent (change-corrected A = 0.18 and p = 0.000009). The analyses indicated greatest cohesion among groups 3 (A = 0.67) and 4 (A = 0.75), and the least cohesion among groups 1 (A = 0.20) and 2 (A = 0.11). In general, the outcrops are similar in composition within each of the groups formed by WPGMA.

With relation to the environmental variables, the first PCA axis explained 47.51% of the groupings formed, and the second axis 34.20% (totaling 81.71%) – indicating a good ability to reduce overlap. The least collinear variables that had the greatest grouping power (in terms of the ROs) are illustrated in Fig 3.

Temperature seasonality and annual precipitation (water availability) were strongly correlated with axis 1. The rocky outcrops that received the lowest annual rainfalls were located in Paraíba State (with the exception of RO14, located in Pernambuco State, which grouped with the ROs in Paraíba). Rocky outcrops in Pernambuco received the greatest annual precipitation and had the most moderate temperatures, with the exception of RO1 in Paraíba (which grouped with those ROs in Pernambuco). The rocky outcrop 8 and 9 grouped close to each other but distant from the other ROs, and were more highly correlated with their distances from the ocean on axis 2 (Fig. 3) (refer to Table 3 for the values of the variable correlations x axes).

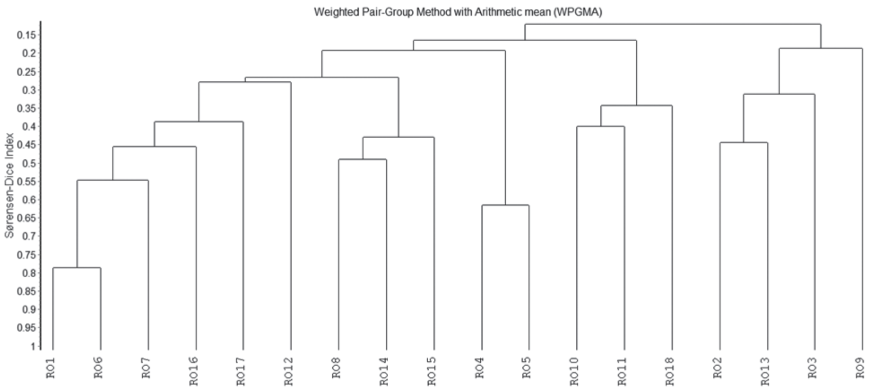

Fig. 2. Dendrogram of floristic similarity (WPGMA) based on the Sørensen similarity index. OR = Rocky Outcrops. The locations data are shown on Table 1. Groups formed by the WPGMA used in the permutation procedure (MRPP) are respectively, group 1 – RO1, 6, 7, 16, 17, 12; group 2 – RO8, 14, 15, 9, 5; group 3 – RO10, 11, 18; group 4 – RO2, 13, 3, 9

Table 2. Comparison between richness and similarity of bryophyte rock outcrops located between Paraíba and Pernambuco states
RO = Rocky Outcrop; Bold = total number of species for rocky outcrop; Italics = Sørensen similarity index with the exclusion of the rare species in each rocky outcrop; SD = standard deviation values for Analysis "Outlier" (cutoff = 2.0) * = higher values for the Sørensen similarity index, ** = lower values for the Sørensen similarity index; common font = number of species common among ROs.

| | **_RO1_** | **_RO2_** | **_RO3_** | **_RO4_** | **_RO5_** | **_RO6_** | **_RO7_** | **_RO8_** | **_RO9_** | **_RO10_** | **_RO11_** | **_RO12_** | **_RO13_** | **_RO14_** | **_RO15_** | **_RO16_** | **_RO17_** | **_RO18_** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **RO1** | **15** | _0.21_ | _0.30_ | _0.32_ | _0.23_ | _0.78*_ | _0.52*_ | _0.40_ | _0.19_ | _0.29_ | _0.27_ | _0.30_ | _0.30_ | _0.45_ | _0.34_ | _0.43_ | _0.38_ | _0.16_ |
| **RO2** | 2 | **4** | _0.22_ | _0.30_ | _0.13_ | _0.23_ | _0.33_ | _0.18_ | _0.20_ | _0.17_ | _0.24_ | _0.22_ | _0.44_ | _0.16_ | _0.25_ | _0.16_ | _0.00**_ | _0.08_ |
| **RO3** | 3 | 1 | **5** | _0.19_ | _0.12_ | _0.44_ | _0.46_ | _0.11_ | _0.18_ | _0.16_ | _0.15_ | _0.00**_ | _0.40_ | _0.24_ | _0.08_ | _0.30_ | _0.18_ | _0.07_ |
| **RO4** | 5 | 3 | 2 | **16** | _0.81_ | _0.27_ | _0.25_ | _0.22_ | _0.09_ | _0.22_ | _0.32_ | _0.09_ | _0.19_ | _0.22_ | _0.38_ | _0.16_ | _0.18_ | _0.05_ |
| **RO5** | 3 | 1 | 1 | 11 | **11** | _0.16_ | _0.21_ | _0.20_ | _0.00**_ | _0.20_ | _0.25_ | _0.12_ | _0.12_ | _0.19_ | _0.32_ | _0.10_ | _0.23_ | _0.06_ |
| **RO6** | 11 | 2 | 4 | 4 | 2 | **13** | _0.57_ | _0.28_ | _0.10_ | _0.18_ | _0.35_ | _0.33_ | _0.33_ | _0.36_ | _0.24_ | _0.38_ | _0.42_ | _0.11_ |
| **RO7** | 6 | 2 | 3 | 3 | 2 | 6 | **9** | _0.21_ | _0.14_ | _0.29_ | _0.20_ | _0.15_ | _0.46_ | _0.35_ | _0.21_ | _0.50*_ | _0.28_ | _0.13_ |
| **RO8** | 9 | 3 | 2 | 5 | 4 | 6 | 4 | **29** | _0.17_ | _0.16_ | _0.24_ | _0.17_ | _0.17_ | _0.49_ | _0.40_ | _0.27_ | _0.28_ | _0.16_ |
| **RO9** | 2 | 1 | 1 | 1 | 0 | 1 | 1 | 3 | **6** | _0.08_ | _0.14_ | _0.00**_ | _0.18_ | _0.30_ | _0.07_ | _0.42_ | _0.00**_ | _0.07_ |
| **RO10** | 5 | 2 | 2 | 4 | 3 | 3 | 4 | 4 | 1 | **20** | _0.40_ | _0.16_ | _0.33_ | _0.25_ | _0.20_ | _0.14_ | _0.08_ | _0.35_ |
| **RO11** | 5 | 3 | 2 | 6 | 4 | 6 | 3 | 6 | 2 | 8 | **21** | _0.23_ | _0.23_ | _0.29_ | _0.29_ | _0.13_ | _0.14_ | _0.33_ |
| **RO12** | 3 | 1 | 0 | 1 | 1 | 3 | 1 | 3 | 0 | 2 | 3 | **5** | _0.20_ | _0.24_ | _0.32_ | _0.15_ | _0.36_ | _0.15_ |
| **RO13** | 3 | 2 | 2 | 2 | 1 | 3 | 3 | 3 | 1 | 4 | 3 | 1 | **5** | _0.24_ | _0.16_ | _0.30_ | _0.18_ | _0.15_ |
| **RO14** | 8 | 2 | 3 | 4 | 3 | 6 | 5 | 12 | 4 | 5 | 6 | 3 | 3 | **20** | _0.45_ | _0.45_ | _0.45_ | _0.45_ |
| **RO15** | 6 | 3 | 1 | 7 | 5 | 4 | 3 | 10 | 1 | 4 | 6 | 4 | 2 | 9 | **20** | _0.14_ | _0.14_ | _0.14_ |
| **RO16** | 5 | 1 | 2 | 2 | 1 | 4 | 4 | 5 | 3 | 2 | 2 | 1 | 2 | 6 | 2 | **8** | _0.42_ | _0.42_ |
| **RO17** | 4 | 0 | 1 | 2 | 2 | 4 | 2 | 5 | 0 | 1 | 2 | 2 | 1 | 4 | 3 | 3 | **6** | _0.07_ |
| **RO18** | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 1 | 7 | 7 | 2 | 2 | 2 | 2 | 1 | 1 | **21** |
| **S.D.** | – 1.82 | 0.55 | 0.46 | – 0.20 | 0.61 | – 1.50 | – 1.21 | – 0.06 | 1.74 | 0.38 | – 0.14 | 0.88 | – 0.30 | – 1.00 | – 0.11 | – 0.46 | 0.32 | 1.87 |

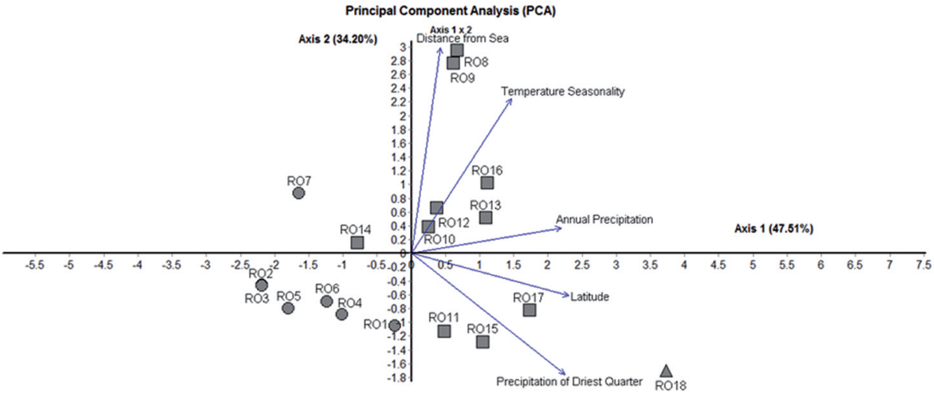

Fig. 3. Principal Component Analysis (PCA) rock outcrops based on the most influential enviromental variables for the studied areas. ● = RO located in the Paraíba state; ■ = RO located in the Pernambuco state; ▲ = RO located in the Bahia state.

Table 3. Correlation between environmental variables with their respective axes chosen (Axis 1 and Axis 2) for Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA)

| | ***PCA*** | | ***CCA*** | |
|---|---|---|---|---|
| ***Environmental variables*** | ***Axis 1*** | ***Axis 2*** | ***Axis 1*** | ***Axis 2*** |
| Temperature Seasonality | 0.7917 | -0.4166 | 0.0495 | – 0.8641 |
| Precipitation of Driest Quarter | 0.4703 | 0.8235 | 0.8191 | 0.1748 |
| Latitude | 0.5802 | 0.4726 | 0.9872 | – 0.1508 |
| Distance from Sea | 0.5207 | – 0.7145 | – 0.1252 | – 0.8689 |
| Annual Precipitation | 0.7909 | 0.3470 | 0.2607 | – 0.4360 |

Although Latitude did not demonstrate a very high correlation index in relation to axis 1 (Table 3), the latitudinal gradient was well demarked in the ordination, separating the rocky outcrop situated at lower latitudes from those at higher latitudes (Fig. 3). This variable was most related to RO17 and 18 (with the highest latitude value).

The CCA (Fig. 4) demonstrated that the bryophyte communities of the rocky outcrops in Paraíba state and some of them in Pernambuco state were related to (the lowest) levels of annual precipitation and to (the lowest) levels of precipitation in the driest trimester. Latitude was the variable that had the greatest explicatory value for the groupings formed. Temperature, Seasonality, and Distance from the sea were found to be the most important variables for grouping another ROs in Pernambuco (refer to the correlations of the variables with the axes in Table 3). The Monte Carlo test confirmed the consistencies of the first three CCA axes (p values = 0.05 (AV1); 0.01 (AV2), and 0.02 (AV3)).

The Mantel test demonstrated significant correlations between the distance matrix and the floristic matrix, whereas correlations between the environmental matrix and the floristic matrix were not significant. The correlation

Table 4. Mantel correlations (rM) of the species similarities of bryophytes (using the Sørensen index) with geographical distance matrix and environmental matrix in 18 Rocky Outcrops

| ***Distance*** | ***Correlation (rM)*** | ***p*** |
|---|---|---|
| Floristic *x* environmental | 0.07 | 0.26 |
| Floristic *x* geographic | 0.41 | 0.01 |
| Environmental *x* geographic | 0.42 | 0.0003 |
| Floristic *x* environmental (controlling the effect of the geographical matrix) | – 0.11 | 0.82 |
| Floristic *x* geographic (controlling the effect of the environmental matrix) | 0.41 | 0.03 |

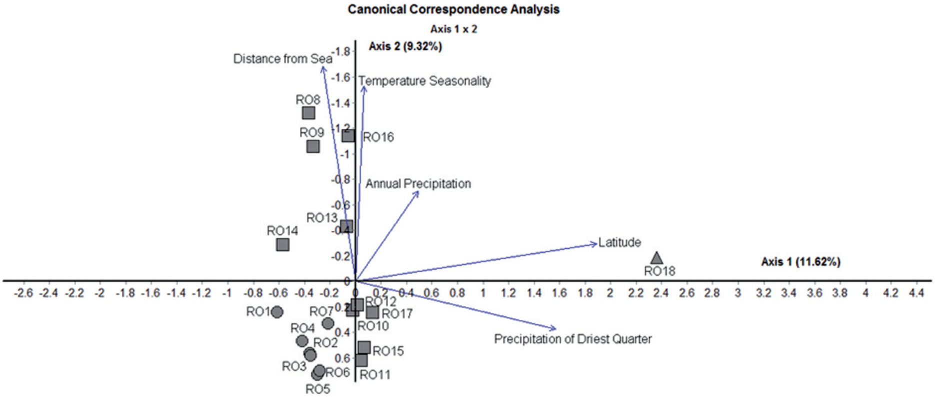

Fig. 4. Results of Canonical Correspondence Analysis (CCA first two axes) showing clusters of rocky outcrops (RO) by state and five influential environmental variables (arrows represent the correlation of physical variables with the canonical axes). ● = RO located in the Paraíba state; ■ = RO located in the Pernambuco state; ▲ = RO located in the Bahia state.

between species composition and geographical distance controlled the influences of the climatic variables, and vice-versa, confirming the results above (refer to the results in Table 4).

## Local level bryofloristic richness and phytogeographical patterns

Thirty species grouped into 18 families and 23 genera were recorded among all the soil islands, with species richnesses varying from 1 to 8 per soil island. Among these species, 12 families, 15 genera and 20 species were mosses, and six families, eight genera and 10 species were liverworts. The best represented liverwort families were Frullaniaceae (3 spp.), Lejeuneaceae, and Cephaloziaceae (2 spp.). The best represented moss families were Leucobryaceae and Fissidentaceae (3 spp.) (Table 5).

In terms of their phytogeographical patterns, most species were Pantropical (40%), followed by those with Neotropical distributions (36.7%). The other species were widely distributed (10%), African and American (6.7%), and Cosmopolitan (3.3%). Most of the taxa typically associated with forests were

Table 5. Frequency of bryophytes occurring in soil islands by rocky outcrop and its phytogeographical pattern

| *Division/Family/Specie* | *Rocky Outcrop (RO)* | | | | | *Pattern Phytogeographic* | *Collector number* |
|---|---|---|---|---|---|---|---|
| | *RO1* | *RO6* | *RO7* | *RO10* | *RO13* | | |
| **BRYOPHYTA** | | | | | | | |
| **Archidiaceae (1/1)** | | | | | | | |
| *Archidium ohioense* Schimp. *ex* Müll. Hal. | – | 1 | – | – | – | Pan | S 175 |
| **Bartramiaceae (1/1)** | | | | | | | |
| *Philonotis hastata* (Duby) Wijk *et* Margad. | 3 | – | – | – | – | Pan | S 224 |
| **Brachytheciaceae (1/1)** | | | | | | | |
| *Zelometeorium patulum* (Hedw.) Manuel | – | – | – | 1 | – | Neo | S 183 |
| **Bryaceae (3/3)** | | | | | | | |
| *Bryum argenteum* Broth. | 2 | 2 | – | 2 | 2 | Cos | S 202 |
| *Gemmabryum exile* (Dozy *et* Molk.) J.R. Spence *et* H.P. Ramsay | 3 | 5 | 6 | 1 | 2 | Pan | S 214 |
| *Rosulabryum billarderi* J.R. Spence | – | 2 | – | 3 | – | Pan | S 192 |
| **Calymperaceae (2/2)** | | | | | | | |
| *Octoblepharum albidum* Hedw. | 2 | – | 1 | – | – | Pan | S 138 |
| *Syrrhopodon prolifer* (Brid.) Besch. | – | – | – | – | 3 | Pan | S 209 |
| **Fissidentaceae (1/3)** | | | | | | | |
| *Fissidens lagenarius* Mitt. var. *lagenarius* | 4 | – | 3 | – | – | Neo | S 142 |
| *Fissidens serratus* Müll. Hal. | 1 | – | 1 | – | – | Pan | S 169 |
| *Fissidens submarginatus* Brusch. | 2 | 1 | 1 | – | – | Neo | S 235 |
| **Leucobryaceae (1/3)** | | | | | | | |
| *Campylopus pilifer* Brid. | 12 | 11 | 6 | – | 15 | Wide | S 216 |
| *Campylopus richardii* Brid. | – | – | – | – | 2 | Pan | S 204 |
| *Campylopus savannarum* (Müll.Hal.) Mitt. | 1 | – | – | – | – | Pan | S 180 |
| **Ortotrichaceae (2/2)** | | | | | | | |
| *Macromitrium richardii* Schwägr. | – | – | – | 3 | – | Africa and America | S 200 |
| *Schlotheimia tecta* Hook. f. *et* Wilson | – | – | – | 3 | – | Neo | S 200 p.p. |
| **Polytrichaceae (1/1)** | | | | | | | |
| **Polytrichum juniperinum* Willd. ex Hedw. | – | – | – | 4 | – | Wide | S 186 |
| **Pottiaceae (1/1)** | | | | | | | |
| *Tortella humilis* (Hedw.) Jenn. | 2 | – | – | – | – | Wide | S 154 |
| **Sematophyllaceae (1/2)** | | | | | | | |
| *Sematophyllum subpnnatum* (Brid.) E.Britton | – | – | – | 1 | – | Pan | S 184 |
| *Sematophyllum subsimplex* (Hedw.) Mitt. | – | – | – | 1 | – | Neo | S 184 p.p. |
| **MARCHANTIOPHYTA** | | | | | | | |
| **Cephaloziaceae (2/2)** | | | | | | | |
| *Cephalozia crassifolia* (Lindenb. *et* Gottsche) Fulford | – | 1 | 1 | – | – | Neo | S 219 |

Table 5. Frequency of bryophytes occurring in soil islands by rocky outcrop and its phytogeographical pattern *(continued)*

| ***Division/Family/Specie*** | ***Rocky Outcrop (RO)*** | | | | | ***Pattern Phytogeographic*** | ***Collector number*** |
|---|---|---|---|---|---|---|---|
| | ***RO1*** | ***RO6*** | ***RO7*** | ***RO10*** | ***RO13*** | | |
| *Odontoschisma longiflorum* (Taylor) Steph. | 1 | – | 1 | – | – | Neo | S 141 |
| **Frullaniaceae (1/3)** | | | | | | | |
| *Frullania caulisequa* (Nees) Nees | – | – | – | 1 | – | Neo | S 201 |
| *Frullania flexicaulis* Spruce | – | – | – | 4 | – | Neo | S 187 |
| *Frullania kunzei* (Lehm. *et* Lindenb.) Lehm. *et* Lindenb. | 2 | – | – | 2 | – | Neo | S 195 |
| **Lejeuneaceae (2/2)** | | | | | | | |
| *Lejeunea flava* (Sw.) Nees | – | – | – | 4 | – | Pan | S 185 |
| *Leucojeunea xanthocarpa* (Lehm. *et* Lindenb.) A. Evans | 1 | – | – | 11 | – | Pan | S 188 |
| **Metzgeriaceae (1/1)** | | | | | | | |
| *Metzgeria uncigera* A. Evans | – | – | – | 2 | – | Neo | S 187 p.p. |
| **Plagiochilaceae (1/1)** | | | | | | | |
| *Plagiochila corrugata* (Nees) Nees *et* Mont. | – | – | – | 2 | – | Africa and America | S 188 p.p. |
| **Ricciaceae (1/1)** | | | | | | | |
| *Riccia vitalli* Ast | 1 | 3 | 2 | – | – | Neo | S 233 |
| **Total sampled islands / Total colonized islands** | 20/16 | 20/17 | 20/13 | 20/20 | 15/15 | | |

The total sampled islands indicates amount of samples by rocky outcrop. S = SILVA J.B. collector number. * = Specie sent to the Manuel de Arruda Câmara Herbarium (UEPB) at the State University of Paraíba as S 172 collector number. Pattern Phytogeographic is abbreviated to the first three letters of each word; compound words were not abbreviated: Cos = Cosmopolitan; Neo = Neotropical; Pan = Pantropical.

encountered exclusively in RO4, although species considered to be typical of xeric environments were also found on the same RO (*e.g. Frullania* spp.). Only *Gemmabryum exile* (Dozy *et* Molk.) J.R. Spence *et* H.P. Ramsay was common in all of the ROs, although *Campylopus pilifer* Brid. (recorded in four ROs) was the most frequent species, occurring in practically all of the soil islands on the four ROs where it was recorded (Table 5). The most common species for each rocky outcrop are shown in absolute numbers (number of occurrences per soil island) in Figure 5.

## Local level composition and similarity

Outlier analyses did not identify any soil island as being discrepant within the total set, although the most consistent results were obtained after subtracting the rare examples (those species that occurred in only a single island, as well as those islands that supported only a single species).

Clustering analyses (UPGMA) did not demonstrate consistent groups formed by rocky outcrops or within them (among soil islands), except in the case of the soil islands of RO13. Although a CCC of 0.90 was obtained when all of the

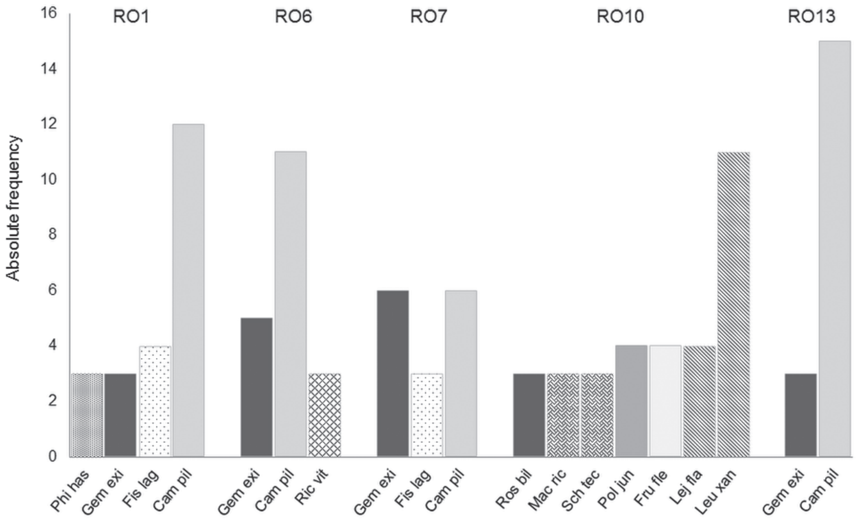

Fig. 5. The most common species for each rocky outcrop in absolute numbers (number of occurrences per soil island). We consider the most common species to be those with more than three occurring in each outcrop. Shades of gray and textures equal between the bars of the blocks of each outcrop indicate species belonging to the same family. Species names were shortened using only the first three letters of the both generic and specific epithet. Phi has = *Philonotis hastata*; Gem exi = *Gemmabryum exile*; Fis lag = *Fissidens lagenarius* var. *lagenarius*; Cam pil = *Campilopus pilifer*; Ros bil = *Rosulabryum billarderi*; Mac ric = *Macromitrium richardii*; Sch tec = *Schloteimia tecta*; Pol jun = *Polytrichum juniperinum*; Ric vit = *Riccia vitalli*; Fru fle = *Frullania flexicaulis*; Lej fla = *Lejeunea flava*; Leu xan = *Leucolejeunea xanthocarpa*.

islands demonstrating the presence of bryophytes were considered, various islands containing only a single species (the same species) and generated similarity indices of 100% and made the dendrogram visually confusing. As such, we chose to use only those islands containing more than one species, generating a dendrogram with a CCC of 0.82 (Fig. 8), within the limits proposed by the “rule of the thumb”.

The smallest Sørensen similarity index values (0-40%) were observed among the soil islands of rocky outcrops 1, 6 and 7, while the largest values (100%) were obtained between the few islands found on RO1 and 6 (considering the soil islands on different ROs) and between the soil islands of RO13 (considering the soil islands on the same RO), followed by those between the soil islands (again, considering the soil islands on the same rock outcrop) of RO10 (50-80%). A comparison between the rocky outcrops and their soil islands can be seen in Figures 7A-C and 8A-B.

## DISCUSSION

### Regional level bryofloristic richnesses and their distribution patterns

Liverworts are generally numerically more frequent than mosses in lowland rain forest types like those considered by Cornelissen and Gradstein (1990), but this pattern is reversed when considering rock outcrops, as confirmed

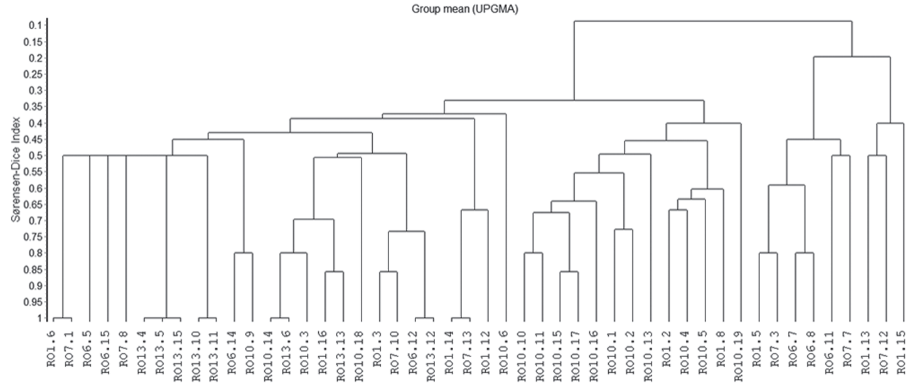

Fig. 6. Dendrogram of floristic similarity (UPGMA) based on the Sørensen similarity index. OR = Rocky Outcrop. OR1, 6 and 7 located in the Paraíba state; OR10 and 13, located in the Pernambuco state. Number before point refers to RO; number after point refers to RO soil island.

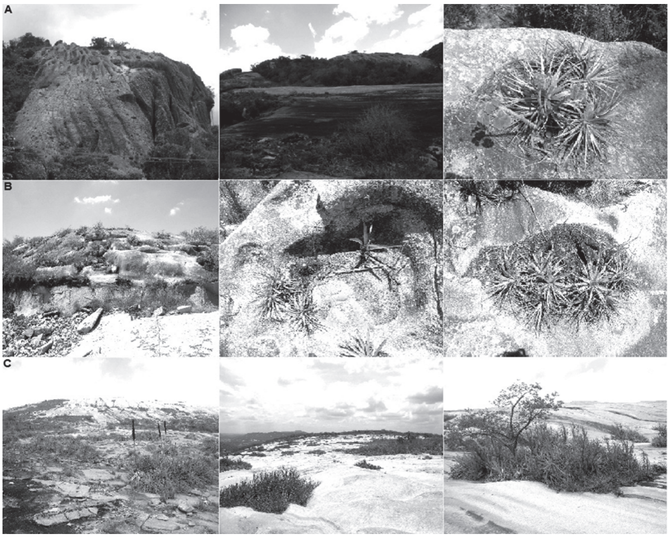

Fig. 7. Rocky outcrops and their soil islands. The first picture of each line corresponds to the overview of the outcrop and the two subsequent pictures to their islands. A = RO1; B = RO6; C = RO7.

in the present work and in earlier publications (*e.g.*, Frahm 1996, 2004; Frahm & Porembski, 1997; Silva & Germano, 2013). These results indicate that although liverworts are quite successful under suboptimal conditions (Slack, 1982), the greater structural complexity of mosses (Glime, 2007; Goffinet & Shaw, 2008) gives them predominance in environments with adverse conditions.

In terms of the representivity of the liverworts at the family level, it was no surprise to see the significant presence of Lejeuneaceae, as this is one of the most diverse tropical families (Gradstein *et al.,* 2001). This taxon comprises a large

Fig. 8. Rocky outcrops and their soil islands. The first picture of each line corresponds to the overview of the outcrop and the two subsequent pictures to their islands. A = RO10; B = RO13.

variety of species with diverse ecological requirements, from photophilous to ombrophilous (Costa & Gradstein, 2003), and they show adaptive features such as amphigastria and lobules that channel and store water (Thiers, 1988; Frahm, 2003) – which increases their chances of being present in areas with differentiated environments. The second most representative liverwort family was Frullaniaceae, one of the 10 most recorded families taxa in the tropics (Gradstein & Pócs, 1989). Its species also demonstrate a series of attributes (*e.g.,* lobules saccate; leaves squarrose; dark pigmentation) that allow them to survive under the rigorous conditions of the rocky outcrops (see Silva & Germano, 2013).

The geographical distribution patterns observed here were in agreement with various other studies undertaken on rock outcrops (with most of the species being Neotropical), whether in terms of phanerogams (*e.g*., Porembski *et al*., 1998; Gomes & Sobral-Leite, 2013) or cryptogams (*e.g.,* Frahm, 1996; Valente *et al*., 2011; Silva & Germano, 2013). The records of rare species (in both the present and in earlier studies) could represent the influence of stochastic processes, as these species are capable of dispersal over very long distances (Hutsemekers *et al.*, 2008).

## Regional level composition and similarity, and correlations with environmental variables

In general, and even though their similarity index values were not very high, WPGMA grouped the rocky outcrops according to their geographical proximity. Nonetheless, it could be seen that the surrounding vegetation matrix influenced the similarity between bryophyte communities, as the ROs with similar surroundings were grouped together. This probably occurred because dispersal of a species is facilitated within any given region, favoring local homogeneity (Chase, 2003; Durigan *et al.*, 2003). Allied to this is the fact that most species demonstrated ample distributions – indicating their tolerance to diverse environmental conditions (Frahm, 2008), which, combined with the dispersal power of the bryophytes (Nekola & White, 1999) would explain the occurrence of similar floristic elements on ROs having similar surrounding environments. Chase & Myers (2011) argued that the influence of stochastic processes would be felt more in more isolated environments, although deterministic processes would not, of course, be excluded (Rosindell *et al.*, 2012).

The Mantel and Partial Mantel tests indicated that geographical distance was a key factor in the composition and similarity of the bryophyte communities on rock outcrops. This contradicted our original hypothesis that deterministic processes based on environmental filters (*e.g.,* temperature amplitudes, rainfall, and latitude) would be the most influential. Our results therefore corroborated those of Oliveira *et al.* (2009) and ter Steege (2010). Nonetheless, as already mentioned, stochastic and deterministic processes are not necessarily mutually exclusive, as even the notable ability of bryophytes to disperse is not sufficient in itself to guarantee establishment in every locality (Hutsemekers *et al*., 2012). Additionally, changes in environmental variables over spatial scales (gradients) can alter the geographical bands of occurrence of a given species (Colwell & Rangel, 2009).

It is possible that the environmental variables considered in the PCA were not the most predictive in terms of rock outcrops. These analyses led us to exclude Altitude, which has otherwise been consecrated in many studies as being directly proportional to bryophyte richness and diversity (Ah-Peng, 2007; Oliveira *et al*., 2009; Corrales *et al*., 2010; Santos & Costa, 2010; Benassi *et al*., 2011; Santon & Horn, 2013). Nonetheless, altitude alone would not explain either high or low diversity, as it is actually only a stand-in for true environmental variables (Körner, 2007) such as humidity, temperature, and solar radiation that can define the altitudinal limits of species (Gradstein *et al.*, 2001) – and the highest rock outcrops were not generally very similar among themselves, nor were they necessarily the richest environments.

Our comprehension of the altitudinal gradient provided by CCA provides us, nonetheless, with a certain confidence in the environmental variables selected, and explanations for the patterns of diversity observed in natural communities will depend on analyses based on more than one geographic scale (Chase & Myers, 2011).

## Local level richnesses and phytogeographical patterns

Richness at the local level follows the model observed for the regional level, with mosses demonstrating greater representivity than liverworts, and follows the same pattern in terms of the representivity of their families. This supports the hypothesis that regional (beta) diversity exercises influence over local (alpha) diversity.

The wide phytogeographical patterns of the species encountered on the soil islands are typical of species found in tropical regions (with Neotropical, Pantropical, and Ample distributions) (Tan & Pócs, 2000).

*Campylopus pilifer* is amply distributed and drought-tolerant and is found at elevations 50-1500 m in the tropics (Frahm, 2002). Some traits of *C. pilifer* such as erect hyaline hairpoints seem to be present in dry conditions (Frahm, 2002). These inherent characteristics of this moss justified its high frequencies on RO1, 6, 7 and 13 – with their typically xeric environmental conditions – as well as its absence from RO10 which offered typical forest conditions. In the same way, *Gemmabyum exile,* a moss that is considered ruderal (Ochi, 1980), has morphologic characteristics that allow it to tolerate xeric conditions (cf. Silva & Germano, 2003), and although it was found in all of the rocky outcrops, it demonstrated its lowest frequency in RO10.

The conditions present in rocky outcrop 10 (*e.g.,* closed vegetation) favored the establishment of epiphytic frequent species (*e.g.* mosses

*Macromitrium richardii*, *Schlotheimia tecta* and liverworts *Lejeunea flava*, *Leucolejeunea xanthocarpa* and *Frullania flexicaulis*). However, the higher frequency of *L. xanthocarpa* found there can be explained by its morphological attributes (Kitagawa, 1968), common to desiccation-tolerant species (Frahm, 2003), for in spite of the generally humid conditions found in RO10, drying winds are constant on rock outcrops and should greatly affect epiphytic species. In this respect the presence of *Lejeunea flava* is justified by this being a xerophytic species (Gradstein & Costa, 2003).

The epiphytic mosses present on RO10 exhibit typical attributes of desiccation-tolerant plants (see Silva & Germano (2013)) such as leaves twisted which reduce water loss during dry periods (Watson, 1933; Frahm, 2003). Furthermore, according to Hedenäs (2001), epiphytic species exhibit equivalent adaptive attributes to those shown in rupicolous species in harsh environments.

Overall species of *Frullania* show adaptive attributes (*e.g.* leaves imbricate or esquarrose, oilbody and blackish color – see Silva & Germano (2013)) for discussion of these characters). However, the highest frequency of *Frullania flexicaulis* on the rocky outcrop 10 indicates that the species may be a better local disperser than the related species *Frullania caulisequa* and *F. kunzei* register for the same RO.

The number of adapted thallose liverworts to xeric environmental conditions is reduced. In this sense, *Riccia* species are well represented in these environments (Cross & Rosselló, 1984) and an explanation for this is the presence of reflective scales to protect from sunlight, increased number of cell layers that protect the photosynthetic cells within and the characteristics inherent in the sporophytic phase (see Bischler & Jovet-Ast (1981) and Jovet-Ast (1991)).

Species *Fissidens lagenarius* var. *lagenarius* and *Rosulabryum billarderi* were not surprising since both species were previously reported for xeric environments and hold morphological structures adaptive to stressful environments (see Silva & Germano (2013) for discussion about *Fissidens* spp. and *R. billarderi* traits). *Philonotis hastata* also shows similar attributes to those shown by these two mosses, such as leaves imbricate and tuft life form acting in reducing water loss and the presence of papillae that provide water movement by capillary action, maximizing the use of tiny amounts of water (Mägdefrau, 1982; Kürschner, 2003, 2004).

It was an amazing record of *Polytrichum juniperinum* in rocky outcrop 10. Although this species is widely distributed, its distribution in Brazil is restricted from the south of the country to the north of Bahia with just one occurrence for northern Brazil (see Peralta & Yano (2010) for map of distribution). Nevertheless, *P. juniperinum* shows attributes such as tubular leaves important in the external water conduction, imbricate leaves that reduce water loss and lamellae that help optimize photosynthesis (Watson, 1933; Kürschner, 2003, 2004). All these functional traits make this species apt to occur in xeric environments.

## Local level composition and similarity

Wide bryophyte distribution patterns resulted in low similarity indices on soil islands. The high similarity between the soil islands on rocky outcrop 1 and 6 (comparing outcrops) was expected in that these ROs are more environmentally similar (in terms of their mean annual temperatures and distance from the sea) than the other ROs. The high similarity between the soil islands of RO13 can be explained by their low numbers of species (5 spp.). The similarities between the soil islands on RO10 probably reflected their surrounding matrix of (apparently) well-preserved high altitude forest (with optimal humidity and shading conditions), and the diversity of the vascular flora on the top of the outcrop – justifying the presence of a bryoflora typical of forest physiognomies.

Therefore, in spite of the fact that deterministic processes are critical to the composition, richness, and similarity of species at the local level (Ricklefs, 1987; Chase, 2003; Corrales *et al.*, 2010), our results indicate that the distributions of bryophytes throughout the rocky outcrops are driven, probably, by stochastic processes related to distance; and although bryophytes are wind-dispersed, certain limitations to their dispersal cannot be discarded. These results refute our initial hypothesis that environmental filters are determinants for the composition of plant communities (especially of bryophytes) on rock outcrops and corroborate (especially in the case of rock outcrops) the theory that however more isolated an environment is the more intense will be the roles of stochastic events in controlling species' distributions (Hubbell, 2001; Chase & Myers, 2011) at both local and regional levels.

Additionally, at least at the local level, other factors must be assessed so that we can make conclusions more firmly on the composition and diversity of communities. Such factors include intraspecific competition, size of the islands (see Hubbell (2001) for consideration about islands size) and depth of these and functional attributes that should be different depending on the importance of each filter for each species. Therefore, we suggest that the spatial scales studies continue with this goal to obtain more conclusive results.

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## REFERENCES

AH-PENG C., CHUAH-PETIOT M., DESCAMPS-JULIEN B., BARDAT J., STAMENOFF P. & SRABERG D. 2007 — Bryophyte diversity and distribution along an altitudinal gradient on a lava flow in La Réunion. *Diversity and distributions* 13: 654-662.

ANDRADE-LIMA D., 2007 — Estudos fitogeográficos de Pernambuco. *Anais da academia Pernambucana de ciência agronômica* 4: 243-274.

BASTOS C.J.P., YANO O. & BÔAS-BASTOS S.V., 2000 — Briófitas de campos rupestres da Chapada Diamantina, Estado da Bahia, Brasil. *Revista brasileira de botânica* 23: 359-370.

BENASSI M., STARK L.R., BRINDA J.C., McLETCHIE D.N., BONINE M. & MISHLER B.D. 2011 — Plant size, sex expression and sexual reproduction along an elevation gradient in a desert moss. *The bryologist* 114: 277-288.

BERGAMINI A. & PEINTINGER M., 2002 — Effects of light and nitrogen on morphological plasticity of the moss *Calliergonella cuspidata. Oikos* 96: 355-363.

BISCHLER H. & JOVET-AST S., 1981 — The biological significance of morphological characters in Marchantiales (Hepaticae). *The bryologist* 84: 208-215.

BISCHLER-CAUSSE H., GRADSTEIN S.R., JOVET-AST S., LONG D.G. & ALLEN N.S., 2005 — Marchantiidae. *Flora neotropica, Monograph* 97: 214-218.

BUCK W.R., 1998 — Pleurocarpous Mosses of the West Indies. *Memoirs of the New York botanical garden* 1: 1-401.

BURKE A., 2002 — Are Namibian inselbergs conservation islands? A floral perspective. *South Africa journal science* 98: 560-56.

BRUMMIT R.K. & POWELL C.E., 1992 — *Authors of plant names*. Royal Botanic Gardens, Kew.

CARDOSO E. & SCHIAVINI I., 2002 — Relação entre distribuição de espécies arbóreas e topografia em um gradiente florestal na Estação Ecológica do Panga (Uberlândia, MG). *Revista Brasileira de botânica* 25: 277-289.

CARLUCCI M. B., 2008 — *Afloramentos rochosos como núcleos de expansão florestal sobre campos nativos no sul do Brasil*. Trabalho de Conclusão de Curso. Universidade Federal do Rio Grande do Sul, RS, BR.

CARVALHO C.J.B. de, 2011 — Áreas de endemismo. *In*: Carvalho C.J.B. de & Almeida E.A.B., *Biogeografia da America do Sul: Padrões e Processos*. São Paulo, ROCA, 306 p.

CHASE J.M., 2003 — Community assembly: when should history matter? *Oecologia* 136: 489-498.

CHASE J.M. & MYERS J.A., 2011 — Disentangling the importance of ecological niches from stochastic processes across scales. *Philosophical transactions of the royal society London, biological science* 366: 51-63.

COLWELL R.K. & RANGEL T.F., 2009 — Hutchinson's duality: the once and future niche. *Proceedings of the national academy of sciences* 106: 19651-19658.

CONCEIÇÃO A.A., GIULIETTI A.M. & MEIRELLES S.T., 2007 — Ilhas de vegetação em afloramentos de quartzito-arenito no Morro do Pai Inácio, Chapada Diamantina, Bahia, Brasil. *Acta botanica Brasilica* 21: 335-347.

CORNELISSEN J.H.C. & GRADSTEIN S.R., 1990 — On the occurrence of bryophytes and macrolichens in different lowland rain forest types at Mabura Hill, Guyana. *Tropical bryology* 3: 29-35.

CORRALES A., DUQUE A., URIBE J. & LONDOÑO V., 2010 — Abundance and diversity patterns of terrestrial bryophyte species in secondary and planted montane forests in the northern portion of the Central Cordillera of Colombia. *The bryologist* 113: 8-21.

CRANDALL-STOTLER B., STOTLER R.E. & LONG D.G., 2009 — Morphology and classification of the Marchantiophyta. *In:* Goffinet B. & Shaw A.J. (eds.), *Bryophyte Biology. 2nd edition*. Cambridge, Cambridge University Press, pp. 1-54.

CRISP M.D., 2001 — Historical Biogeography and Patterns of Diversity in Plants, Algae and Fungi: Introduction. *Journal of biogeography* 28: 153-155.

CROSS R.M., ROSSELLÓ J.A., 1984 – An approach to the bryophytic flora of the Pityusic Islands. *Monographiae biologicae* 52: 155-170.

DURIGAN G., RATTER J.A., BRIDGEWATER S., SIQUEIRA M.F. & FRANCO G.A.D.C., 2003 — Padrões fitogeográficos do cerrado paulista sob uma perspectiva regional. *Hoehnea* 30: 39-51.

FLORA OF NORTH AMERICA, 2008 — Available in <http://floranorthamerica.org/families>. Access on Oct. 18, 2013.

FLORA DO BRASIL. JARDIM BOTÂNICO DO RIO DE JANEIRO, 2012 — Available in <http://floradobrasil.jbrj.gov.br/jabot/listaBrasil/PrincipalUC/PrincipalUC.do>. Access on Oct. 18, 2013.

FRAHM J-P. & POREMBSKI S., 1997 — Moose von Inselbergen in Benin. *Tropical bryology* 14: 3-9.

FRAHM J.-P., 2000 — Bryophytes. *In*: Barthlott W. & Porembski S. (eds.), *Inselbergs.* Ecological Studies 146, Springer Verlag, pp. 91-102.

FRAHM J.-P., 2002 — *Campylopus*. *In*: Brum, R. (ed.) Bryophyte flora of North America, Provisional publication. Available in <http://www.mobot.org/plantscience/bfna/v1/dicrcampylopus.htm>. Access on February 12, 2014.

FRAHM J.-P., 2003 — Manual of Tropical Bryology. *Tropical bryology* 23: 9-195.

FRAHM J.-P., 2004 — Recent Developments of Commercial Products from Bryophytes. *The bryologist* 107: 277-83.

FRAHM J.-P., 2008 — Diversity, dispersal and biogeography of bryophytes (mosses). *Biodiversity and conservation* 17: 277-284.

GABRIEL R. & BATES J.W. 2005 — Bryophyte community composition and habitat specificity in the natural forests of Terceira, Azores. *Plant ecology* 177: 125-144.

GIGNAC D., 2001 — New Frontiers in Bryology and Lichenology Bryophytes as Indicators of Climate Change. *The bryologist* 104: 410-420.

GLIME J.M., 2007 — *Bryophyte Ecology*. Volume 1. Physiological Ecology. Ebook sponsored by Michigan Technological University and the International Association of Bryologists. Available in <http://www.bryoecol.mtu.edu/ >. Access on July 01, 2013.

GOFFINET B. & BUCK W.R., 2004 — Systematics of Bryophyta: from molecules to a revised classification. *Monographs in systematic botany from the Missouri botanical garden* 98: 205-239.

GOFFINET B. & SHAW A.J. (eds.), 2008 — *Bryophyte Biology, 2nd edition.* Cambridge, Cambridge University Press, 565 p.

GOFFINET B., BUCK W.R. & SHAW A.J., 2009 — Morphology, anatomy, and classification of the Bryophyta. *In*: Goffinet B. & Shaw A. J. (eds.), *Bryophyte Biology, 2nd edition*. Cambridge, Cambridge University Press, pp. 55-126.

GOMES P. & SOBRAL-LEITE M., 2013 — Crystalline rock outcrops in the Atlantic Forest of northeastern Brazil: vascular flora, biological spectrum, and invasive species. *Brazilian journal of botany* 36: 111-123.

GRADSTEIN S.R. & PÓCS T., 1989 — Bryophytes. *In*: Lieth H. & Werger M.J.A. (eds.), *Tropical Rainforest Ecosystems*, Elsevier, Amsterdam, pp. 311-325.

GRADSTEIN S.R., CHURCHILL S.P. & SALAZAR A.N., 2001 — Guide to the bryophytes of Tropical America. *Memoirs of the New York botanical garden* 86: 1-577.

GRADSTEIN S.R. & COSTA D.P., 2003 — The Hepaticae and Anthocerotae of Brazil. *Memoirs of the New York botanical garden* 87: 1-318.

GRYTNES J.A., HEEGAARD E. & IHLEN P.G., 2006 — Species richness of vascular plants, bryophytes, and lichens along an altitudinal gradient in western Norway. *Acta oecologia* 29: 241-246.

HAIR J.F., BLACK W.C., BABIN B.J., ANDERSON R.E. & TATHAM R.L., 2006 — *Multivariate data analysis, 6th edition.* Upper Saddle River, NJ, Pearson Prentice Hall.

HEDENÄS L., 2001 — Environmental Factors Potentially Affecting Character States in Pleurocarpous Mosses. *The bryologist* 104: 72-91.

HUBBELL S.P., 2001 — *The Unified Neutral Theory of Biodiversity and Biogeography.* Princeton, New Jersey, Princeton University Press, 375 p.

HUTCHINSON G.E., 1957 — Concluding remarks. *Cold spring harbor Symposia on quantitative biology* 22: 415-427.

HUTSEMEKERS V., DOPAGNE C. & VANDERPOORTEN A., 2008 — How far and how fast do bryophytes travel at the landscape scale? *Diversity and distributions* 14: 483-492.

INUTHAIL J. & SRIDITH K., 2010. — The vegetation structure on the granitic inselberg in Songkhla province, Peninsular Thailand. *Thailand forest bulletin (botanical)* 38: 74-89.

JOVET-AST S., 1991 — *Riccia* (Hépatique, Marchantiales) d'Amérique Latine, Taxons du sous-genre *Riccia*. *Cryptogamie, Bryologie et Lichénologie* 12: 189-370.

KITAGAWA N., 1968 — Studies on the Hepaticae of Thailand III. The genus *Leucolejeunea*. *Tonan Ajia Kenkyu* 6: 608-613.

KÖRNER C., 2007 — The use of 'altitude' in ecological research. *Trends in ecology and evolution* 22: 569-574.

KÜRSCHNER H., 2003 — Epiphytic bryophyte communities of southwestern Arabia-phytosociology, ecology and life strategies. *Nova Hedwigia* 77: 55-71.

KÜRSCHNER H., 2004 — Life Strategies and Adaptations in Bryophytes from the Near and Middle East. *Turkish journal of botany* 28: 73-84.

LEGENDRE P. & LEGENDRE L., 1998 — *Numerical ecology, 2nd edition.* English edition. Amsterdam, Elsevier.

MÄGDEFRAU K., 1982 — Life-forms of bryophytes. *In:* Smith, A.J. (ed.) *Bryophyte Ecology*. London, Chapman and Hall Ltd., pp. 45-58.

McCUNE B. & GRACE J.B., 1999 — *Analysis of Ecological Communities*. Gleneden Beach, Oregon, MjM Software Design.

McCUNE B. & MEFFORD M.J., 1999 — *PC-ORD: multivariate analysis of ecological data, version 4.10.* Gleneden Beach: MjM Sofware Design.

NEKOLA J.C. & WHITE P.S., 1999 — The distance decay of similarity in biogeography and ecology. *Journal of biogeography* 26: 867-878.

OCHI H., 1980 — A revision of the neotropical Bryoideae, Musci (First part). *The Journal of the faculty of education Tottori university - Natural science* 29: 49-154.

OLIVEIRA S.M. de, ter STEEGE H., CORNELISSEN J.H.C. & GRADSTEIN S.R., 2009 — Niche assembly of epiphytic bryophyte communities in the Guianas: a regional approach. *Journal of biogeography* 36: 2076-2084.

PERALTA D.F. & YANO O., 2010 — Taxonomic treatment of the Polytrichaceae from Brazil. *The bryologist* 113: 646-672.

POREMBSKI S., MARTINELLI G., OHLEMÜLER R. & BARTHLOTT W., 1998 — Diversity and ecology of saxicolous vegetation mats on inselbergues in the Brazilian Atlantic rainforest. *Diversity and distributions* 4: 107-119.

PROCTOR M.C.F., 2008 — Physiological Ecology. *In*: Goffinet B. & Shaw J.A. (eds.) *Bryophyte Biology*. Cambridge, Cambridge University Press, pp. 237-268.

REESE W.D., 1993 — Calymperaceae. *Flora Neotropica. Monograph* 58. New York, Botanical Garden, 102 p.

RICKLEFS R.E., 1987 — Community Diversity: Relative Roles of Local and Regional Processes. *Science* 235: 167-171.

RICKLEFS R.E. & SCHLUTER D. (eds.), 1993 — *Species Diversity in Ecological Communities: Historical and Geographical Perspectives*. Chicago, University of Chicago Press.

ROMERO C., PUTZ F.E. & KITAJIMA K., 2006 — Ecophysiology in Relation to Exposure of Pendant Epiphytic Bryophytes in the Canopy of a Tropical Montane Oak Forest. *Biotropica* 38: 35-41.

ROSENBERG M.S. & ANDERSON C.D., 2011 — PASSaGE: Pattern Analysis, Spatial Statistics and Geographic Exegesis. Version 2. *Methods in ecology and evolution* 2: 229-232.

ROSINDELL J., HUBBELL S.P., HE F., HARMON L.J. & ETIENNE R.S., 2012 — The case for ecological neutral theory. *Trends in ecology and evolution* 27: 203-208.

SANTON D.E. & HORN H.S., 2013 — Epiphytes as "filter-drinkers": life-form changes across a fog gradient. *The bryologist* 116: 34-42.

SANTOS N.D. & COSTA D.P., 2010 — Altitudinal zonation of liverworts in the Atlantic Forest, Southeastern Brazil. *The bryologist* 113: 631-645.

SANTOS N.D., COSTA D.P., KINOSHITA L.S. & SHEPHERD G.J., 2011 — Aspectos brioflorísticos e fitogeográficos de duas formações costeiras de Floresta Atlântica da Serra do Mar, Ubatuba/SP, Brasil. *Biota Neotropica* 11: 425-438.

SANTOS N.D., COSTA D.P., KINOSHITA L.S. & SHEPHERD G.J., 2014 — Windborne: can liverworts be used as indicators of altitudinal gradient in the Brazilian Atlantic Forest? *Ecological indicators* 36: 431-440.

SARTHOU C., VILLIERS J.-F. & PONGE J.-F., 2003 — Shrub thicket vegetation on tropical granitic inselbergs (French Guiana). *Journal of vegetation science* 5: 645-652.

SHEPHERD G.J., 2010 — Fitopac 2.1. *Manual do usuário*. Campinas: UNICAMP.

SILVA T.O., 2012 — *Riqueza e Diversidade de Briófitas em Afloramentos Rochosos do Estado de Pernambuco, Nordeste do Brasil*. Dissertação de Mestrado. Recife, PE, BR.

SILVA J.B. & GERMANO S.R., 2013 — Bryophytes on rocky outcrops in the caatinga biome: A conservationist perspective. *Acta botanica Brasilica* 27: 827-835.

SILVA M.P.P. & PÔRTO K.C., 2013 — Bryophyte communities along horizontal and vertical gradients in a human-modified Atlantic Forest remnant. *Botany* 91: 155-166.

SLACK N.G., 1982 — Bryophytes in relation to ecological niche theory. *Journal of the Hattori botanical laboratory* 52: 199-217.

SMOUSE P.E., LONG J.C. & SOKAL R.R., 1986 — Multiple-regression and correlation extensions of the Mantel test of matrix correspondence. *Systematic zoology* 35: 627-632.

SUN S.Q., WU Y.H., WANG G.X., ZHOU J., YU D., BING H.J. & LUO J., 2013 — Bryophyte species richness and composition along an altitudinal gradient in Gongga Mountain, China. *PLoS ONE* 8: 1-10.

SVENNING J.-C., KINNER D.A., STALLARD R.F., ENGELBRECHT B.M.J. & WRIGHT S.J., 2004 — Ecological determinism in plant community structure across a tropical forest landscape. *Ecology* 85: 2526-2538.

TAN B.C. & PÓCS T., 2000 — Bryogeography and conservation of bryophytes. Pp. 403-448. *In:* A.J. Shaw & B. Goffinet (eds.). *Bryophyte Biology.* Cambridge, Cambridge University Press, pp. 403-448.

THIERS B.M., 1988 — Morphological adaptations of the Jungermanniales (Hepaticae) to the tropical rainforest habitat. *Journal of the Hatttori botanical laboratory* 64: 5-14.

ter STEEGE H., 2010 – How Neutral is Ecology? *Biotropica* 42: 631-633.

ter STEEGE H. & ZAGT R., 2002 — Ecology: density and diversity. *Nature* 417: 698-699.

TILMAN D., 1984 — Plant dominance along an experimental nutrient gradient. *Ecology* 65: 1445-1453.

TILMAN D., 1985 — The Resource-ratio hypothesis of plant succession. *The American naturalist* 125: 827-852.

TRYON R.M., 1986 — Some new names and new combinations in Pteridaceae. *American fern journal* 76: 184-186.

VALENTE E.B. & PÔRTO K.C., 2006 — Briófitas do afloramento rochoso na Serra da Jibóia, município de Santa Teresinha, Bahia, Brasil. *Boletim do instituto de botânica* 18, 207-211.

VALENTE E.B., PÔRTO K.C. & BASTOS C.J.P., 2011 — Checklist of Bryophytes of Chapada Diamantina, Bahia, Brazil. *Boletim do instituto de botânica* 21: 111-124.

VALENTE E.B., PÔRTO K.C. & BASTOS C.J., 2013 — Species richness and distribution of bryophytes within different phytophysiognomies in the Chapada Diamantina region of Brazil. *Acta botanica Brasilica* 27: 294-310.

VALENTIN J.L., 2012 — *Ecologia Numérica: uma introdução à análise multivariada de dados ecológicos*. Rio de Janeiro, Interciência, 168 p.

W$^3$ TROPICOS. TROPICOS HOME, MISSOURE BOTANICAL GARDEN, 2010 — Available in <http://www.tropicos.org/NameSearch.aspx>. Access Oct. 18, 2013.

WATSON W., 1933 — The Evolutionary Aspects of Some Xerophytic Adaptations in the Bryophyta. *The bryologist* 32: 32-34.

YANO O., 1981 — A checklist of Brazilian mosses. *Journal of the Hattori botanical laboratory* 50: 279-456.

YANO O., 1984a — Briófitas. *In:* Fidalgo O. & Bononi V.L.R. (Coords.). *Técnicas de coleta, preservação e herborização de material botânico*. São Paulo, Instituto de Botanica. 62 p. (Manual 4).

YANO O., 1984b — Checklist of Brazilian liverworts and hornworts. *Journal of the Hattori botanical laboratory* 56: 481-548.

YANO O. & ANDRADE-LIMA D., 1987 — Briófitas no nordeste brasileiro: estado de Pernambuco. *Revista Brasileira de botânica* 10: 171-181.

YANO O., 1989 — An additional checklist of Brazilian bryophytes. *Journal of the Hattori botanical laboratory* 66: 371-434.

YANO O. & COSTA D.P., 1992 — Novas ocorrências de briófitas no Brasil. *In: Anais do Congresso da Sociedade Botânica de São Paulo.* Campinas. Pp. 33-45.

YANO O., 1993 — Briófitas do nordeste brasileiro: Estado da Paraíba, Brasil. *Biologica Brasilica* 5: 87-100.

YANO O., 1995 — A new additional annotated checklist of Brazilian bryophytes. *Journal of the Hattori botanical laboratory* 78: 137-182.

YANO O., 1996 — A checklist of brazilian bryophytes. *Boletim do instituto de botânica* 10: 47-232.

YANO O. & MELLO Z.R., 1999 — Frullaniaceae dos manguezais do litoral sul de São Paulo, Brasil. *Iheringia, Série Botânica* 52: 65-87.

YANO O., 2004 — Novas ocorrências de briófitas para vários estados do Brasil. *Acta Amazonica* 34: 559-576.

YANO O. & CÂMARA P.E.A.S., 2004 — Briófitas de Manaus, Amazon Rain Forestas, Brasil. *Acta Amazônica* 34: 445-457.

YANO O., 2006 — Novas adições ao catálogo de briófitas brasileiras. *Boletim do instituto de botânica* 17: 1-142.

YANO O. & PÔRTO K.C., 2006 — Diversidade das briófitas das matas serranas do Ceará, Brasil. *Hoehnea* 33: 7-39.

YANO O. & PERALTA D.F., 2006 — Novas ocorrências de briófitas para os estados de Alagoas e Sergipe, Brasil. *Arquivos do museu nacional* 64: 287-297.

YANO O. & PERALTA D.F., 2006 — Briófitas coletadas por Daniel Moreira Vital no Estado da Bahia, Brasil. *Boletim do instituto de botânica* 18: 33-73.

YANO O. & PERALTA D.F., 2007 — Briófitas da Ilha do Bom Abrigo, Estado de São Paulo, Brasil. *Hoehnea* 34: 87-94.

YANO O. & PERALTA D.F., 2007 — As briófitas ameaçadas de extinção no Estado do Espírito Santo. *In:* Simonelli M. & Fraga C.M. (Orgs.). *Espécies da flora ameaçadas de extinção no Estado do Espírito Santo Instituto de Pesquisas da Atlantic Rain Forest.* Vitória, Ipema, Pp. 81-87.

YANO O., 2010 — *O atual conhecimento da Flora Brasileira: Briófitas.* Available in <http://www.infobibos.com/Artigos/2010_3/Briofitas/index.htm>. Access on Oct. 2, 2013.

YANO O., 2011 — *Catálogo de musgos brasileiros: literatura original, basiônimo, localidade-tipo e distribuição geográfica*. São Paulo, Instituto de Botânica.

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| **BRYOPHYTA** | | | |
| **Archidiaceae (1/1)** | | | |
| *Archidium ohioense* Schimp. *ex* Müll. Hal. | AL, BA, CE, GO, PB, PE, PI, MG, MS, MT, RN, RS | Pantropical | Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| **Bartramiacaea (1/2)** | | | |
| *Philonotis cernua* (Wilson) D.G. Griffin *et* W.R.Buck | CE, DF, GO, MA, MG, MT, PB, PR, RJ, RS, SC, SE, SP | Wide | Caatinga, Cerrado, Atlantic Rain Forest |
| *Philonotis hastata* (Duby) Wijk *et* Margad. | AC, AM, AP, BA, CE, DF, ES, GO, PA, PB, PE, PI, PR, MG, MS, MT, RJ, RO, RS, SC, SP, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Philonotis uncinata* (Schwägr.) Brid. | AC, AM, AP, BA, CE, DF, ES, GO, MG, PA, PB, PE, PR, RJ, RO, SC, SP, TO | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| **Brachytheciacae (3/3)** | | | |
| **Brachythecium ruderale* (Brid.) W.R. Buck | BA, ES, MG, MS, PR, RJ, RS | Neotropical | Mata Altântica, Pantanal |
| *Squamidium leucotricum* (Taylor) Broth. | AC, AL, AM, BA, CE, ES, MG, PA, PE, PR, RJ, RR, RS, SC, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| *Zelometeorium patulum* (Hedw.) Manuel | AC, AL, AM, AP, BA, CE, ES, GO, MG, MS, MT, PA, PE, PR, RJ, RO, RR, RS, SC, SP, TO | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| **Bryaceae (5/6)** | | | |
| *Bryum argenteum* Broth. | AL, AM, BA, CE, DF, ES, GO, MG, MT, PE, PB, PR, RJ, RR, RS, SC, SP | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa |
| *Bryum leptocladon* Sull. | BA, DF, GO, PE | Wide | |
| *Gemmabyum exile* (Dozy *et* Molk.) J.R. Spence *et* H.P. Ramsay | BA, DF, ES, GO, PE, PE, MS, RJ, RR, RS, SP | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest |
| *Rosulabryum billarderi* (Schwägr.) J.R. Spence | AC, AM, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, RJ, RO, SC, SP | Pantropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Rosulabryum capillare* (Hedw.) J.R. Spence | BA, CE, DF, ES, GO, MG, MT, PA, PB, PE, PI, RJ, RO, SC, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Rosulabryum densifolium* (Brid.) Ochyra | AC, BA, DF, ES, MG, PE, PR, RJ, RS, SC, SP, TO | Neotropical | Cerrado, Atlantic Rain Forest |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| **Calymperaceae (3/6)** | | | |
| *Calymperes loncophyllum* Schwägr. | AC, AL, AP, AM, BA, ES, GO, MA, MG, MS, MT, PA, PB, PE, PR, RJ, RO, RR, SP, TO | Pantropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| *Calymperes palisotii* Schwägr. | AC, AL, AM, AP, BA, ES, GO, MA, MG, MS, MT, PA, PB, PE, PI, PR, RN, RJ, RO, RR, SE, SP, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest |
| *Octoblepharum albidum* Hedw. | AC, AL, AM, AP, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, PI, PR, TO, RJ, RN, RO, RS, SE, SC, SP | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Syrrhopodon gaudichaudii* Mont. | AM, AP, BA, DF, ES, GO, MA, MG, MT, MS, PA, PE, PR, RR, RJ, RS, SC, SP, TO | Africa and America | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Syrrhopodon parasiticus* Schwägr. | AC, AM, BA, DF, ES, GO, MG, MT, MS, PA, PE, PR, RJ, RO, RR, SC, SP | Pantropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| *Syrrhopodon prolifer* (Brid.) Besch. | AC, AL, AP, BA, CE, DF, ES, GO, MG, MT, PA, PE, PI, PR, SC, SE, SP, RJ, RO, RS, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest |
| **Cryphaeaceae (1/1)** | | | |
| *Schoenobryum concavifolium* (Griff.) Gangulee | AC, AM, BA, DF, ES, MG, MS, MT, PE, PR, SP, RJ, RO, RS, SC | Wide | Pampa, Atlantic Rain Forest, Pantanal, Cerrado, Amazon Rain Forest |
| **Entondontaceae (1/1)** | | | |
| *Entodon beyrichii* (Schwägr.) Müll.Hal. | BA, ES, MG, MT, PA, PE, PR, RJ, RS, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| **Fabroniacaea (1/3)** | | | |
| *Fabronia ciliaris* (Brid.) Brid. | AL, AM, BA, CE, DF, ES, GO, MG, MT, MS, PB, PE, PR, RJ, RS, SC, SP | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Fabronia ciliaris* var. *polycarpa* (Hook.) W.R. Buck | AL, AM, BA, CE, PB, PE, MT, GO, DF, MS, MG, ES, SP, RJ, PR, SC, RS, SE | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Fabronia ciliaris* var. *wrightii* (Sull. *ex* Sull. *et* Lesq.) W.R.Buck | RJ, PB | Neotropical | Atlantic Rain Forest |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| **Fissidentaceae (1/6)** | | | |
| *Fissidens intramarginatus* (Hampe) Mitt. | AC, BA, CE, ES, GO, MG, MS, MT, PA, PB, PR, RJ, RO, RS, SC, SP | Africa and America | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Fissidens goyazensis* Broth. | AM, BA, CE, DF, GO, MG, PB, PE, PI, RJ, SP | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest |
| *Fissidens lagenarius* Mitt. var. *lagenarius* | CE, DF, ES, GO, MA, MG, MS, MT, PB, PE, PI, PR, RJ, RS, SC, SP | Neotropical | Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Fissidens pallidinervis* Mitt. | AC, AL, AM, BA, CE, DF, GO, MA, MG, MT, MS, PA, PE, PI, PR, RJ, RR, RS, SP | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| **Fissidens serratus* Müll. Hal. | AM, BA, CE, PI, ES, GO, MG, MT, PE, RJ, RS, SC, SP | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest |
| *Fissidens submarginatus* Brusch. | AC, AM, BA, CE, DF, ES, GO, MA, MG, MT, MS, PA, PB, PE, PI, RO, RJ, RS, SC | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| **Funariaceae(1/1)** | | | |
| *Funaria hygrometrica* Hedw. | BA, DF, MG, MT, PA, PE, PR, RJ, RS, SC, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pampa |
| **Helicophyllaceae (1/1)** | | | |
| *Helicophyllum torquatum* (Hook.) Brid. | AL, AM, BA, CE, ES, GO, MG, MS, MT, PA, PB, PE, PI, PR, RJ, RS, SC, SP, TO | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| **Leucobryaceae (1/5)** | | | |
| *Campylopus occultus* Mitt. | AP, BA, DF, ES, GO, MG, MT, MS, PA, PE, PR, RJ, RR, RS, SC, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| **Campylopus pilifer* Brid. | AL, AM, BA, CE, DF, ES, MG, MT, PA, PE, PR, SP, RJ, RR, RS | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa |
| *Campylopus richardii* Brid. | BA, CE, ES, MG, PE, PR, RJ, RR, SC, SP | Pantropical | Atlantic Rain Forest |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| *Campylopus savannarum* (Müll.Hal.) Mitt. | AC, AM, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PE, PI, PR, RO, RJ, RR, SE, SP, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Campylopus surinamensis* Müll. Hal. | AM, BA, ES, MG, MT, PA, PI, PR, RJ, RO, SC, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| **Orthotrichaceae (4/6)** | | | |
| *Groutiella tomentosa* (Hornsch.) Wijk *et* Margad. | AC, AM, BA, CE, ES, MA, MS, MT, PA, PE, PR, RJ, RO, SC, SP | Wide | Atlantic Rain Forest, Pantanal, Cerrado, Amazon Rain Forest |
| *Macrocoma tenuis* (Hook. *et* Grev.) Vitt | DF, MG, PE, PR, RS, SC, SP | Wide | Cerrado, Atlantic Rain Forest |
| ***Macromitrium punctatum* (Hook. *et* Grev.) Brid. | AM, AP, BA, CE, ES, GO, MG, PR, RJ, RS, SP | Neotropical | Atlantic Rain Forest, Cerrado, Caatinga, Amazon Rain Forest |
| *Macromitrium richardii* Schwägr. | AM, BA, DF, ES, MG, PE, PR, RJ, RS, SC, SP | Africa and America | Amazon Rain Forest e Atlantic Rain Forest |
| *Schlotheimia rugifolia* (Hook.) Schwägr. | AC, AM, BA, CE, DF, ES, GO, MG, MT, PA, PE, PR, RJ, RO, SC, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| ***Schlotheimia tecta* Hook. f. *et* Wilson | CE, ES, MG, PR, RJ, RS, SC | Neotropical | Atlantic Rain Forest |
| **Polytrichaceae (1/2)** | | | |
| *Polytrichum commune* L. *ex* Hedw. | AM, BA, DF, ES, GO, MG, PR, RJ, RO, RR, RS, SC, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| ***Polytrichum juniperinum* Willd. *ex* Hedw. | BA, DF, ES, GO, MG, PR, RO, RJ, RR, RS, SC, SP, TO | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| **Pottiaceae (5/5)** | | | |
| *Aschisma carniolicum* (F. Weber *et* D. Mohr) Lindb. | BA, PB, PE | Holoartic | Caatinga |
| *Barbula indica* (Hook.) Spreng. | AC, AM, BA, DF, ES, GO, MG, MS, MT, PA, PE, RJ, RS, SE, SP | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Hyophilla involuta* (Hook.) A.Jaeger | AL, AM, BA, CE, DF, ES, GO, MG, MS, MT, PA, PB, PE, PI, PR, RJ, RO, RR, RS, SP | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| *Hyophiladelphus agrarius* (Hedw.) R.H. Zander | AC, AM, BA, CE, DF, MG, PA, PB, PE, RJ, RN, RO, SE, SP, TO | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest |
| ***Tortella humilis* (Hedw.) Jenn. | BA, DF, ES, GO, MA, MG, MS, PR, RJ, RS, SC, SP | Wide | Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| ***Weisiopsis nigeriana* (Egunyomi *et* Olar.) R.H. Zander | PE, PI, TO | Africa and America | Cerrado |
| **Racopilacae(1/1)** | | | |
| *Racopilum tomentosum* (Hedw.) Brid. | AC, AM, BA, CE, DF, ES, GO, MG, MS, MT, PA, PE, PR, RJ, RO, RS, SC, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| **Sematophyllaceae (2/3)** | | | |
| *Donnellia commutata* (Müll.Hal.) W.R.Buck | AM, BA, DF, ES, GO, MG, MS, RJ, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| *Sematophyllum subpnnatum* (Brid.) E.Britton | AC, AL, AM, AP, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, PR, RJ, RO, RR, RS, SC, SP, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Sematophyllum subsimplex* (Hedw.) Mitt. | AC, AM, AP, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, PI, PR, RJ, RJ, RO, RR, RS, SC, SE, SP, TO | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| **Stereophyllaceae (1/1)** | | | |
| *Entodontopsis leucostega* (Brid.) W.R. Buck *et* Ireland | AC, AM, BA, CE, DF, GO, MA, MG, MS, MT, PA, PB, PE, PI, RJ, RM, RO, SP, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| **MARCHANTIOPHYTA** | | | |
| **Cephaloziaceae (2/2)** | | | |
| ***Cephalozia crassifolia* (Lindenb. *et* Gottsche) Fulford | BA, ES, RJ, RS, SP | Neotropical | Atlantic Rain Forest |
| ***Odontoschisma longiflorum* (Taylor) Steph. | GO, MG, MT, PB, PR, RJ, SP | Neotropical | Cerrado, Atlantic Rain Forest |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| **Frullaniaceae (1/10)** | | | |
| *Frullania apiculata* (Reinw. *et al.*) Nees | AM, BA, DF, GO, MS, PA, PE, RJ, SC, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| *Frullania brasiliensis* Raddi | BA, CE, DF, ES, GO, MG, PE, RJ, RS, SC, SP | Neotropical | Cerrado, Atlantic Rain Forest |
| *Frullania caulisequa* (Nees) Nees | AC, AL, BA, CE, DF, ES, GO, MG, MT, PA, PB, PE, RJ, RR, RS, SC, SP | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa |
| *Frullania dusenii* (Nees) Nees | Al, BA, ES,GO, MG, PB, PE, RJ, RR, RS, SC, SE, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| *Frullania ericoides* (Nees) Mont. | AC, AL, AM, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, PR, RJ, RS, SC, SE, SP | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Frullania flexicaulis* Spruce | SC, SP | Neotropical | Atlantic Rain Forest |
| *Frullania gibbosa* Nees | AC, AM, BA, DF, ES, GO, MG, MS, MT, PA, PB, PE, RJ, RR, SC, SP | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Frullania glomerata* (Lehm. *et* Lindenb.) Mont. | BA, CE, DF, ES, GO, MA, MG, PR, RJ, RS | Neotropical | Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Frullania kunzei* (Lehm. *et* Lindenb.) Lehm. *et* Lindenb. | AC, AM, BA, CE, DF, ES, GO, MG, MT, PA, PB, PE, PR, RJ, RR, RS, SE, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| *Frullania riojaneirensis* (Raddi) Spruce | BA, CE, DF, ES, GO, MG, MS, MT, PA, PB, PE, PR, RJ, RS, SC, SE, SP | Pantropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| **Lejeuneaceae (10/14)** | | | |
| *Acanthocoleus aberrans* var. *laevis* Gradst. | BA, PB, RJ | Neotropical | Atlantic Rain Forest |
| *Acrolejeunea emergens* (Mitt.) Steph. | AC, AM, BA, CE, DF, ES, GO, MG, MS, MT, PA, RJ, RO, SP | Pantropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Acrolejeunea torulosa* (Lehm. *et* Lindenb.) Schiffn. | AC, AM, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PE, PR, RJ, RO, RR, RS, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| *Anoplolejeunea conferta* (C.F.W. Meissn. *ex* Spreng.) A. Evans | AL, BA, ES, MG, PA, PB, PE, PR, RJ, RR, RS, SC, SP | Neotropical | Amazon Rain Forest, Atlantic Rain Forest |
| *Brachiolejeunea phyllorhiza* (Nees) Kruijt *et* Gradst. | AM, BA, ES, MG, RJ, SP | Africa and America | Atlantic Rain Forest |
| *Cheilolejeunea trifaria* (Reinw. *et al.*) Mizut. | AC, AM, BA, CE, DF, ES, GO, MG, MS, MT, PA, PB, PE, PR, RJ, RO, SP | Pantropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest, Pantanal |
| *Lejeunea flava* (Sw.) Nees | AC, AL, AM, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, PR, RJ, RR, RS, SC, SE, SP, TO | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |
| *Lejeunea laetevirens* Nees *et* Mont. | AC, AL, AM, AP, BA, CE, DF, ES, GO, MA, MS, MT, PA, PB, PE, RJ, RN, RR, RS, SE, SC, SP | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Leucojeunea xanthocarpa* (Lehm. *et* Lindenb.) A.Evans | CE, PE, BA, MG, ES, PE, SP, RJ, SC, RS | Pantropical | Atlantic Rain Forest |
| *Leucolejeunea unciloba* (Lindenb.) A.Evans | AC, AM, BA, CE, ES, MG, PA, PB, PE, RJ, RS, SC, SP | Wide | Amazon Rain Forest, Atlantic Rain Forest |
| *Microlejeunea bullata* (Taylor) Steph. | AL, AP, BA, CE, ES, GO, MA, MG, MS, PA, PB, PE, RJ, SP, TO | Neotropical | Atlantic Rain Forest |
| *Microlejeunea epiphylla* Bischl. | AC, AL, AM, AP, BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PB, PE, PR, RJ, RN, RR, RS, SC, SE, SP | Wide | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| *Omphalanthus filiformis* (Sw.) Nees | AM, BA, CE, ES, MG, PE, RJ, RS, SE, SP | Neotropical | Amazon Rain Forest, Atlantic Rain Forest, Pantanal |
| *Schiffneriolejeunea polycarpa* (Nees) Gradst. | AC, AL, AM, BA, CE, DF, ES, GO, MG, MS, MT, PA, PB, PE, RJ, RR, RS, SC, SE, SP | Pantropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pantanal |
| **Metzgeriaceae (1/5)** | | | |
| *Metzgeria brasiliensis* Schiffn. | AL, BA, PR, RJ, RS, SC, SP | Neotropical | Atlantic Rain Forest |
| *Metzgeria convoluta* Steph. | PE, RA, RJ, RS, SC, SP | Not identified | Atlantic Rain Forest |
| *Metzgeria furcata* (L.) Dumort. | AC, BA, CE, ES, GO, MG, PB, PE, PR, RJ, RS, SC, SP | Wide | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |

Annex – Detailed floristic information on the regional level bryofloristic richness and distribution patterns *(continued)*

| *Division/Family/Specie* | ***Geographycal Brazil distribution*** | ***World distribution*** | ***Phytogeographic domains*** |
|---|---|---|---|
| *Metzgeria lechleri* Steph. | CE, DF, ES, GO, MG, PB, PE, PR, RJ, RS, SC, SP | Neotropical | Cerrado, Atlantic Rain Forest |
| *Metzgeria uncigera* A.Evans | ES, MG, PE, PR, RJ, RS, SC | Neotropical | Atlantic Rain Forest |
| **Plagiochilaceae (1/3)** | | | |
| *Plagiochila corrugata* (Nees) Nees *et* Mont. | AC, BA, DF, ES, GO, MG, PE, PR, RJ, RS, SC, SP | Africa and America | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| *Plagiochila gymnocalycina* (Lehm. *et* Lindenb.) Lindenb. | BA, ES, MG, PE, RJ, SC, SP | Neotropical | Atlantic Rain Forest |
| *Plagiochila raddiana* Lindenb. | AC, AM, BA, CE, ES, MG, MT, PA, PB, PE, PR, RJ, RS, SC, SP | Neotropical | Amazon Rain Forest, Cerrado, Atlantic Rain Forest |
| **Ricciaceae (1/2)** | | | |
| *Riccia taeniaeformis* Ast | RS | Brasil | Atlantic Rain Forest |
| *Riccia vitalii* Jovet-Ast | AM, AL, BA, CE, ES, GO, MA, MS, PB, PE, PI, SE, RN, RS TO | Neotropical | Amazon Rain Forest, Caatinga, Cerrado, Atlantic Rain Forest, Pampa, Pantanal |

AC – Acre; AL – Alagoas; AM – Amazonas; AP – Amapá; BA – Bahia; CE – Ceará; DF – Distrito Federal; ES – Espírito Santo; GO – Goiás; MA – Maranhão; MS – Mato Grosso do Sul; MT – Mato Grosso; MG – Minas Gerais; PA – Pará; PB – Paraíba; PE – Pernambuco; PI – Piauí; PR – Paraná; RJ – Rio de Janeiro; RN – Rio Grande do Norte; RO – Rondônia; RR – Roraima; RS – Rio Grande do Sul; SC – Santa Catarina; SE – Sergipe; SP – São Paulo; TO – Tocantins.