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BEETLE ASSEMBLAGE COMPOSITION (COLEOPTERA) ACROSS THE BORBOREMA PLATEAU IN NORTHEASTERN BRAZIL[1]

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ABSTRACT – The objective of this work was to compare soil beetle (Coleoptera) species composition between two sites on the Borborema Plateau in Northeastern Brazil. We collected 483 individuals belonging to 23 Coleoptera families and 75 species/morphospecies. On the east face of the Borborema Plateau (Areia-PB) we collected a total of 332 individuals representing 58 species/morphospecies and 21 families. On the west face (Cabaceiras-PB) we collected 151 individuals representing 24 species/morphospecies and eight families. Among the 75 total species/morphospecies collected, 51 occurred exclusively on the eastern face of the plateau and 17 occurred exclusively on the west face. Only seven morphospecies were sampled in both areas. The marked difference in beetle assemblage species composition between the west and east sides of the Borborema Plateau suggests that the positioning and climatic variations maintain and promote high levels of beetle diversity in northeastern Brazil.

Keywords: Northeastern Brazil. Altitudinal gradientes. Beetle distribution. Orographic effect.

COMPOSIÇÃO DA ASSEMBLEIA DE BESOUROS (COLEOPTERA) NO PLANALTO DA BORBOREMA, NORDESTE DO BRASIL

RESUMO – O objetivo deste trabalho foi comparar as assembleias de besouros de solo entre dois locais no Planalto da Borborema. Dados de georreferenciamento e climáticos foram usados para comparar as condições locais com as assembleias de besouros. Foram coletados 483 indivíduos, classificados em 75 espécies/ morfoespécies, pertencentes a 23 famílias de Coleoptera. As coletas na face leste do Planalto da Borborema (Areia-PB) totalizaram 332 indivíduos (58 espécies/morfoespécies) pertencentes a 21 famílias. No lado oeste (Cabaceiras-PB) foram coletados 151 indivíduos, 24 espécies/morfoespécies pertencentes a oito famílias. Entre as 75 morfótipos/espécies coletadas, 51 ocorreram exclusivamente na face oriental do Planalto e 17 ocorreram exclusivamente na face oeste. Entre eles, apenas sete morfoespécies foram amostradas em ambas as áreas. A diferença de composição de espécies de besouros entre os lados oeste e leste do Planalto da Borborema sugere que o posicionamento e variações climáticas mantêm e promovem altos níveis de diversidade de besouros no nordeste do Brasil.

Palavras-chave: Nordeste. Clima. Distribuição de besouros. Efeito orográfico.

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INTRODUCTION

The orographic effect is an important driver of climate. Mountains force air masses upward, cooling the air and resulting in precipitation on the windward side. By the time the air mass crosses the mountain, it has lost most of its moisture, resulting in less precipitation on the leeward side of mountain or range (ROE, 2005; JUNQUAS et al., 2016). The orographic effect, therefore, promotes changes in temperature and humidity, which may affect species distribution (GUEDES ALCOFORADO-FILHO et al., 2003; ANDRADE et al., 2006; OLIVEIRA; ANDRADE; FÉLIX, 2006). This phenomenon occurs on the coast of Northeastern Brazil (UVO; BERNDTSSON, 1996; LYRA; OLIVEIRA-JÚNIOR; ZERI, 2014). However, how this process shapes soil beetle species assemblages still unknown.

The Borborema Plateau is considered one of the most important orographic features in Northeastern Brazil, shaping hydrography and climate (EMBRAPA, 1972). The vegetation of this region is highly variable, from the Caatinga (GUEDES ALCOFORADO-FILHO et al., 2003) to the Ombrophilous forests (ANDRADE et al., 2006; OLIVEIRA; ANDRADE; FÉLIX, 2006). The region lacks taxonomic information (Linnean Shortfall) and records of species' distributions (Wallacean Shortfall). However, the few studies on buprestids (IANNUZZI; MAIA; VASCONCELOS, 2007); seasonal variation of insect orders (VASCONCELLOS et al., 2010); galling insects (SANTOS; ALMEIDA-CORTEZ; FERNANDES, 2011); treehopper diversity (CREÃO-DUARTE et al., 2016; ROTHEÁ et al., 2019) and the temporal and spatial patterns of dung beetles in semiarid regions (HERNÁNDEZ, 2007; LIBERAL et al., 2011), indicate a relative high insect species richness.

In tropical mountains, the species occurrence tends to be restricted to certain altitude ranges. This pattern is based on species responses to climatic variation, which is often correlated with altitude (JANZEN, 1967; JANZEN et al., 1976; RANGEL et al., 2018; RAHBEK et al., 2019). Thus far, a comprehensive assessment of Coleoptera diversity along a gradient of climatic variation in the Borborema Plateau has not been conducted. It is likely that differences in climatic characteristics between the east and west of the Borborema Plateau affect the distribution of soil beetle species. The objective of this work was therefore to compare the beetle species assemblage between these areas. Specifically, we address the following questions: (1) How many beetles species are found on both the east and west face of the plateau? (2) How does the richness and abundance of beetle species vary between the west and east side of the plateau? and (3) How does beetle species composition change at the outer edges of this east-west gradient? A dearth of taxonomic information is recognised as one of the major obstacles in the conservation of biodiversity in Northeast Brazil (COLEMAN, 2015; HORTAL et al., 2015), and information about species distribution and assemblage composition are crucial to land management and conservation best practices.

MATERIAL AND METHODS

Beetles were studied in two areas, located 85 km apart, on the Borborema Plateau (Figure 1). One site is located on the east plateau at Mata do Pau-Ferro State Ecological Reserve (REMPF) (6°57'S; 35°44'W) (Figure 1) managed by the *Superintendência de Administração do Meio Ambiente* (SUDEMA) in a remaining section of the Open Ombrophilous Forest (VELOSO; RANGEL FILHO; LIMA, 1991), and ranges in altitude from 552 to 662 m. The Reserve has a total area of ~600 hectares and is part of the Areia municipality in Paraíba. The average temperature at this site during the study period was 22ºC, with a maximum of 23.93ºC and a minimum of 19.76ºC. The relative humidity is around 85% and the annual precipitation is 1,400 mm (MAYO; FEVEREIRO, 1982).

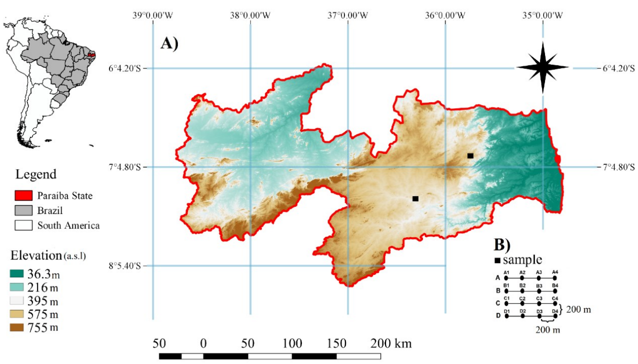

Figure 1. A) Topographic variation and B) Location of the sampling design on the east (Mata do Pau Ferro State Reserve) and west (São Francisco rural community) and west (São Francisco rural community) faces of the Borborema Plateau, Paraíba, Brazil. The data used were DEM (digital elevation model), SRTM (shuttle radar topography mission) from project TOPODATA/INPE with 30 m resolution, available at: http://www.dsr.inpe.br/topodata/acesso.php.

The second site is located on the west plateau, in the rural community of San Francisco (7°24’S; 36°18’W), in Cabaceiras municipality, Paraíba (Figure 1). The area is not a conservation unit, but has never been explored beyond extensive goat breeding raising that occurs at low density (1.5 goats/ha) (PARENTE et al., 2010). The landscape at this site is typical for the Caatinga (ANDRADE-LIMA, 1981), ranging in altitude from 427 to 463 m. During the study period, the average temperature was 24ºC, with a maximum 27.32ºC and minimum of 21.43ºC, and relative humidity of 68.8%. The annual rainfall average is 336.6 mm based in 86 years of observation (BORGES et al., 2012; INMET, 2017).

Experimental design and beetle sampling

Beetle specimens collected from the traps were identified and morphotyped using identification keys (LUEDERWALDT, 1931; GIDASPOW, 1963; WATT, 1974; ARNETT; THOMAS 2000, 2002; TRIPLEHORN; JOHNSON; BORROR, 2005; SOULA, 2009; VAZ-DE-MELLO et al., 2011; SILVEIRA; MERMUDES, 2014; CELLI et al., 2015; SPIESSBERGER; MERMUDES 2018; HUCHET; COSTA-SILVA 2018; NASCIMENTO; BOTERO 2018; RATCLIFFE, 2018; SOUSA, 2019) and expert assistance. Specimens were deposited in the collection of the to the Laboratory of Invertebrate (LABIN) of the *Centro de Ciências Agrárias* of the *Universidade Federal da Paraíba*, Campus II – Areia/PB.

Environmental variables

To test the effect of environmental variables on species occurrence, richness and abundance, five possible predictors were selected: total monthly precipitation (mm), monthly minimum temperature average (ºC), monthly maximum temperature average (ºC), and monthly relative humidity average (%). The climate data were obtained from the *Instituto Nacional de Meteorologia* (INMET) Sensors are located about 9.3 km from the rural community of San Francisco and 3.8 km from REMPF (Table 1).

Table 1. Monthly averages of climate variables of sampled areas, data from the *Instituto Nacional de Meteorologia* (INMET).

Cabaceiras-PB	2011							2012				
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Precipitation	42.60	17.80	10.40	0.00	0.20	1.40	0.20	1.40	0.80	3.60	1.20	15.80
Air humidity	80.34	83.72	75.68	67.38	64.62	64.67	60.79	67.10	67.80	64.50	62.16	66.51
Maximum temperature	23.74	22.48	23.26	24.35	26.17	26.64	27.32	26.55	26.27	26.96	27.28	26.22
Minimum temperature	22.66	21.43	22.00	22.90	24.77	25.27	25.90	25.24	25.01	25.57	25.89	24.88
Areia-PB	2011							2012				
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Precipitation	188.40	387.00	136.80	21.80	15.00	49.80	30.00	179.40	149.60	36.80	33.00	110.40
Air humidity	92.44	93.75	92.00	85.58	85.16	84.60	82.36	87.24	87.98	85.96	83.25	86.02
Maximum temperature	21.56	20.45	20.85	21.34	22.73	23.24	23.75	23.11	22.95	23.93	23.93	23.10
Minimum temperature	20.83	19.76	20.01	20.40	21.69	22.15	22.63	22.12	22.04	22.55	22.89	22.11

Statistical Analysis

Preliminary analysis showed that all climatic variables (Table 1) were strongly correlated (r Pearson >0.6, Figure 5). Therefore, we opted to use site as the predictor variable (proxy for climatic variables) in the models. An individual generalised linear mixed model (GLMM) (BOLKER et al., 2009) was constructed for Coleoptera species richness and abundance against “site” (Areia and Cabaceiras) as the explanatory variable. We adopted Poisson error distribution and included “transect” nested in “month" as random effects in the model to control for spatial and temporal dependence on these data. To validate the model fit, we compared the Akaike Information Criterion (AIC) of each GLMM with the respective AIC of the null model (intercept and random effects only). Full GLMM models were selected when the delta AIC (difference between full and null models) were >2 (AKAIKE, 1982). We calculated the marginal and conditional R^2 for each GLMM to measure the importance of the random variables in our results. Marginal R^2 provides the variation explained only by the fixed variables, while the conditional R^2 gives the variation explained by fixed and random effects in the model (NAKAGAWA; SCHIELZETH, 2013).

We also created rarefaction plots for both sites. Rarefaction methods calculate the expected number of species based on a random subsample of the data, making the comparisons among sites more reliable (GOTELLI; COLWELL, 2001). We used the Mao Tao's analytical method to generate valid 95% confidence intervals for the rarefaction curves, which do not converge to zero at the maximum sample size (COLWELL et al., 2004).

We used a permutational multivariate analysis of variance (PERMANOVA), based on Bray-Curtis distances of standardised diversity data, to evaluate the effects of "site" on coleopterans species composition. This analysis allows simultaneous testing of multiple factors and covariates based on permutation tests (ANDERSON, 2001). We created a stratified permutation procedure, with "transect" nested in "month". Therefore, randomisations occur only between transects from different months and not within transects sampled in the same month. The statistical probabilities of PERMANOVA were based in 999 permutations. All analyses were carried out in R 3.2.3 (R CORE TEAM, 2019). GLMM models were created with *lme4* package (BATES et al., 2015) and residual analysis was done using the *DHARMa* package (HARTIG, 2016). PERMANOVA was created using the function *adonis* from the vegan package.

RESULTS AND DISCUSSIONS

During the study period the eastern plateau (Areia) site had higher annual precipitation (1,338 mm), higher relative monthly humidity (87%) and lower monthly mean temperatures maximum (22.6ºC) and minimum (21.6ºC) than the western area (Cabaceiras), which had an annual precipitation of 95.4 mm, a monthly relative humidity of 68.8% and monthly temperature maximum of 25.6ºC and minimum 24.3ºC. The proximity of the Borborema Plateau to the Atlantic Ocean results in higher rainfall and more stable and milder temperatures on the eastern side of the plateau than on the western side (leeward) (ROE, 2005).

We captured 483 individuals, classified into 75 species/morphospecies, belonging to 23 Coleoptera families. The collections on Borborema eastern Plateau (Areia) totalled 332 individuals (58 species/morphospecies) belonging to 21 families. On the western side (Cabaceiras), 151 individuals were collected, belonging to 24 species/morphospecies and eight families. Seven common species were collected in both localities. Due to a lack of taxonomic information on the species of Northeastern Brazil, only 44 specimens were identified to the generic/specific level, and remaining specimens could be identified to tribe or family only (Table 2).

Table 2. List of species and morphospecies of beetles recorded on the east (Areia-PB) and west (Cabaceiras-PB) faces of the Borborema Plateau, Paraiba State, Brazil.

Anobiidae	East	West	Total
Anobiidae sp. 10	1		1
Anthicidae	East	West	Total
Anthicidae sp. 76		3	3
Bolboceratidae	East	West	Total
Neoathyreus sp. 56	1		1
Brentidae	East	West	Total
Paratrachelizus sp. 55	1		1
Carabidae	East	West	Total
Brachygnathus sp. 87		3	3
Calosoma (*Castrida*) *alternans granulatum* Perty, 1830	1		1
Carabidae sp. 46	1		1

Table 2. Continuation.

Carabidae	East	West	Total
Carabidae sp. 48	1		1
Carabidae sp. 79		1	1
Carabidae sp. 81		2	2
Carabidae sp. 86		3	3
Carabidae sp. 88		1	1
Dercylus sp. 9	6		6
Galerita sp. 84		4	4
Tetracha brasiliensis (Kirby, 1819)		2	2
Notiobia sp. 1		36	36
Notiobia sp. 2		12	12
Odontocheila nitidicollis (Dejean, 1825)	1		1
Scarites sp. 14	7	9	16
Cerambycidae	East	West	Total
Chlorida festiva (Linnaeus, 1758*)*	1		1
Jupoata rufipennis (Gory, 1831)	7		7
Leptostylus sp. 70	1		1
Mallodon spinibarbis (Linnaeus, 1758)	1		1
Oreodera sp. 57	1		1
Cetoniidae	East	West	Total
Gymnetis aurantivittae Ratcliffe, 2018	1		1
Inca clathratus (Olivier, 1792)	2		2
Chrysomelidae	East	West	Total
Bruchinae sp. 24	1		1
Eumolpinae sp. 36	1		1
Galerucinae sp. 16	1		1
Hispinae sp. 50	1		1
Coccinellidae	East	West	Total
Coccinella sp. 90		1	1
Curculionidae	East	West	Total
Curculionidae sp. 34	3		3
Curculionidae sp. 41	3		3
Curculionidae sp. 42	2	3	5
Curculionidae sp. 44	1		1
Curculionidae sp. 45	4		4
Curculionidae sp. 47	1		1
Curculionidae sp. 53	9		9
Curculionidae sp. 61	2		2
Curculionidae sp. 66	16		16
Curculionidae sp. 80	2	1	3

Table 2. Continuation.

Curculionidae	East	West	Total
Curculionidae sp. 91		8	8
Platypodinae sp. 58	1		1
Scolytinae sp. 18	3		3
Elateridae	East	West	Total
Elateridae sp. 23	1	1	2
Erotylidae	East	West	Total
Episcapha sp. 11	1		1
Episcapha sp. 54	1		1
Episcapha sp. 65	3		3
Histeridae	East	West	Total
Omalodes (Omalodes) foveola Erichson, 1834	1		1
Lampyridae	East	West	Total
Amydetes sp. 17	1		1
Leiodidae	East	West	Total
Leiodidae sp. 20	1		1
Melolonthidae	East	West	Total
Ancistrosoma sp.1	2	1	3
Cyclocephala sp. 89		11	11
Dyscinetus dubius (Olivier, 1789)	23		23
Pelidnota chalcothorax Perty, 1830	2		2
Strategus sp. 71	1		1
Mordellidae	East	West	Total
Paramordellaria sp. 29	1		1
Paramordellaria sp. 77		1	1
Nitidulidae	East	West	Total
Nitidulidae sp. 6	3		3
Passalidae	East	West	Total
Passalus interruptus (Linnaeus, 1758)	10		10
Scarabaeidae	East	West	Total
Canthon sp. 38	1		1
Coprophanaeus cyanescens (Olsoufieff, 1924)	10		10
Deutochilum sp. 30	1		1
Deutochilum sp. 73	7	4	11
Deutochilum sp. 74		26	26
Dichotomius sp. 72	167		167
Eurysternus hypocrita Balthasar 1939	2		2

Table 2. Continuation.

Staphylinidae	East	West	Total
Deleaster sp. 21	1		1
Tenebrionidae	East	West	Total
Epitragini sp. 68	1	5	6
Goniaderini sp. 49	1		1
Mylaris maxima (Germar, 1824)	3		3
Scotinus sp. 75		8	8
Strongylium sp. 33	1		1
Tenebrionidae sp. 78		5	5
Trogidae	East	West	Total
Polynoncus vazdemelloi Huchet and Costa-Silva, 2018	1		1

Species richness and abundance differed between locations; an average of 2.79 species/ morphospecies per sample were collected at the eastern site, while the average number of species/ morphospecies per sample at the western site was two times lower. The same pattern was observed for the average abundance of individuals per sample; the eastern site had twice the number of individuals (6.87) than the western site (3.14). For both richness and abundance, the complete models had better fit than their respective null models (delta AIC >2). The site, controlling the effects of seasonality and locality, explained around 12% of the variation in richness (R^2 marginal = 0.11) and abundance of beetles (R^2 marginal = 0.12). Most of the variation can be explained by seasonality (temporal replicas) and transects (spatial replicas). Approximately 41% of the average richness variation (conditional R^2 = 0.41) and ~30% of the average abundance variation (conditional R^2 = 0.30) was explained, considering the random variables included in the models (Figure 2).

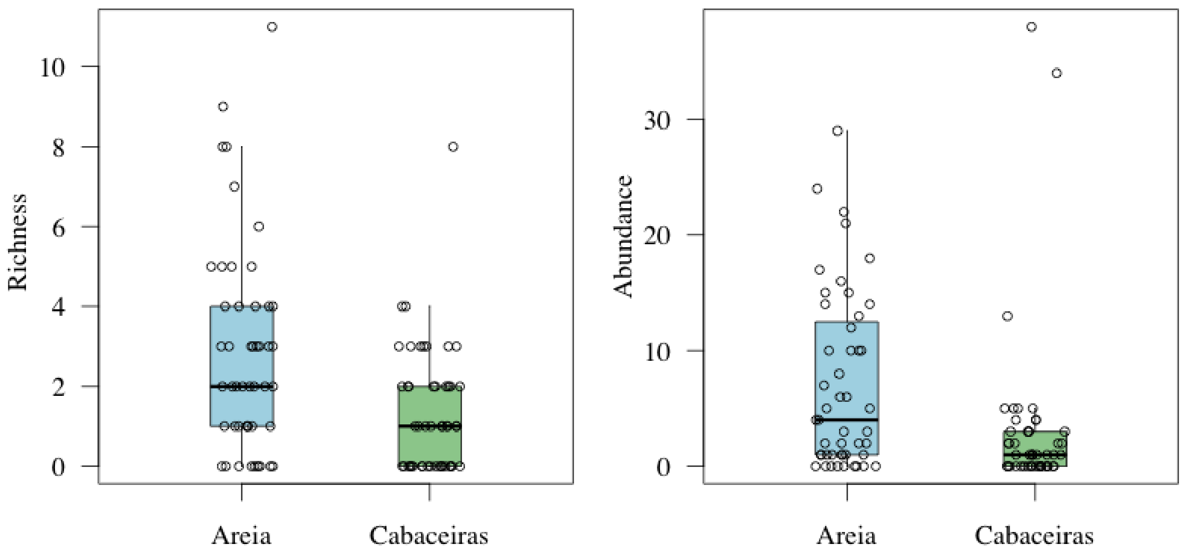

Figure 2. Number of species/morphospecies and abundance of coleopterans sampled at Areia (East) and Cabaceiras (West), Paraiba State, Brazil.

Our results support the conclusion that in Northeastern Brazil, the abundance and richness of insects is greater in humid areas than in more arid locations (WOLDA, 1992; VASCONCELLOS et al., 2010; CREÃO-DUARTE et al., 2016). These climatic parameters are strongly affected by the positioning (east or west) on the Borborema Plateau, which causes changes in the beetle assemblages.

Temperature is an important predictor of the distribution of beetle species in tropical areas, where most species have smaller ranges and lower thermal tolerance than in temperate areas, making them more susceptible to temperature variations (ANGILLETTA; NIEWIAROWSKI; NAVAS, 2002; HARRIS; RODENHOUSE; HOLMES, 2019; BARRETTO; SALOMÃO; IANNUZZI, 2019).

The rarefaction curves did not reach the asymptote, especially from east side (Areia) (Figure 3). However, 10 transects (approximately 2 months of collection) was sufficient to demonstrate that the number of accumulated species/morphospecies per collection event is lower in west face (Cabaceiras) than in Areia for any given sampling event.

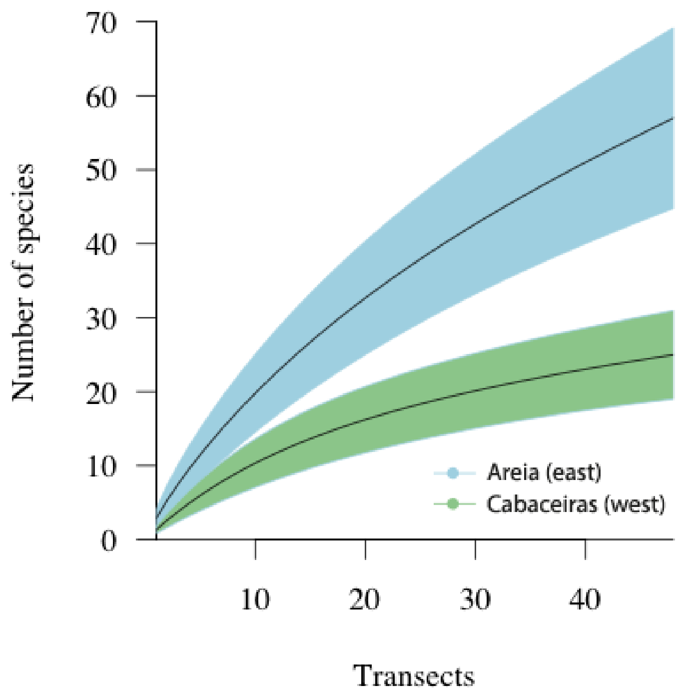

Figure 3. Species rarefaction curve by locality. The colour wrapped around the continuous lines represents 95% confidence interval.

We were able to sample only a portion of the total number of species/morphospecies from both areas, which is common for tropical areas. The rarefaction curves did not reach an asymptote, because when megadiverse taxa such as beetles are sampled, species richness is very likely to increase as more samples are incorporated (BUNGE; FITZPATRICK, 1993). However, comparing the two areas, on the east side (Areia), the rarefaction curve remained higher than on the west face (Cabaceiras), highlighting a higher species density in this area, regardless of the sampling effort employed.

The composition of beetle species was markedly different between the locations (PERMANOVA, $r^2 = 0.098$, $p = 0.001$). Among the 75 species/morphospecies collected, 51 occurred exclusively on the east face of the plateau and 17 occurred exclusively on the west face. Only seven morphospecies were sampled in both areas. The low variation explained by PERMANOVA is related to the large number of singletons and doubletons. Among the total sampled species/morphospecies, 50 were collected only once or twice in the localities, with 35 (47.29%) exclusive to the east face of the plateau, and 11 (14.86%) to the west face (Figure 4).

Our data suggest that the markedly different environmental conditions (Figure 5) on opposing faces of the plateau may explain the differences in beetle species composition. The low overlap of species/morphospecies (9%) (see Figure 5) between both localities and the many rare taxa sampled reinforce the hypothesis that most species in tropical mountains occur in small climatic zones (JANZEN et al, 1976) and that different rate of diversification can be driven by topography and climate. However, to further understand this interaction, additional tools will be needed to refine the identification and control of landscape parameters. For example, despite the fact that the pitfall traps were installed more than 3 km from the goat's stables in Cabaceiras site, which reduces the chance of catching dung beetles attracted by goat faeces, we cannot completely rule out the indirect effects of goat breeding or other economic activities on beetles' composition. An increase in taxonomic knowledge coupled with a deeper understanding of human impacts on the distribution of biodiversity in important to provide necessary information for conservation and environmental planning in this highly threatened environment.

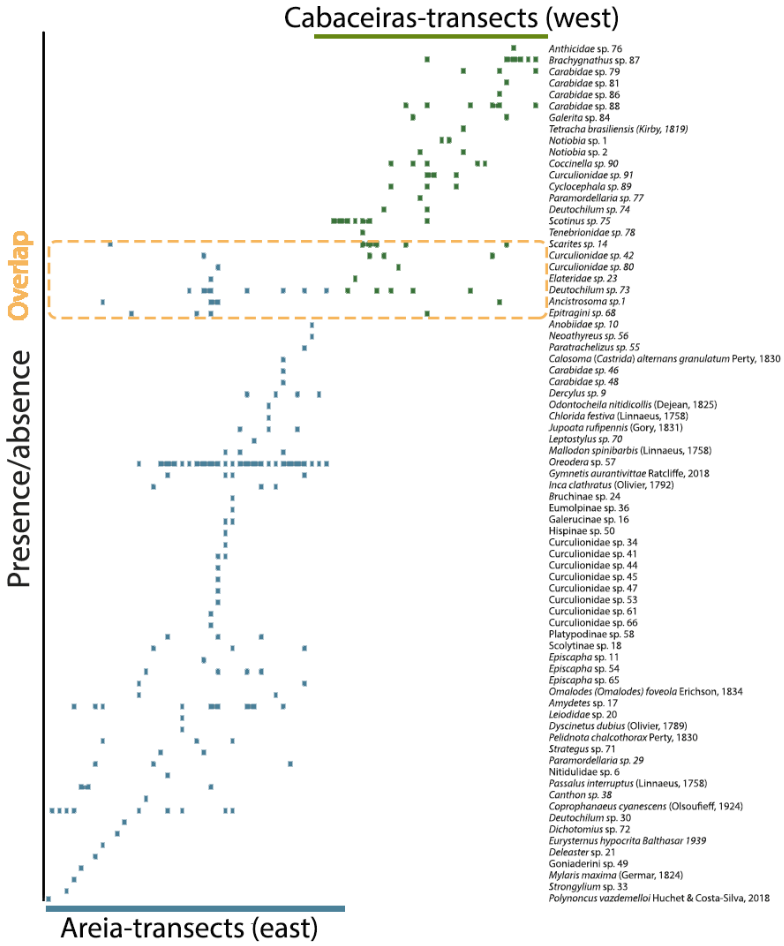

Figure 4. Presence/absence of species/morphospecies in east (blue bars - Areia) and west (green bars - Cabaceiras) faces of the Borborema Plateau, Paraíba State, Brazil. The dashed rectangle shows the beetle composition shared between the areas. Each column represents one transect and sequence was ordered based on beetle composition.

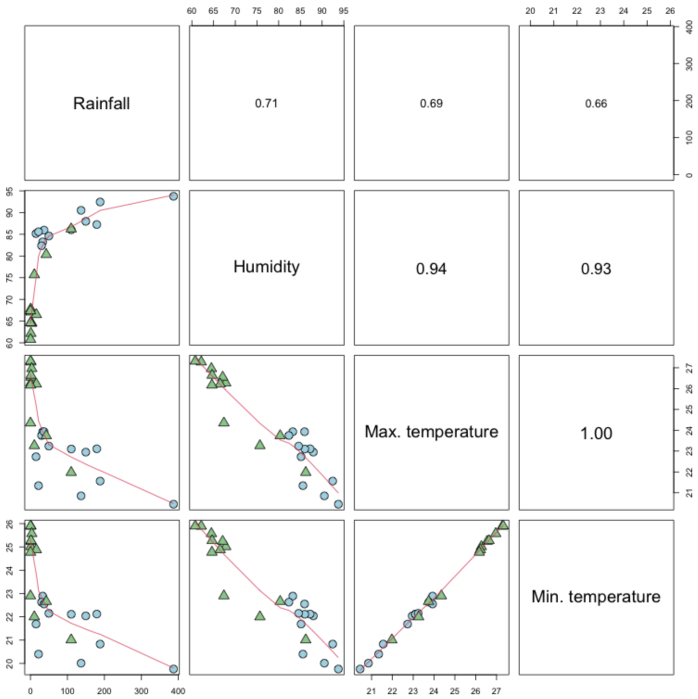

Figure 5. Pearson correlation between climatic variables from east (blue circle) and west (green triangle) faces of the Borborema Plateau, Paraíba, Brazil

CONCLUSION

This study has shown that Borborema Plateau supports a very different beetle assemblage between the eastern and western areas. The variation in climate must be considered critical in maintaining and promoting high levels of beetle diversity in northeastern Brazil.

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